GEOCHEMICAL SURVEY OF MISSOURI

Elemental Composition of Selected Native Plants and Associated Soils from Major Vegetation-Type Areas in Missouri

U.S. DEPARTMENT OF THE INTERIOR
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An examination of statewide geochemical
variations as indicated by plant
and soil analyses

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GEOCHEMICAL SURVEY OF MISSOURI

ELEMENTAL COMPOSITION OF SELECTED NATIVE PLANTS AND ASSOCIATED SOILS FROM MAJOR VEGETATION-TYPE AREAS IN MISSOURI

By JAMES A. ERDMAN, HANSFORD T. SHACKLETTE, and JOHN R. KEITH

ABSTRACT

The native plants in Missouri can be grouped into six principal vegetation types whose general areas are physiographically defined. Representative plant species and associated soils, sampled in each vegetation-type area according to a geographically nested (hierarchical) design, were analyzed for about three dozen chemical elements.

Analysis of variance and Duncan's (1955) multiple range test demonstrated that the concentrations of most elements in uncultivated soils differ significantly between the areas. Moreover, the areal patterns of variability for many elements are strikingly similar, which indicates a large degree of interdependency and suggests that these elements reflect some common underlying control on chemical variability. *Q*-mode factor analysis indicated that there are at least four such controls (factors). These four factors are believed to reflect the different compositions of soil parent materials as found in the prairies, cedar glades, upland forests, and floodplain forests.

A similar statistical analysis of the elemental composition of stems of sumac, a shrub common throughout the State, revealed only a few differences between vegetation-type areas, and these differences are thought to be caused largely by soil pH. The correlation is generally weak between the chemical composition of stems of several tree and shrub species and the composition of associated soils in each area. Compositional variability in ash of native plants appears to be mostly local in scale, and individuals of a single species growing within a few miles of each other tend to be as chemically different as individuals growing at opposite ends of the State.

INTRODUCTION

The influences of vegetation on the kinds and concentrations of chemical elements in surficial materials and waters, and on the biological component of the natural environment, are of such importance that the chemical composition of plants must be considered in a comprehensive geochemical survey of an area. Plants are a direct link in the complex chain of inorganic and organic processes of environmental geochemistry, in that chemical elements from the geologic source material or its weathered products are absorbed and translocated to above-ground plant organs, combined to form complex organic compounds in plants and in animals that feed on the plants, and then finally released through death and decomposition of the organisms to return to surficial deposits and waters. This interplay between inorganic and organic geochemical processes tends to redistribute the elements in surficial materials by concentrating some elements in upper soil horizons and, through solubilization, causing the downward displacement, or loss in surface runoff, of others. The nature of these processes of element mobility was first formalized by Goldschmidt (1954), and the concentration of elements in upper soil horizons was designated the Goldschmidt enrichment principle (Rankama and Sahama, 1955, p. 333–334).

A study of the botanical segment of the geochemical cycle, therefore, must serve to evaluate the role of soil-plant interactions in the movements and concentrations of elements. Our objectives in this study emphasized this concept in that, first, the geochemistry of the plants and soils were characterized separately on the basis of conceptual units of vegetation at a regional scale and, second, correlations of element concentrations in the two natural materials were determined. The resulting geochemical evaluations of soil-plant interactions could then be examined on a regional basis in relation to the results of geochemical studies of rocks, unconsolidated geologic deposits, soils, and waters in Missouri that were conducted concurrently by other members of the U.S. Geological Survey.

The scope and general objectives of these studies were outlined previously by the U.S. Geological Survey, (1972a) and by Connor, Erdman, Tidball, and Feder (1972); they were discussed further by Miesch (1976). These reports emphasized that the Missouri geochemical investigations were considered to constitute a pilot study of how to effectively conduct a geochemical survey of a large area by means of efficient methods of sampling and sampling design and the collection and synthesis of geochemical data in a rigorous, scientifically defensible manner. Special efforts were made in these studies to unify methodology in sampling, chemical analysis, statistical evaluation, and data presentation for the several disciplines so that results from each study would be directly comparable with results of the other studies, insofar as appropriate.

Informal collaboration of the Geological Survey projects and the Environmental Health Surveillance Center, University of Missouri, was promoted by seven semiannual releases of progress reports (U.S. Geological Survey, 1972a – f, 1973) which described the current status of the geochemical studies and gave results of these studies as they became available. The Surveillance Center was simultaneously conducting epidemiological studies in Missouri in the search for possible geographical patterns of animal and human health problems that might correspond to patterns of geochemical abundances in natural materials. In order to make our geochemical data readily useful in epidemiological and other studies, regional-scale maps of element abundance in the several sampling media were prepared, where possible.

The plant and soil data obtained in this study not only enabled regional geochemical patterns to be delineated, but also were sufficiently extensive to permit "normal" or baseline geochemical values to be established for some soils and plant species. These baseline values, used in conjunction with geochemical data from local areas, formed the basis for appraising an occurrence of roadside pollution from the transport of lead ore (Connor, Shacklette, and Erdman, 1971), and a problem of metabolic imbalance in beef cattle that was attributed to contamination from a clay mining operation (Ebens and others, 1973).

The diverse types of vegetation and soils that are present in Missouri can be conveniently divided into two large categories encompassing (a) native vegetation and associated uncultivated soils, and (b) cultivated vegetation (largely field crops) and agricultural soils, some of which have been cultivated for more than a century. Both categories of materials are geochemically important—the first to provide insight regarding the natural geochemical environment, the second to permit realistic evaluations to be made of the effects of cultivation on the abundance and distribution of the elements and to furnish baseline geochemical data for some field crops. The study described in this report was directed at only the native plants and uncultivated soils. Results of the cultivated plants and soils study are presented in a separate report (Erdman and others, 1976).

We are indebted to many U.S. Geological Survey colleagues for their assistance during this study. A. T. Miesch provided valuable guidance both in coordinating the Missouri geochemical studies as a whole and in the use of statistical techniques. R. J. Ebens and R. W. White provided determinations of soil minerals. Jessie M. Bowles drafted the maps of element distribution, and Josephine G. Boerngen assisted in computer processing the data. Plant materials were chemically analyzed by Thelma F. Harms, Harriet G. Neiman, and Clara C. S. Papp. The soil samples were prepared for analysis by John Moreland, and were analyzed by Leon A. Bradley, F. W. Brown, G. T. Burrow, Joseph W. Budinsky, J. P. Cahill, I. C. Frost, Johnnie Gardner, B. A. McCall, Leung Mei, Violet M. Merritt, Roosevelt Moore, Harriet G. Neiman, Ramona L. Rahill, G. D. Shipley, M. W. Solt, J. A. Thomas, J. S., Wahlberg, and T. L. Yager. We acknowledge with gratitude the facilities and services provided by Dr. Carl J. Marienfeld and his associates of the Environmental Health Surveillance Center, University of Missouri.

DESCRIPTION OF VEGETATION TYPES

In undertaking a geochemical survey of an area as large as Missouri one must deal with the mass of plants (vegetation) covering the landscape, rather than with individual species which in this State number about 2,438 (Steyermark, 1963, p. 1665). Vegetation was defined by Gray (1967, p. 561) as "the sum total of plant growth in a given area." A more practical definition, however, is the one by Küchler (1964, p. 1), who stated, "Vegetation may be defined as the mosaic of phytocenoses [plant communities] in the landscape." Plant communities, considered as discrete entities are, therefore, units of vegetation that are convenient to use in looking for biogeochemical similarities or differences among areas.

Plant communities can be recognized and named to suit the needs of a specific research study. The communities considered in this report are based on species of the higher (vascular) plants only, and are the conceptual units of vegetation on which we based our plant and soil sampling design. The potential natural vegetation of the conterminous United States was organized into broad plant communities or vegetation types, and the areas occupied by these types were mapped at a scale of 1:3,168,000, by Küchler (1964). In order to avoid certain complexities in mapping at this scale, particularly the problem of including or excluding cultivated fields or forests and urban areas, Küchler (1964, p. 1–2) used the concept of "potential natural vegetation" in delineating vegetation types, and defined the concept as "the vegetation that would exist today if man were removed from the scene and if the resulting plant succession were telescoped into a single moment." Following this concept, the parts of Missouri that he mapped as "mosaic of Bluestem Prairie and Oak-hickory Forest" are, in fact, largely cultivated farmland at present.

Because of the relationship of topography and type of surficial materials to the habitat requirements of plant species, any reasonable organization of vegetation types in Missouri, including that of Küchler, will result in patterns of vegetation types that correspond to a relatively high degree with physiographic regions or provinces as, for example, those outlined by Fenneman (1946) and U.S. Geological Survey (1968, p. 8–9) that are illustrated in figure 1. We chose Küchler's organization of vegetation types as the general basis for our sampling plan in Missouri, but we made some modifications of his organization which we believe are more relevant to geochemical studies.

FLOODPLAIN FOREST VEGETATION TYPE

The part of this vegetation type (fig. 2) that occurs in Missouri is a northern extension of the principal area lying along the lower reaches of the Mississippi River, as mapped by Küchler (1964). This area in Missouri formerly was densely forested swampy land on which the dominant tree species were tupelo (*Nyssa aquatica*), cypress (*Taxodium distichum*), and many species of oaks (*Quercus* sp.). The land has since been cleared of timber and drained by the construction of many large ditches in the southeastern corner of the state (fig. 3) to the extent that the forest has virtually disappeared and has been replaced by cultivated fields of soybeans, cotton, and other crops (fig. 4). The trees that are now present generally grow along the drainage ditches and roadsides, where at many places they are being eradicated by means of herbicides.

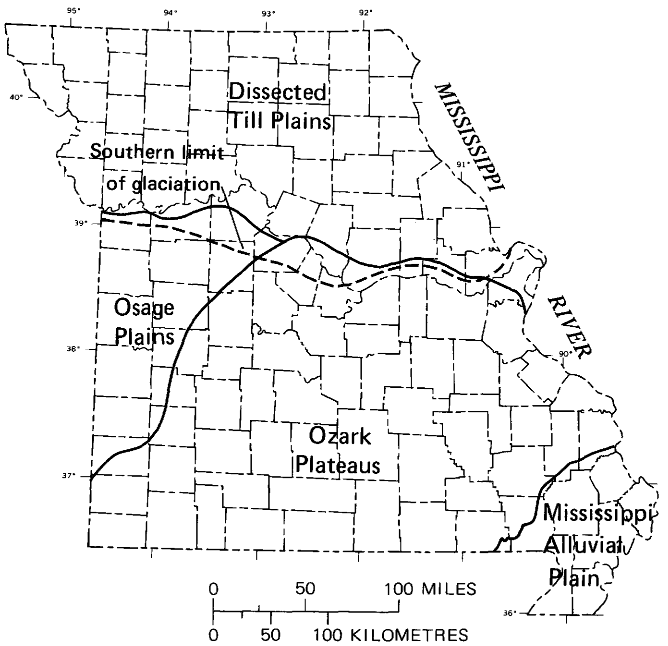

FIGURE 1—Physical divisions, southern limit of glaciation, and counties in Missouri. Physical divisions follow those of Fenneman (1946); glacial boundary from American Association of Petroleum Geologists (1966).

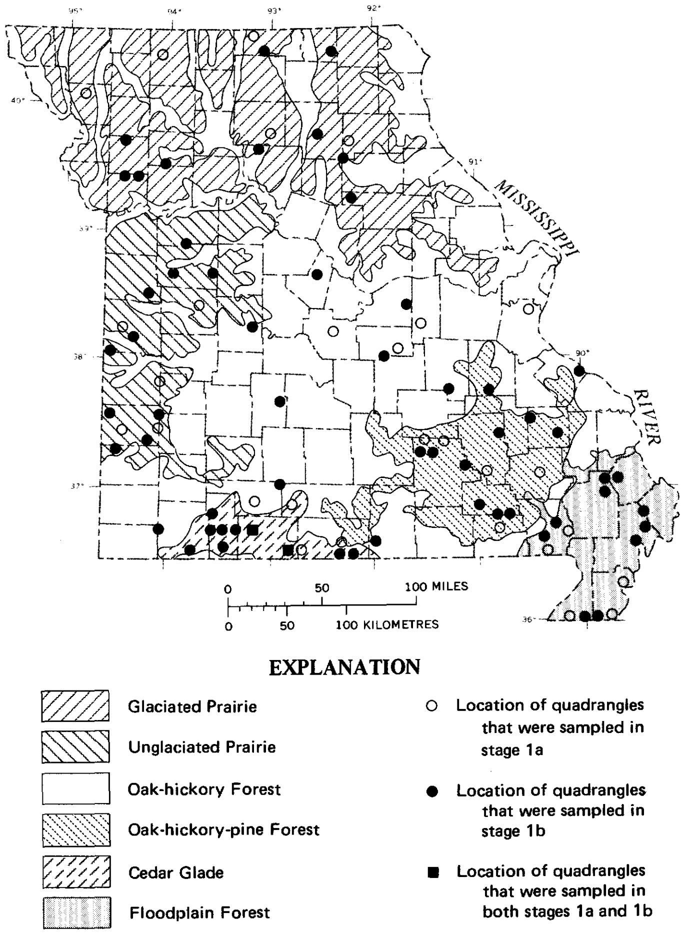

FIGURE 2.—Major vegetation-type areas (modified from Küchler, 1964), location of quadrangles where soils and plants were sampled in sampling stages 1a and 1b, and counties in Missouri.

These trees were not dominant species in the original forests, but because they reproduce freely and are tolerant of the dryer soils that resulted from effects of the drainage ditches, have persisted in the area. Prominent among these species are willow oak (*Quercus phellos*) and sweetgum (*Liquidambar styraciflua*). Sumac (*Rhus glabra*), a shrub, also occurs in the area.

The soils of this area have weakly developed horizons (U.S. Soil Conservation Service, 1969), but zonation with depth is common and reflects changes in the nature of the alluvial deposits at a location with time. Consequently, the texture of the surficial soil may range from sand to dark clay within the lateral extent of only a few metres.

GLACIATED PRAIRIE VEGETATION TYPE

Küchler (1964) mapped the vegetation of the entire prairie region of northern and western parts of Missouri as one type, the "mosaic of Bluestem Prairie and Oak-hickory Forest." Because the prairie area lying north of the Missouri River was largely glaciated, whereas the prairie area south and west of this river generally was not glaciated (fig. 1), we expected soils of the two areas to be geochemically

FIGURE 3.—Counties, county seats, and major drainage features in Missouri. Parellel lineations shown in the southeastern corner of the State are agricultural drainage ditches.

FIGURE 4.—A cypress tree that remained after a stand of the Floodplain Forest had been destroyed by lumbering and farming operations, New Madrid County, This tree (*Taxodium distichum*) measured approximately 1.3 m in diameter 2 m above the ground surface. Soybeans are now cultivated in the nearly level field. The grove on the horizon, consisting of second-growth trees, borders a drainage ditch. Photographed September 24, 1971.

different to the extent that plant chemistry might be affected. Accordingly, we divided Küchler's prairie mosaic area into glaciated and unglaciated parts, the former corresponding to the Dissected Till Plains and the latter being largely included in the Osage Plains (fig. 1). This division followed, in part, that of Steyermark (1963, p. xix), who divided the Prairie Region into three subdivisions—loess mounds (narrow strips along the Missouri River), unglaciated, and glaciated.

Krusekopf (1957, p. 20), in discussing the effects of vegetation on soil formation in Missouri, wrote:

> Approximately 40 per cent of the state originally was prairie, mainly big bluestem. * * * The vegetation factor has great significance in determining the great soil groups—brunizems and planosols on the grasslands, and gray-brown podzolic in the forested area. * * * Although forest is dominant in this climate, the prairie maintained itself under virgin conditions. In the "tension zone," the equilibrium was disturbed by man and the forest invaded the prairie. In the prairie region, prairie and forest exist side by side, in an intricate pattern, determined largely by topography, that is, grass on the level areas and trees on the slopes. Soils of the great soil groups, therefore, occur intermingled in close association.

The prairie component of this vegetation-type area at present is largely under cultivation or pastured by farm animals, therefore the mosaic of Bluestem Prairie and Oak-hickory Forest as mapped by Küchler has virtually disappeared. Only scattered remnants of the Bluestem Prairie are now present, and they occur in fence rows, on roadsides, and in other small areas that are not cultivated (fig. 5). A few areas of very limited extent, though nearly flat, have never been plowed, and they support an unbroken cover of prairie grasses and forbs. We examined one such remnant, locally known as Tucker Prairie (Kucera and others, 1963) which lies in Callaway County about 17 miles (27.2 km) east of Columbia (fig. 3), in order to learn its composition and structure as a basis for identifying this vegetation type at our sampling sites.

Small groves of oak and hickory trees at some homesteads appear to represent the forest component of this vegetation mosaic, but these forested areas are easily confused with the extensions of the Oak-hickory Forest vegetation type within the general area of prairies, as shown in figure 2. Soils and plants in these forested components of the mosaic were not sampled.

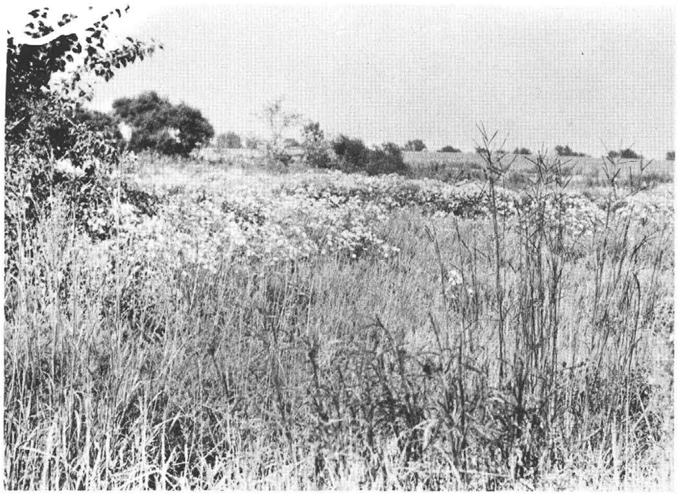

FIGURE 5.—A remnant of the bluestem prairie, Glaciated Prairie vegetation type, Chariton County. Big bluestem grass (*Andropogon gerardi*) in right foreground is about 2 m tall. Prairie forbs are in the center of the picture, and trees and shrubs in the background outline fencerows. Photographed August 30, 1970.

UNGLACIATED PRAIRIE VEGETATION TYPE

The pre-settlement mosaics of vegetation in this area and those of the glaciated area probably were similar. The vegetation of the two areas is still generally similar in that land of slight to moderate relief is commonly used for the cultivation of corn, soybeans, and other field crops and pasture grasses, with remnants of the native vegetation persisting only in waste places (fig. 6). Several small areas of potential prairie, as mapped by Küchler (1964), lie outside the principal area of the Unglaciated Prairie. These outlier areas are recognized by the present or historic occurrence of treeless patches in a region

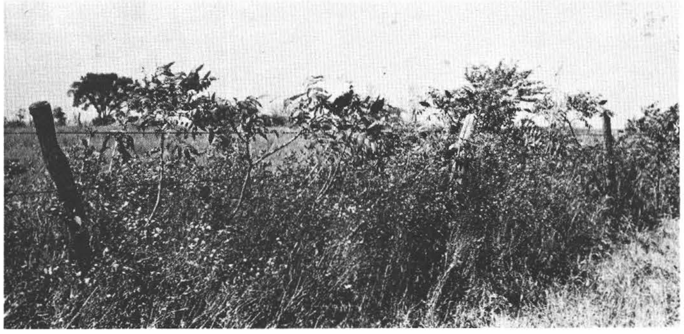

FIGURE 6.—A shrub association in a fencerow, Unglaciated Prairie vegetation type, Barton County. The tall fruiting shrubs in the foreground are sumac (*Rhus glabra*) and the low shrubs are buckbush (*Symphoricarpos orbiculatus*); both are widely distributed in this State. Trees and shrubs in this area are generally restricted to fencerows. Photographed September 4, 1970.

otherwise largely forested, as attested at some locations by place names such as West Plains in Howell County and East Prairie in Mississippi County (fig. 3.). These outlier prairie areas, because of their small size, were not included in the principal sampling plan for the State, but were considered in a separate study.

CEDAR GLADE VEGETATION TYPE

The existence and extent of this distinctive vegetation type are dependent on the occurrence of near-surface deposits of limestone or dolomite, and a ground surface usually having low to moderate relief. The development and unique floral composition of cedar glades vegetation were described by Quaterman (1950), who defined cedar glades as open spaces surrounded by cedar (*Juniperus virginiana*) where the limestone is at or near the surface. Some investigators have distinguished cedar glades, which occur on nearly level terrain, from cedar barrens or cedar bluffs that develop on more precipitous outcrops of limestone or dolomite (Anderson and Lemmon, 1973, p. 140). We made no such distinctions in this study; we considered all areas to be cedar glades that had shallow seasonally dry soils over these rock types where cedar trees were the dominant overstory species and where the distinctive associated species formed the ground cover.

Typical cedar glades (fig. 7) have a parklike aspect, with symmetrical cedar trees spaced a few to tens of metres apart, and a ground cover composed principally of little bluestem grass (*Andropogon scoparius*) and poverty grass (*Sporobolus neglectus* var. *ozarkanus*) mixed with fewer numbers of forbs that are largely restricted to this habitat, including palafoxia (*Palafoxia callosa*) and American aloe (*Agave virginica*). The thin (2 – 20 cm) highly organic soil over the bedrock is circumneutral to basic in reaction, with poorly developed zonality. Soils of this area were designated "glade-rock soils" by Kucera and Martin (1957, p. 290).

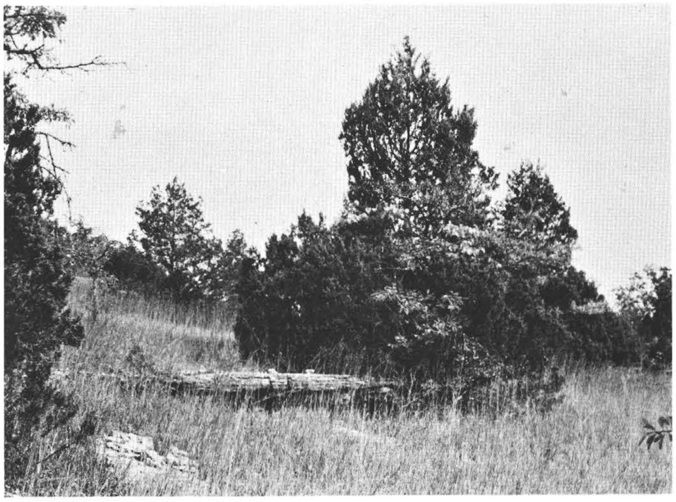

FIGURE 7.—Characteristic species of the Cedar Glade vegetation type, Ozark County. Cedar (*Juniperus virginiana*) trees are dominant, and are associated with lesser numbers of other trees including white ash (*Fraxinus americana*), buckthorn (*Bumelia lycioides*), and redbud (*Cercis canadensis*). Little bluestem grass (*Andropogon scoparius*) forms the principal ground cover. Photographed September 26, 1970.

The cedar glades furnish limited pasturage for livestock, but no commercial timber except the cedar trees that are occasionally felled. The land is not cultivated, therefore it probably exists today in much the same condition as before settlement. The area mapped as cedar glades by Küchler (1964) is actually a mosaic of Oak-hickory Forest and Cedar Glades vegetation types, with cedar glades composing only a small part of the area. Small, but typical, cedar glades occur outside the designated area mapped in figure 2; these glades were not sampled.

OAK-HICKORY FOREST VEGETATION TYPE

Oak-hickory forests formerly covered large areas in the central United States which were grouped as the Oak-Hickory Forest region by Braun (1950, p. 162 – 163), who described the region as follows:

> The most westerly forest region of the deciduous forest is one in which oaks are dominant and hickories usually more or less abundant. This region extends from Texas to Canada; it varies in width from place to place and is frequently interrupted by prairie. Oak-Hickory Forest is best developed and most continuous in the Interior Highlands—the Ozark and Ouachita Mountains region. It is widely distributed north of that region, where it extends over the older drift of the upper Mississippi Valley and into the Driftless area, and, in Minnesota, over the younger drift as a narrow band at the western margin of forest. * * * Along the western border of the Oak-Hickory Forest region, and southwestward in Texas, decreased precipitation results in transition to prairie. Here are

> savannah forests, scrubby oak communities, and tongues of woodland along the streams in the Prairie region. * * * The boundaries of the Oak-Hickory Forest region are very irregular and indefinite, except along its contact with the Mississippi alluvial plain in Arkansas and Missouri.

The extent of this vegetation type in Missouri, as mapped by Küchler (1964), is given in figure 2. This area is not homogeneous in forest species composition; several species of oak and hickory alternate as dominants from place to place in response to physiographic and edaphic site conditions, and zones transitional to prairie and oak-hickory-pine communities are common. Land of low to moderate relief is generally devoted to farming, and the forest is represented only by isolated groves that have remained from the original forest. Land of more extreme relief, some of which is in national forests, is largely uncultivated although extensively logged, and dense second-growth stands cover large areas (fig. 8).

Extensions of this vegetation type that follow drainage features northward in Missouri differ markedly from the central area, in that soils reflect the influence of stream alluvium, and species composition of the forest tends toward a predominance of wetland species including sycamore (*Platanus occidentalis*), red maple (*Acer rubrum*), and elms (*Ulmus americana* and *U. rubra*). These northward extensions of the vegetation type area were not sampled.

OAK-HICKORY-PINE FOREST VEGETATION TYPE

The area of this vegetation type in Missouri is separated from the principal area in southeastern United States, as mapped by Küchler (1964). This type was recognized as only a facies of the Oak-Hickory Forest region by Braun (1950, p. 167), who referred to pine-oak communities within the region. The greater part of the area shown in figure 2 as Oak-hickory-pine Forest actually is a mosaic of oak-hickory forests on the more mesic sites and oak-pine communities at sites over sandstone that are more xeric. This relationship of the two communities, however, is stated only as a generality; the composition and structure of the many communities within the broad vegetation type are complex, and probably are controlled by subtle differences in topography and soils or soil parent materials. At some xeric sites a scrub oak (*Quercus stellata* and *Q. marylandica*) community occurs where an oak-pine community would be expected.

Steyermark (1963, p. 42–43) stated that in Missouri shortleaf pine "Grows on acid, non-calcareous soils, associated with sandstone, chert, or granitic rock, in rocky wooded ravines, bluffs, steep slopes, tops of narrow ridges, dry uplands, or in valleys along streams where the soil has sand, chert, or granitic components."

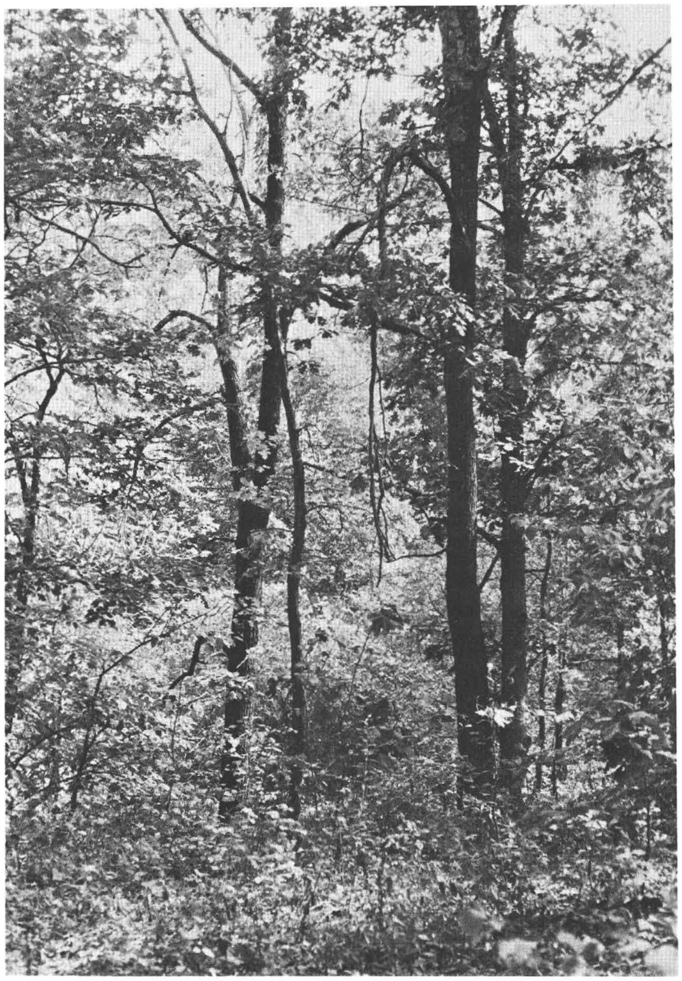

FIGURE 8.—Overstory and understory vegetation of the Oak-hickory Forest vegetation type, Christian County. The principal tree species are white oak (*Quercus alba*), red oak (*Quercus rubra*), black oak (*Quercus velutina*), bitternut hickory (*Carya cordiformis*), and shagbark hickory (*Carya ovata*). Understory shrubs include sumac (*Rhus glabra*) and buckbush (*Symphoricarpos orbiculatus*). Photographed September 27, 1970.

Pine (*Pinus echinata*) trees were observed to form almost pure stands at only a few localities (principally on ridge summits) within this vegetation-type area. More commonly, pines occur only as scattered individual trees in a predominantly oak-hickory community (fig. 9). Areas of reforestation bear pure stands of loblolly pine (*Pinus taeda*), a species not native to Missouri. These stands can be easily distinguished from stands of shortleaf pine, and were not sampled in this study. A small disjunct area of Oak-hickory-pine Forest in southwestern Missouri was not sampled. Within the main area of the vegetation type, soils and plants were sampled only if shortleaf pine occurred at the locality.

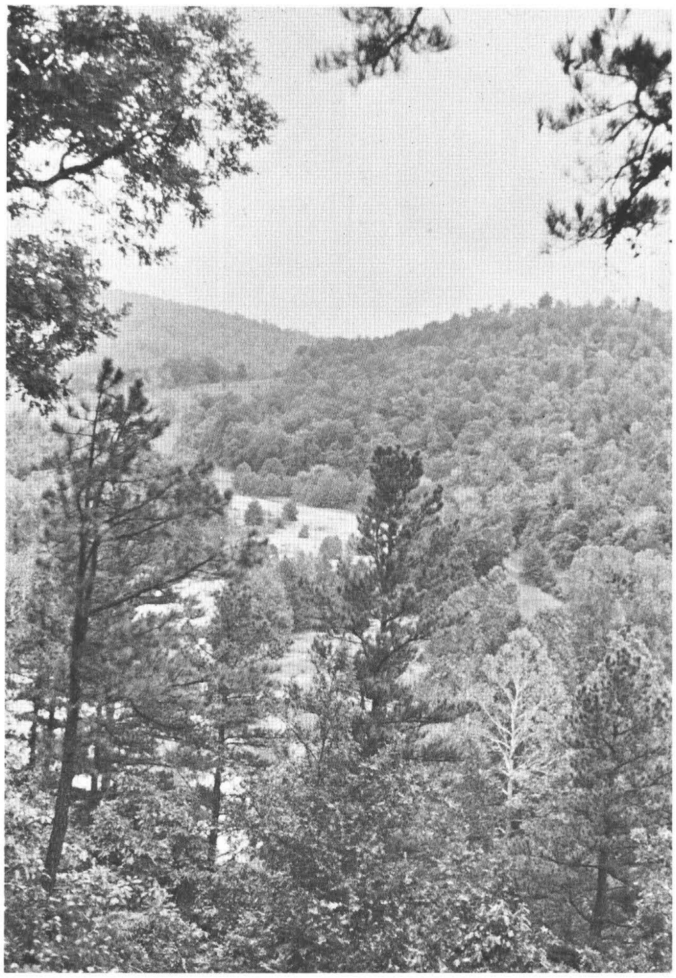

FIGURE 9.—Oak-hickory-pine Forest vegetation type on ridges and slopes, Shannon County. Shortleaf pine (*Pinus echinata*) trees grow intermixed with deciduous tree species that are characteristic of the Oak-hickory Forest vegetation type. Photographed September 24, 1970.

METHODS OF SAMPLING PLANTS AND SOILS

SAMPLING DESIGN

The principal objectives in sampling the vegetation of Missouri were to determine the major variations in the chemical composition of plants that grew throughout the State or that were considered to be representative of vegetation units in the State, and to investigate the relationships of their chemical composition to that of the associated soils. The boundaries of the vegetation-type areas that were previously described served to outline the categories or mapped units at which the sampling was directed. Sampling for the purpose of describing the major differences between these areas constituted phase 1 of a general sampling plan for geochemical surveys of large regions that was described by Connor and others (1972) and by Miesch (1976). No sampling of the phase 2 type was conducted.

The phase 1 sampling was accomplished in two stages called 1a and 1b by Miesch (1976). Stage 1a was used to estimate the magnitude of variability in chemical composition of the sampled materials at various geographic scales. Based on these results, an estimate was made of the amount of additional sampling necessary in stage 1b to achieve the desired degree of stability (Miesch, 1976) in any resultant geochemical maps.

Sampling in stage 1a was based on a three-level geographically nested design in which each level is associated with a specific range of scales. The top level represents the six vegetation-type areas as modified from Küchler (1964). The two lower levels represent, respectively, 7½-minute topographic quadrangles within areas, and sites within quadrangles. One soil sample and one plant sample from each of two or more species were collected at each site. The geographic units at the two lower levels were selected for sampling by formal randomization procedures, in an attempt to reduce sampling bias.

The general statistical model employed was:

$$x_{ijk} = \mu + \alpha_i + \beta_{ij} + \gamma_{ijk}, \qquad (1)$$

where x_{ijk} represents the concentration of an element, or other constituent, reported by the analyst in a soil or plant sample at the kth site taken from the jth 7½-minute quadrangle of the ith vegetation-type area; and μ is the average concentration of the element in the material under study within all areas of the State. α_i represents the difference between the true mean concentration of an element in the ith vegetation-type area and the grand mean, μ ; β_{ij} represents the difference between the true mean concentration for the jth quadrangle and the mean of the ith vegetation-type area, and the γ_{ijk} represents, in part, the difference between the element concentration of the sample at the kth site and the mean of the jth quadrangle of the area. Included in the last term, γ_{ijk}, are all effects of sample preparation and laboratory analysis, commonly referred to as "analytical error."

The model in equation 1 follows a specific case of the analysis of variance termed the hierarchical, or "nested" case, discussed in mathematical detail by Krumbein and Slack (1956) and described as it applies to the Missouri studies by Miesch (1976). The terms α_i, β_{ij}, and γ_{ijk} are assumed to be random variables with means of zero and variances of σ_α^2 , σ_β^2 , and σ_γ^2 . The goal of the sampling design is to obtain unbiased estimates of these variances. Thus, the total variability of the element x, estimated as s_x^2, may be partitioned into three components of variance:

$$s_x^2 = s_\alpha^2 + s_\beta^2 + s_\gamma^2, \tag{2}$$

where s_α^2 estimates the regional (statewide) variation between vegetation-type areas, s_β^2 estimates the large-scale geographic variation between quadrangles within areas, and s_γ^2 estimates small-scale geographic variation between sites within quadrangles plus the variance attributable to analytical error.

With the exception of the silicon and pH data for soils, the variance components were estimated on logarithmic transforms (base 10) of the data, because the concentrations of most elements—particularly the trace elements—tended to have marked positive skewness in their frequency distributions.

For stage 1a sampling, a 6-5-2 design was used consisting of six vegetation-type areas, five quadrangles from each area, and two sites within each quadrangle for a total of 60 sites. Quadrangles that overlapped two vegetation types about equally were excluded from the population of quadrangles that was to be sampled.

All samples were analyzed in a completely and formally randomized sequence in order to circumvent any effects of systematic analytical bias. A small number of duplicate samples used to estimate the magnitude of analytical error were included in this sequence. In effect, these duplicate analyses constitute a lower fourth level of the sampling design. (See the section "Laboratory procedures used.")

Results of the analysis of variance of the soil and plant data collected in stage 1a provided estimates of the three components of variance in equation 2: between-vegetation-type variance, between-quadrangle variance, and the sum of between-site and analytical variance. These components not only shed light on the geographic aspects of elemental variation in Missouri but may also be used to assess the reproducibility of any mean values computed from the stage 1a results. In addition, they are useful in estimating the amount of additional sampling that may be required to insure a given reproducibility of such means.

An investigation of the reliability of any areal mean that is to be used for constructing a geochemical map begins with an examination of the variance ratio, v (Miesch, 1976):

$$v = N_v/D_v = s_\alpha^2/(s_\beta^2 + s_\gamma^2), \tag{3}$$

where N_v is the estimated variance between vegetation-type areas and D_v is the estimated variance within areas. The larger v is, the smaller is the number of randomly-selected samples, n_r, needed to describe geochemical differences between areas. The terms v and n_r are related to the F-statistic, as follows:

$$F = 1 + n_r v, \tag{4}$$

where F is the value of the conventional F-statistic at some specified confidence level.

Miesch (1976) gave graphs for determining the minimum acceptable value of n_r, and the maximum acceptable error variance associated with each vegetation-type area mean is given by:

$$E_r = D_v/n_r. \tag{5}$$

The observed error variance for each vegetation-type area mean is:

$$E_s = s_\beta^2/n_\beta + s_\gamma^2/n_\beta n_\gamma, \tag{6}$$

where n_β and n_γ are, respectively, the numbers of quadrangles (five) sampled in each area and the number of samples (two) collected within each quadrangle. If E_s is less than or equal to E_r, differences between the observed areal means based on the stage 1a sampling are accepted as meaningful. If not, additional sampling (stage 1b) is required in each area before the observed differences among areal means can be accepted with confidence.

The utility of a given sample suite (whether from stage 1a or 1b) for distinguishing between means may be assessed in terms of a variance mean ratio (Miesch, 1976) defined as:

$$v_m = N_v/E_s. \tag{7}$$

This ratio may be viewed as an index of stability. The larger v_m is, the more stable are any observed differences between areas. In this study, we have defined an acceptable value of v_m as one which exceeds the variance mean ratio when based on the acceptable maximum error variance (E_r) for the 95-percent confidence level. The critical value of v_m in our studies is defined as

$$v_{m(0.95)} = N_v/E_r. \tag{8}$$

On the basis of these considerations, it was found necessary to employ a stage 1b sampling program in order to insure that each areal mean was based on a sufficient number of samples so that the important statewide chemical variation in soils and plants could be displayed on maps. We determined that a stage 1b sampling plan based on the same nested arrangement as stage 1a but consisting of a 6-10-5 plan (instead of a 6-5-2 plan) would fulfill this need.

After the average geochemical characteristics of each vegetation-type area had been estimated, maps were constructed to show at a glance which of the vegetation-type areas were believed to be different from the others with respect to most chemical constituents. Such maps, even though of satisfactory stability, shown only the gross or broad-scale geochemical variations over the State in the sampled materials. They are of poor resolution in the sense that Miesch (1976) uses this term.

The map of potential natural vegetation by Küchler (1964) includes a number of small areas in Missouri that are geographically separated from the principal vegetation-type area to which they are assigned. These outlier areas were not formally included in the sampling design, because we were uncertain if the chemistry of their soils and plants corresponds more closely to that of their assigned classification or to that of the vegetation-type area surrounding them. As a test of this relationship, three soil samples were collected at random in each of six representative outlier areas and classified chemically by stepwise discriminant function methods. (See Dixon, 1968.) Of the 18 samples from outlier areas, the chemical classification of only two agreed with the classification of samples from the vegetation-type areas to which Küchler assigned them. Most of the outlier samples were clearly more similar in chemical composition to samples from adjacent areas. For this reason, the geochemical map patterns given in this report do not differentiate these outlier areas.

SAMPLING TECHNIQUES

A pronounced "roadside effect" on the natural geochemical regime was found (Connor, Erdman, and others, 1971; Connor, Shacklette, and Erdman, 1971) at sites in Missouri near heavily traveled highways, as evidenced by unusually high concentrations of lead, zinc, and some other metals in plant and soil samples from these sites. We restricted sampling to sites as far as practicable from major roads in order to preclude or at least minimize this roadside effect. This precaution was not always feasible in sampling the prairie vegetation-type areas, inasmuch as sites where the required plant species grew were invariably along fencerows that commonly paralleled a road. However, contamination that could be attributed to vehicular traffic was not demonstrated (with but few exceptions) in samples of this report.

A site for collecting samples of native plants and uncultivated soils was defined as an area in which the required species of plants could be found rooted in a soil unit that was judged to be relatively homogeneous. The extent of the sampling site area was considered to be within a radius of about 10 m from the point that was selected for sampling the soil. This radius was extended at some sites in order to include a desired species in the sampling area, if the same soil unit extended into this enlarged area.

These constraints imposed on sample site selection did not impede sampling in the Glaciated Prairie vegetation-type area because only two plant species—sumac and buckbush—were sampled, and they were generally abundant. In the Oak-hickory-pine Forest area, on the other hand, a complete suite of samples of the desired species (sumac, buckbush, white oak, shagbark hickory, and pine) was impossible to obtain at some sites.

Several sites that were selected from quadrangle maps proved on examination in the field to be inadequate by our sampling criteria, in that one or more of the principal species could not be found at the sites. Alternate sites, consequently, were selected on a random basis from the quadrangles being sampled. Because some of the desired species could not be found either at the sites that were originally selected or at the alternate sites, some suites of plant species samples were of necessity incomplete. As an example of this deficiency, sumacs were found at 295 of a possible 300 sites that were sampled throughout Missouri. The resulting incomplete data set, however, caused only minor difficulties in statistical analyses of the data. In contrast to sumac, buckbush was found at only 4 of a possible 50 sites in the Floodplain Forest area, consequently buckbush was omitted in the chemical characterization of native plants from this area.

PLANTS

It is obviously impractical to sample all of the large number of plant species that occur in Missouri. Of the two major plant lifeforms, herbaceous and woody, we chose only woody (tree and shrub) species for sampling. This decision was based on the fact that woody plants usually are long lived and deeply rooted, in contrast to herbaceous species which commonly are short lived and shallowly rooted. We believe that woody plants, therefore, generally have a better opportunity to accumulate elements from their environment and to better integrate annual and seasonal fluctuations in element absorption than have herbaceous species. This belief is supported by the results given by Shacklette, Erdman, and Keith (1973) in their comparisons of element concentrations in woody plants and herbaceous vegetables.

Each vegetation-type area in Missouri includes several to many species of woody plants. We decided to collect two kinds of species—those that grow statewide, and those that characterize only one or two vegetation-type areas. Two species that generally occur throughout Missouri, sumac and buckbush, were sampled to obtain a measure of biogeochemical variability throughout the State as a whole. Woody plant species characteristic of each vegetation-type area were sampled to obtain an estimate of biogeochemical characteristics and variability within each area. For example, white oak, shagbark hickory, and shortleaf pine, among others, were sampled in the Oak-hickory-pine Forest vegetation-type area.

The kinds of plants that were sampled, and their scientific names as given by Steyermark (1963) follow:

Sumac, *Rhus glabra* L.
Buckbush, *Symphoricarpos orbiculatus* Moench
Post oak, *Quercus stellata* Wang.
White oak, *Quercus alba* L.
Willow oak, *Quercus phellos* L.
Sweetgum, *Liquidambar styraciflua* L.
Shagbark hickory, *Carya ovata* (Mill.) K. Koch
Cedar, *Juniperus virginiana* L.
Shortleaf pine, *Pinus echinata* Mill.

Plant samples consisted of stems about 30 cm long that were cut with shears from the terminal part of branches. In sampling deciduous trees, leaves were removed from the stems and discarded, the stems only being collected for analysis. The decision to follow this procedure was based on economy in sampling and analysis, and was supported by a conclusion of an earlier biogeochemical study in Georgia by Shacklette, Sauer, and Miesch (1970, p. C38), who stated, "The concentrations of elements in stems and leaves are strongly related. Where high concentrations occur in the stems, high concentrations are also found in the leaves."

It is impractical to remove the scalelike leaves from cedar stems, therfore both leaves and stems were included in the samples. In order to achieve a degree of uniformity in sampling coniferous trees, the leaves and stems were likewise included in the samples of pine. All plant samples were cut into 5 – 10 cm segments, sealed in quart-size freezer cartons, and shipped to the Denver laboratories.

SOILS

We decided to sample only one horizon at a site in order to promote economy in sampling and analysis of soils from the vegetation-type areas. This decision was supported by studies of soils from two distinct areas of Georgia by Shacklette, Sauer, and Miesch (1970), who stated (p. C35), "Because of the similarities in element content of soil horizons at a sample site, the differences in concentrations of almost all elements in uncultivated soils from the two areas could have been determined by sampling any one of the three soil horizons."

We selected the B horizon of uncultivated soils for sampling because this horizon is considered to be the zone of greatest accumulation of materials that are removed from the A, or upper, soil horizon; accordingly, the B-horizon soils would seem to offer the greatest opportunity for study of a wide variety of elements. Movement of materials in the solum (the A and B horizons of a zonal soil) was described by Hawkes and Webb (1962, p. 94 – 95) as follows:

> Under moist conditions and free drainage, the more soluble constituents leached from the A horizon will descend to the water table and eventually pass into surface drainage. Some suspended matter may follow the same course. More usually, however, colloidal sesquioxides and clays eluviated from the A horizon are soon redeposited in the zone of accumulation, or *illuviation*, constituting the B horizon. As a result, the B horizon characteristically tends to be enriched in clay relative to the A horizon and to assume a red- or yellow-brown color in those profiles where illuviation involves iron sesquioxides.
>
> Metals indigenous to the parent material vary in their response during the development of soil horizons. Soluble metals and those incorporated or adsorbed on clays and colloids are liable to be removed from the A horizon whereas those contained in resistant primary minerals are liable to be enriched in that horizon. Metals taken up by deep-rooted plants will be returned to the surface in the organic debris, and their subsequent fate will depend on the stability of their organic compounds in the A_1 horizon. Some of the metals which are removed from the A horizon may tend to accumulate along with hydrous Fe and Mn oxides or clays in the B horizon.

The uncultivated soils sampled at each site were collected from holes made by using a clamshell digger or a trowel, depending on which of the two was appropriate for use at the site, at a depth which we judged to reflect the structural and color features of the B horizon. This depth ranged from considerably less than 30 cm in upland areas of the Ozark Plateaus to about 80 cm in the well-developed soils of the northern prairies. The highly organic lithosols typical of the Cedar Glades commonly are only a few centimetres thick and occur in shallow depressions on carbonate bedrock. In some upland forested areas a dense layer of coarse chert fragments commonly occurs at a depth of about 15 cm, which restricts the depth of soil sampling; at these localities, and generally in the Cedar Glade area, a well-developed B horizon was not present, therefore samples were taken from the lowest level of the sampling hole. Conspicuous rock fragments were culled from the sample, and about 300 – 400 g of the remaining soil material was put in a waterproof paper envelope and shipped to the Denver laboratories.

LABORATORY PROCEDURES USED

Before submitting plant samples from the 1b stage of sampling to the laboratories for chemical analysis, we selected 50 samples at random from the total of 950 of all species that were collected. These selected samples were divided into two approximately equal parts in order to obtain duplicate analyses, then merged with the 900 samples that had not been divided. After reordering the entire set of 1,000 samples in a sequence that was random with respect to both geographical location and to species which were, therefore, unknown by the analysts, the samples were submitted for analysis.

The plant samples were prepared for analysis by air drying and then pulverizing in a Wiley mill. A part of the pulverized material was weighed, then burned to ash in an electric oven in which the heat was increased 50°C per hour to a temperature of 500°C and held at this temperature for 14 hours. The resulting ash was then weighed to determine the ash yield of the dry plant material. Analytical methods for most elements employ a weighed aliquot of the ash. For determining concentrations of a few elements that would be volatilized and lost by burning the sample, weighed aliquots of the dry plant material were used for analysis.

By following the same procedures used for dividing and randomizing plant samples, we divided 30 samples of soil to provide duplicates, the 60 resulting duplicates were then merged with the 270 samples that were not divided, and the total of 330 samples were submitted to the laboratories in a randomized order.

TABLE 2.—*Approximate lower limits of determination for elements in soils and plant materials*

[Dry soil was used for analyses of all elements. Dry plant material was used for arsenic, fluorine, iodine, mercury, and selenium analyses; plant ash was used for analyses of all other elements. Limits are given in parts per million. Leaders (...) in figure columns indicate no data available]

Element	Lower limit of determination		Element	Lower limit of determination	
	Soils	Plant materials		Soils	Plant materials
Al	10,000	50	Li	5	4
As	.2	.25	Mg	300	50
B	20	50	Mn	1	2
Ba	1.5	3	Mo	3	5
Be	1	2	Na	100	100
C, in CO_3	100	...	Nb	10	...
C, organic	1,000	...	Nd	70	150
Ca	1,000	100	Ni	5	2
Cd	1	.5	P	300	40
Ce	150	300	Pb	10	20
Co	3	1	Se	.1	.01
Cr	1	2	Sc	5	7
Cu	1	2	Si	10,000	...
F	40	.5	Sr	5	10
Fe	[1]1,000	[2]20	Ti	2	5
Ga	5	5	V	7	5
Hg	.01	.025	Y	10	20
I	...	1	Yb	1	2
K	1,000	100	Zn	10	25
La	30	70	Zr	10	20

[1] In Fe_2O_3
[2] Total

The soil samples were dried in an oven with circulating air held at about 50°C before the samples were pulverized in a ceramic mill to approximately minus-100-mesh particle size. Before being pulverized, the samples were *not* sifted through a 200-mesh sieve, as is done in some soil studies, therefore rock

TABLE 1.—*Analytical methods used in this study*

Name of method	Elements and plant ash commonly reported	Principal reference
Six-step emission spectrographic	In soils and plant ash: B, Ba, Be, Cr, Cu, Ga, La, Mn, Mo, Nb, Ni, Pb, Sc, Sr, Ti, V, Y, Yb, and Zr. In soils only: Co. In plant ash only: Al, Fe, and Mg.	Myers, Havens, and Dunton (1961).
Atomic absorption, flame	In soils and plant ash: Cd, Li, Na, and Zn. In soils only: Mg. In plant ash only: Ca, Co, and K.	Ward, Nakagawa, Harms, and VanSickle (1969).
Atomic absorption, flameless	In soils and dry plant material: Hg.	Vaughn (1967). Unpublished modification used for plants.
X-ray fluorescence	In soils: Al, Ca, Fe, K, P, Se, and Si.	Liebhofsky, Pfeiffer, Winslow, and Zemany (1960).
Colorimetric	In plant ash only: P. In dry plant material and soils: As.	Ward, Lakin, Canney, and others (1963).
Catalytic	In dry plant material only: I.	Cuthbert and Ward (1964).
Selective ion electrode	In dry plant material and soils: F.	Ingram (1970).
Gasometric	In soils only: Carbonate carbon.	Tourtelot, Huffman, and Rader (1964).
Calculated	In soils only: Organic carbon.	Do.
2-3 diaminonaphthtalene fluorimetric	In dry plant material only: Se.	No data available.
Gravimetric	In dry plant material only: Ash.	Ward, Lakin, Canney, and others (1963).

TABLE 3.—*Elements commonly looked for, but rarely or never detected, by semiquantitative spectrographic analysis, and their approximate lower limits of determination in parts per million for samples in this report*

[Leaders (. . .) in a figure column indicate that the element is commonly detected in the sample material listed in the column heading]

Element	Material analyzed		Element	Material analyzed	
	Soils	Plant ash		Soils	Plant ash
Arsenic	1,000	2,000	Palladium	1	2
Antimony	150	300	Platinum	30	70
Bismuth	10	20	Praseodymium[2]	100	200
Cadmium	20	50	Rhenium	30	70
Cerium	150	300	Samarium[2]	100	200
Dysprosium[1]	50	100	Silver	.5	.5
Erbium[1]	50	100	Scandium	...	7
Europium[2]	100	200	Tantalum	200	500
Gadolinium[1]	50	100	Tellurium	2,000	5,000
Germanium	10	20	Terbium[1]	300	700
Gold	20	50	Thallium	50	100
Hafnium	100	200	Thorium	200	500
Holmium[1]	20	50	Thulium[1]	20	50
Indium	10	20	Tin	10	15
Lithium	50	100	Tungsten	100	300
Lutetium[1]	30	70	Uranium	500	1,000
Neodymium	70	150	Zinc	200	...
Niobium	10	20			

[1] Looked for if yttrium is greater than 50 ppm.

[2] Looked for is lanthanum or cerium is found.

TABLE 4.—*Variance of errors attributed to laboratory procedures, based on duplicate analyses of uncultivated soils and native plants from Missouri*

[Variance components calculated on data transformed to logarithms, except as noted. Leaders (. . .) in figure column indicate no data available]

Element, ash, or pH	Soils	Plants	Element, ash, or pH	Soils	Plants
	Component n=60 (30 pairs)	Component n=100 (50 pairs)		Component n=60 (30 pairs)	Component n=100 (50 pairs)
Al	0.00300	0.04263	Mg	0.00556	0.01643
As	.00698	...	Mn	.02261	.01975
B	.01385	.01411	Na	.02307	.01793
Ba	.01310	.02977	Ni	.00986	.01771
C, in CO_3	.19020	...	P	.02877	.00526
C, organic	.01624	...	Pb	.00821	.04097
Ca	.01759	.00157	Sc	.00836	...
Cd	...	.00714	Se[1]	.03334	.00687
Co	.01222	...	Si	11.15	...
Cr	.00874	.03164	Sr	.01544	.01342
Cu	.03490	.01796	Ti	.00575	.03049
F	.14937	...	V	.00515	...
Fe	.00188	.02568	Y	.00610	...
Ga	.01246	...	Yb	.00872	...
Hg	.06799	...	Zn	.00257	.00657
K	.00912	.00198	Zr	.02906	...
La	.00717	...	Ash	...	.00168
Li	.00069	...	pH[2]	.02900	...

[1] Error component derived from nontransformed data.

[2] Error component expressed in standard units.

particles larger than this mesh size were retained and pulverized in some samples.

The methods of analysis used for all samples of the Missouri geochemical study were described in detail by Miesch (1976). The methods used for analysis of plant and soil samples are outlined in table 1.

The approximate lower limits of determination for materials analyzed in this study are given in table 2.

All samples of both soils and plants were analyzed first by semiquantitative emission spectrophotometry, and the concentrations reported for many elements were satisfactory for our purposes, as is indicated in table 2. Many other elements were commonly looked for by this analytical method, but were rarely or never detected. These elements are listed in table 3.

The error attributed to laboratory procedures, based on the duplicate analyses, is given in table 4 as variance components. By comparing these components with the final or lowest components in the nested analysis of variance, one can estimate the extent to which laboratory error affects the apparent natural variability. Owing to vagaries in the selection of samples for duplicate analysis, the analytical variance component in some cases exceeded the variance component at the locality level. For such occurrences, as for example with fluorine in the uncultivated soils, one can only interpret the disparity to mean that most if not all of the local variability is more correctly attributed to laboratory procedures than to natural causes.

RESULTS

GEOCHEMICAL CHARACTERISTICS AND VARIABILITY OF UNCULTIVATED SOILS

UNIVARIATE STATISTICAL ANALYSIS

Estimated components of chemical variability (as variance) in uncultivated B-horizon soils in Missouri are listed in table 5. Each of these components is associated with one of the geochemical sampling units (vegetation-type areas, quadrangles within areas, and sites within quadrangles). A comparison of the estimated logarithmic variance components based on analyses of the soils collected in both sampling stages 1a and 1b indicates that these estimates are reasonably reproducible. They agree, for the most part, within a factor of two, and show substantially the same proportion of total variance at each of the three levels of the sampling design.

All 34 elements and soil pH in samples of the 1b sampling stage exhibit statistically significant variation (at the 95-percent confidence level) at statewide scales—that is, among vegetation-type areas. In addition, most of the properties measured exhibit a relatively large part of their variation at this scale, indicating that maps of this variation could be meaningful tools in an assessment of the major geochemical variations across the State.

TABLE 5.—*Components of variance estimated for samples of uncultivated Missouri soils collected in stages 1a and 1b of the sampling plan*

[First and second lines of data following each element give components derived from stages 1a and 1b sampling, respectively. Variance calculated on data transformed to logarithms, except as noted. Asterisk (*), significantly greater than zero at the 0.05 probablity level. Leaders (...) in figure column indicate no data available]

Element, or pH	Variance						
	Total log 10 variance	Between areas		Between quadrangles		Between sites	
		Component, s^2_α	Percent of total	Component, s^2_β	Percent of total	Component, s^2_γ	Percent of total
Al	...	...	...	...	...	...	...
	0.04593	*0.02730	55	*0.00448	9	0.01775	35
As	...	...	...	...	...	...	...
	.06443	*.01115	17	*.00803	12	.04515	70
B	.03591	0	<1	.00361	10	.03230	90
	.02602	*.00264	10	.00139	5	.02199	85
Ba	.05880	*.01770	30	.00629	11	.03481	59
	.06926	*.02118	30	*.01626	23	.03182	46
C, carbonate	...	...	...	...	...	...	...
	.45277	*.12758	28	.00993	2	.31526	70
C, organic	...	...	...	...	...	...	...
	.10299	*.04500	44	.00202	2	.05597	54
Ca	...	...	...	...	...	...	...
	.33837	*.20049	59	*.02719	8	.11069	33
Co	.05727	.00636	11	.00436	8	.04655	81
	.05752	*.00439	8	*.00435	7	.04878	85
Cr	.03431	*.00969	28	.00435	13	.02027	59
	.04849	*.01721	35	*.00547	11	.02581	53
Cu	.06399	.00852	13	*.02697	42	.02850	45
	.08142	*.00908	11	*.00899	11	.06335	78
F	...	...	...	...	...	...	...
	.14251	*.03356	23	*.01031	7	.09864	69
Fe	...	...	...	...	...	...	...
	.05260	*.02239	43	*.00332	6	.02635	51
Ga	.07183	*.03633	51	.00944	13	.02606	36
	.06789	*.02820	42	*.00693	10	.03276	48
Hg	...	...	...	...	...	...	...
	.12628	*.03720	29	.00458	4	.08450	67
K	...	...	...	...	...	...	...
	.04608	*.01164	25	*.01254	27	.02190	48
La	...	...	...	...	...	...	...
	.02090	*.00411	20	*.00236	11	.01443	69
Li	...	...	...	...	...	...	...
	.03895	*.01514	39	*.00414	11	.01967	51
Mg	...	...	...	...	...	...	...
	.19132	*.10137	53	*.01285	7	.07710	40
Mn	.17501	*.01666	10	0	<1	.15835	90
	.13203	*.10532	12	*.01601	12	.10070	76
Na	...	...	...	...	...	...	...
	.12190	*.06442	53	*.01901	16	.03848	32
Ni	.06464	*.01191	18	*.01926	30	.03347	52
	.09832	*.02861	29	*.01557	16	.05414	55
P	...	...	...	...	...	...	...
	.08760	*.03289	38	*.00669	8	.04802	55
Pb	.02529	*.00804	32	.00276	11	.01449	57
	.03469	*.00255	7	*.00341	10	.02872	83
Sc	.05742	*.03144	55	.00289	5	.02309	40
	.05230	*.02064	40	*.00645	12	.02521	48
Se	...	...	...	...	...	...	...
	.12912	*.03312	26	*.01089	8	.08511	66
Si[1]	...	...	...	...	...	...	...
	164.02	*77.04	47	3.58	2	83.40	51
Sr	.08030	*.03010	37	*.01662	21	.03358	42
	.06808	*.03050	45	*.01144	17	.02614	38
Ti	.04957	*.01981	40	.00410	8	.02566	52
	.03821	*.01238	32	*.00439	12	.02144	56
V	.07414	*.03447	47	.00618	8	.03349	45
	.06763	*.02866	42	*.00742	11	.03155	47
Y	.03483	*.01121	32	0	<1	.02362	68
	.04351	*.00601	14	*.01020	23	.02730	63

TABLE 5.—*Components of variance estimated for samples of uncultivated Missouri soils collected in stages 1a and 1 b of the sampling plan*—Continued

Element, or pH	Total $\log_{10}$ variance	Variance: Between areas: Component, s^2_α	Percent of total	Between quadrangles: Component, s^2_β	Percent of total	Between sites: Component, s^2_γ	Percent of total
Yb	0.03280	0.01464	45	0.00386	12	0.01430	43
	.03988	*.00644	16	*.00819	21	.02524	63
Zn	...	...	...	...	...	...	...
	.05488	*.01559	28	*.00742	14	.03187	58
Zr	.10171	*.04204	41	0	<1	.05967	59
	.07483	*.02550	34	*.01077	14	.03856	52
pH[2]	...	...	...	...	...	...	...
	.92250	*.58844	62	*.03004	3	.33402	35

[1] Variance components derived from nontransformed data.

[2] Variance components expressed in standard units.

TABLE 6.—*Mean chemical composition and chemical variation of uncultivated soils from six vegetation-type areas in Missouri*

[Mean concentrations given in parts per million except where percent or parts per billion (ppb) are indicated. Dry soil used for chemical analyses; soil slurry used for pH determinations. *GM*, geometric mean, except as indicated; *GD*, geometric deviation, except as indicated; Ratio, number of samples in which detected to total number of samples; leaders (...), no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of certain elements in soils from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Because of insufficient data, differences in concentrations of Be, Ce, Mo, Nb, and Nd were not tested]

Element, or pH	Vegetation-type area: Floodplain Forest: *GM*	*GD*	Ratio	Glaciated Prairie: *GM*	*GD*	Ratio	Unglaciated Prairie: *GM*	*GD*	Ratio	Cedar Glade: *GM*	*GD*	Ratio	Oak-hickory Forest: *GM*	*GD*	Ratio	Oak-hickory-pine Forest: *GM*	*GD*	Ratio
Al, percent	4.4	1.29	50.50	**6.0**	1.21	50:50	4.7	1.34	50:50	3.2	1.42	50:50	2.7	1.47	50:50	*2.1*	1.63	50:50
As	7.5	2.03	50:50	**13**	1.27	50:50	12	1.55	50:50	8.4	1.73	50:50	8.0	1.83	50:50	*6.7*	1.67	50:50
B	29	1.44	46:50	33	1.38	49:50	35	1.40	50:50	*27*	1.48	43:50	**39**	1.41	49:50	32	1.43	49:50
Ba	**660**	1.43	50:50	560	1.46	50:50	490	1.58	50:50	*250*	1.61	50:50	390	1.78	50:50	340	1.96	50:50
Be	.99	1.46	33:50	1.2	1.29	46:50	1.3	1.27	47:50	.88	1.47	27:50	.77	1.42	20:50	.77	1.47	21:50
C, carbonate, percent	.046	3.06	45:50	.055	2.95	44:50	*.046*	3.34	42:50	**.40**	8.43	47:50	.054	4.14	44:50	.055	3.11	45:50
C, organic, percent	.89	2.09	50:50	.83	1.69	50:50	.98	1.48	50:50	**2.8**	1.64	50:50	.96	1.69	50:50	*.70*	1.81	50:50
Ca, percent	.42	1.75	50:50	.38	1.36	50:50	.24	1.79	49:50	**1.7**	4.52	49:50	.15	2.80	46:50	*.065*	2.44	28:50
Ce	<150	...	0:50	97	1.36	11:50	110	1.34	16:50	<150	...	5:50	78	1.45	6:50	<150	...	2:50
Co	*8.3*	1.72	50:50	11	1.55	50:50	**14**	1.83	50:50	9.5	1.48	50:50	10	1.71	49:50	9.5	1.89	50:50
Cr	39	1.80	50:50	**66**	1.15	50:50	65	1.23	50:50	42	1.51	50:50	43	1.45	50:50	*30*	1.67	50:50
Cu	15	1.99	50:50	**24**	1.66	50:50	18	1.63	50:50	17	1.94	50:50	13	1.99	50:50	*12*	1.88	50:50
F	250	2.21	50:50	**460**	1.54	50:50	360	1.71	50:50	410	2.18	50:50	190	2.40	50:50	*160*	2.66	50:50
Fe, percent	2.1	1.69	50:50	3.5	1.26	50:50	**3.5**	1.53	50:50	1.9	1.43	50:50	1.9	1.43	50:50	*1.5*	1.51	50:50
Ga	12	1.53	50:50	**19**	1.40	50:50	14	1.51	50:50	11	1.64	47:50	8.4	1.54	48:50	*5.9*	1.92	37:50
Hg, ppb	57	2.07	50:50	68	1.70	50:50	46	1.76	50:50	**160**	2.39	50:50	55	1.91	50:50	45	2.05	50:50
K, percent	**1.8**	1.14	50:50	1.5	1.28	50:50	1.3	1.45	50:50	1.7	1.50	50:50	1.1	1.61	50:50	*.86*	1.96	50:50
La	*32*	1.24	46:50	39	1.35	50:50	**45**	1.37	50:50	33	1.36	45:50	35	1.37	46:50	30	1.31	40:50
Li	20	1.63	50:50	**32**	1.21	50:50	29	1.33	50:50	23	1.55	50:50	18	1.33	50:50	*15*	1.41	50:50
Mg, percent	.31	1.80	50:50	.54	1.38	50:50	.35	1.57	50:50	**.84**	3.06	50:50	.18	2.25	50:50	*11*	1.67	50:50
Mn	710	2.72	49:50	*430*	2.25	50:50	780	2.29	50:50	**1,200**	1.57	50:50	730	2.16	50:50	660	2.09	50:50
Mo	< 3	...	1:50	< 3	...	4:50	< 3	...	1:50	< 3	...	3:50	<3	...	2:50	< 3	...	1:50
Na, percent	**.62**	1.65	50:50	.50	1.45	50:50	.31	1.62	50:50	*.13*	1.70	50:50	.27	2.01	50:50	.19	1.86	50:50
Nb	5.8	1.38	7:50	7.9	1.24	19:50	8.1	1.26	22:50	<10	...	1:50	8.0	1.38	22:50	7.9	1.36	21:50
Nd	46	1.36	11:46	60	1.21	27:50	61	1.18	30:50	37	1.55	8:45	47	1.35	12:48	36	1.47	5:43
Ni	19	1.65	50:50	23	1.49	50:50	20	1.88	49:50	**23**	2.31	49:50	12	1.82	47:50	*8.8*	1.75	47:50
P, percent	.068	1.86	49:50	.033	1.58	44:50	.038	1.56	47:50	**.083**	1.73	50:50	.033	1.88	40:50	*.030*	1.67	42:50
Pb	19	1.56	49:50	19	1.31	50:50	24	1.50	50:50	**25**	1.52	50:50	23	1.50	50:50	*18*	1.64	49:50
Sc	7.1	1.58	42:50	**12**	1.34	50:50	10	1.33	50:50	6.8	1.59	43:50	5.4	1.49	37:50	*4.7*	1.78	30:50
Se	.31	2.78	42:50	**.73**	2.11	49:50	.67	1.64	50:50	.31	2.10	46:50	.31	1.90	48:50	*.27*	2.01	46:50
Si, percent	36	7.70	50:50	32	5.06	50:50	34	6.82	50:50	*29*	17.42	50:50	39	7.43	50:50	**41**	5.68	50:50
Sr	**120**	1.32	50:50	120	1.35	50:50	95	1.51	50:50	72	1.51	50:50	66	1.66	50:50	*42*	1.90	50:50
Ti, percent	.26	1.51	50:50	.37	1.30	50:50	**.39**	1.34	50:50	*.19*	1.43	50:50	.35	1.44	50:50	.33	1.61	50:50
V	64	1.87	50:50	**110**	1.34	50:50	92	1.39	50:50	59	1.58	50:50	53	1.48	50:50	*37*	1.70	50:50
Y	23	1.63	48:50	30	1.30	50:50	**37**	1.35	50:50	22	1.79	49:50	27	1.50	50:50	*22*	1.69	49:50
Yb	2.1	1.56	48:50	3	1.27	50:50	**3.4**	1.42	49:50	*2*	1.66	49:50	2.8	1.44	50:50	2.4	1.69	50:50
Zn	54	1.67	50:50	**67**	1.41	50:50	51	1.41	50:50	54	1.71	50:50	36	1.59	50:50	*30*	1.62	50:50
Zr	160	1.93	50:50	210	1.42	50:50	**300**	1.52	50:50	*120*	1.68	50:50	300	1.63	50:50	260	1.74	50:50
pH[2]	5.8	.68	50:50	*5.3*	.50	50:50	5.3	.38	50:50	**7.3**	.51	50:50	5.6	.81	50:50	5.5	.65	50:50

[1] Arithmetic means and standard deviations.

[2] Standard units and stand deviations.

In general, however, the largest amount of variation occurs at the lowest level—between samples collected within the 7½-minute quadrangles. The variance components at this level constitute, for the most part, one-half or more of the total variance. Part of the variance at this level is caused by error due to laboratory procedures (sample preparation and analysis), but because these effects tend to be small (table 4) most of the variance can be attributed to natural causes (that is, to actual small-scale variation within the soil).

Although statistically significant variation occurs between quadrangles within vegetation-type areas, it is commonly only a small part of the total variance. In summary, the major sources of compositional variability in the uncultivated soils are found between vegetation-type areas and, locally, between samples collected within 7½-minute quadrangles.

Results of the chemical analyses of the uncultivated soils from the six vegetation-type areas that were sampled in Missouri are summarized in table 6. The geometric mean (*GM*) for each vegetation-type area represents the most probable concentration of the element in a randomly selected sample from an area. In those cases where the detection ratio does not equal unity, the mean logarithms were computed using procedures developed by Cohen (1959) and described as they were applied to the Missouri geochemical studies by Miesch (1976). The geometric deviation (*GD*) is a measure of the variation of the data about this central tendency. For example, a *GD* near 1.0 indicates virtually no variability of that element in the soil material that was analyzed.

As discussed in the sampling design section of this report, the stability of the areal means for the elements listed in table 6 for which statistically significant differences were found between soils from vegetation-type areas may be assessed by v_m (equation 7). E_S for stage 1b sampling is derived from

$$E_S = s^2_\beta/10 + s^2_\gamma/50, \qquad (9)$$

where s^2_γ and s^2_β are the variance components estimated between sites and between quadrangles, rspectively (table 5). In table 7, the generally large values of the stability index, v_m (see equation 7), all (except for lead) of which are greater than the corresponding critical v_m, indicate that the stage 1b data are sufficient for distinguishing, at the 95-percent confidence level, the chemical characteristics of the soils between the major regions of the State.

Considerable variation between the vegetation-type areas in the concentrations of chemical constituents in the uncultivated soils is apparent in table 6. For all constituents tested, at least the highest and lowest means are significantly different at the 0.05 probability level. Relatively high concentrations of many elements occur in soils from the Glaciated Prairie, the Unglaciated Prairie, and the Cedar Glades, and the lowest concentrations of many elements occur in soils from the Oak-hickory-pine Forest vegetation-type area.

Basically, the analysis of variance (table 5) assures us that significant differences in concentrations of the elements and pH occur at the very least between the two vegetation types that have the extreme mean

TABLE 7.—*Statistics used to assess adequacy of stage 1b sampling for distinguishing vegetation-type areas, based on soil analyses*

Element, or pH	s^2_α (or N_v)	E_s	v_m	$v_{m(0.95)}$	Element, or pH	s^2_α (or N_v)	E_s	v_m	$v_{m(0.95)}$
Al.........	0.02730	0.00080	34.0	6.1	Mg........	0.10137	0.00283	35.9	5.6
As........	.01115	.00171	6.5	3.4	Mn........	.01532	.00361	4.2	3.2
B..........	.00264	.00058	4.6	3.4	Na........	.06442	.00267	24.1	5.6
Ba.........	.02118	.00226	9.4	4.0	Ni.........	.02861	.00264	10.8	3.7
C, carbonate	.12758	.00730	17.5	3.5	P..........	.03289	.00163	20.2	4.2
C, organic..	.04500	.00132	34.1	4.7	Pb........	.00255	.00092	2.8	3.0
Ca.........	.20049	.00493	40.6	5.8	Sc.........	.02064	.00115	18.0	4.6
Co.........	.00439	.00141	3.1	2.9	Se.........	.03312	.00279	11.9	3.5
Cr.........	.01721	.00106	16.2	3.9	Si	77.038	2.0259	38.0	4.4
Cu........	.00908	.00217	4.2	2.9	Sr.........	.03050	.00167	18.3	4.9
F..........	.03356	.00300	11.2	3.7	Ti.........	.01238	.00087	14.3	3.8
Fe.........	.02239	.00086	26.1	4.5	V.........	.02866	.00137	20.9	4.4
Ga........	.02820	.00135	20.9	4.3	Y.........	.00601	.00157	3.8	3.2
Hg........	.03720	.00215	17.3	3.8	Yb........	.00644	.00132	4.9	3.3
K.........	.01164	.00169	6.9	3.7	Zn.........	.01559	.00138	11.3	3.2
La.........	.00411	.00052	7.8	3.4	Zr.........	.02550	.00185	13.8	4.1
Li.........	.01514	.00081	18.8	4.5	pH	.58844	.00968	60.8	6.5

[1] Variance components derived from nontransformed data.

[2] Variance components expressed in standard units.

values. In order to depict these differences on maps, a judgment is needed as to whether the six areal means can be naturally grouped into some smaller subsets. For making this judgment we relied on results of Duncan's multiple range test (Duncan, 1955), the application of which was more fully described by Miesch (1976). An example of the application and interpretation of this test follows.

For an element—in this example, zinc—the vegetation-type areas are ranked by geometric mean concentrations in the uncultivated soils (table 6) as follows:

Vegetation-type area	*Geometric mean, (in ppm)*
Glaciated Prairie	67
Floodplain Forest	54
Cedar Glade	54
Unglaciated Prairie	51
Oak-hickory Forest	36
Oak-hickory-pine-Forest	30

On the basis of the multiple range test, which provides a measure of the SSR (shortest significant range or difference) between means, the bracketed means shown above cannot be demonstrated to be significantly different at the 0.05 level of probability. Only one clear discontinuity can be identified in the ranked means; it occurs between the Unglaciated Prairie and the Oak-hickory Forest and the Oak-hickory-pine Forest. Therefore, the six vegetation-type areas may be unequivocally classified into two groups with respect to zinc concentrations in the soils. One of these groups, relatively high in zinc, is formed by the Glaciated Prairie, the Floodpain Forest, the Cedar Glade, and the Unglaciated Prairie. The other group, relatively low in zinc, is formed by the Oak-hickory Forest and the Oak-hickory-pine Forest. The vegetation-type areas are classified in this manner in figures 10 – 43. Thus zinc (fig. 41), for example, tends on a broad scale to be about equally abundant in the prairie soils in the northern and western parts of the State and in the soils of the Cedar Glade and Floodplain Forest areas. The geometric mean zinc concentration for this entire area is given as 61 ppm. It is computed as the weighted arithmetic average of the four geometric means for the individual vegetation-type areas making up the group. Each areal mean was weighted by the size of the area it represents. As is also shown in figure 41, the mean zinc concentration of soils in the Oak-hickory and Oak-hickory-pine forested areas is about one-half that of the other four areas—about 36 ppm.

These maps present the very broad or statewide features of the element distribution patterns at a glance. Also included on the maps are histograms representing the frequency distributions of analytical values for each of the six vegetation-type area soils, the geometric mean (*GM*) and geometric deviation (*GD*) for each group, and the locations of the randomly selected quadrangles that were sampled. These locations are indicated by numbers representing the average compositions of the soil samples from each quadrangle.

Certain limitations should be observed in interpreting the data presented in figures 10 – 43. For example, the zinc map shows only that the soils from the Oak-hickory Forest and Oak-hickory-pine Forest areas tend to contain less zinc than do soils elsewhere in the State. This tendency does not mean that all soils in these upland forested areas contain less zinc than do soils in other vegetation-type areas, as can be seen by examining the histograms on the figures. The few highest samples from the Oak-hickory Forest are higher than any from the Unglaciated Prairie, and the analysis of variance (table 5) demonstrated that more than half of the total variance occurs at local scales or in laboratory procedures.These facts are not evident in the quadrangle means plotted on the maps because the natural local variability has been smoothed out and largely obscured by computing these means.

The principal value of these maps is their usefulness in presenting a quantitive first-order description of the chemistry of uncultivated B-horizon soils in Missouri. Local areas of the State which for one reason or another may be suspected of having atypical soils can now be assessed in a quantitive way by reference to these maps. In determining if the concentration of an element in soil from such an area is anomalous, the *GM* and the *GD* for the element and vegetation-type area from which the samples were taken are the proper statistics to compare with data provided by these maps. (See Miesch, 1976.)

Some of the map patterns in figures 10 – 43 are based on distinctions in soil chemistry among all six vegetation-type areas. Other patterns are based on distinctions between two or more groupings of these areas if Duncan's (1955) multiple range test indicated the presence of distinct groupings. Maps for nine elements (barium, boron, copper, lanthanum, lead, potassium, silicon, ytterbium, and yttrium), however, contain only three rather arbitrary groupings. For these elements, the analysis of variance indicated that at least the highest and lowest areas are distinct from each other, but Duncan's test failed to unambiguously define any groups. For these elements, we conclude only that the areas of extreme high and extreme low mean concentrations are significantly different.

Six principal distinctive geochemical patterns in uncultivated soils from Missouri are summarized in table 8.

Soils from the two prairie areas cannot be distinguished by their concentrations of chromium, lithium, scandium, selenium, and vanadium.However, the two prairie areas do differ in that the Glaciated Prairie soils tend to be higher in aluminum, calcium gallium, and magnesium content, whereas the Unglaciated Prairie soils tend to have greater concentrations of cobalt and manganese. These differences justify our decision, made at the beginning of the study, to divide Küchler's (1964) prairie-mosaic type (which was established on the basis of plant species composition) into glaciated and unglaciated areas for conducting geochemical studies of soils and vegetation.

The Cedar Glade soils are distinct from soils of the other vegetation-type areas in Missouri in that they have a significantly higher pH, and their concentrations of calcium, carbonate and organic carbon, mercury, and magnesium are also significantly higher. On the other hand, these soils tend to have the lowest concentrations of sodium, titanium, and zirconium. The high concentrations of organic carbon and mercury (figs. 16 and 28) suggest that organic materials in soils of this area may serve as a sink for mercury moving through the environment, and corroborates reports in the literature (for example, Shacklette, Boerngen, and Turner, 1971, p. 3) that organic materials tend to "scavenge" mercury.

The evidence that Missouri soils outside the Cedar Glade area compose a single population based on their mercury concentrations is supported by results of two programs of sampling the State's agricultural soils (U.S. Geological Survey, 1972f, p. 42; Erdman and others, 1976). These studies indicated that mercury concentrations in cultivated soils vary locally, but not regionally. (Cedar Glade soils were not sampled in the studies.) Moreover, the mercury content of these agricultural soils—39 ppb (parts per billion) and 42 ppb, respectively—is in reasonable accord with the 55 ppb that we estimated for uncultivated soils from outside the Cedar Glade area (fig. 28).

Some unusually high values for arsenic and molybdenum were found in samples of uncultivated soils from Howell County, south-central Missouri (figs. 2 and 3). The average arsenic concentration in five samples collected in the Pottersville area (Cureall quadrangle) is 26 ppm, a concentration considerably greater than those of other quadrangle averages (fig. 11). These five samples contained 59, 51, 28, 21, and 7 ppm arsenic. With but one exception, these values greatly exceed the 8 ppm characteristic of soils from that general area (the Oak-hickory Forest). The two samples from the Cureall quadrangle with the highest arsenic concentrations also have high molybdenum levels, 30 and 7 ppm, and are the only soil samples collected in the Oak-hickory Forest area that were found to contain molybdenum in detectable concentrations.

The Pottersville area must be judged anomalous in

TABLE 8.—*Geographic patterns of variation in chemical elements and pH of uncultivated soils from Missouri*

[Patterns based on results of the analysis of variance and a multiple range test (Duncan, 1955)]

Geographic pattern No.	Vegetation type or types	Variation in chemical elements and pH
1	Glaciated Prairie and Unglaciated Prairie[1]	Highest in arsenic, chromium, iron, scandium, selenium, and vanadium.
2	Glaciated Prairie and Unglaciated Prairie[2]	Aluminum, calcium, gallium, and magnesium higher in Glaciated Prairie; cobalt and manganese higher in Unglaciated Prairie.
3	Oak-hickory Forest and Oak-hickory-pine Forest[1]	Lowest in nickel, scandium, and zinc.
4	Oak-hickory-pine Forest[1]	Lowest in aluminum, calcium, chromium, iron, gallium, lithium, magnesium, strontium, and vanadium; and low in sodium.
5	Cedar Glade[1]	Highest in calcium, total carbon, carbonate carbon, organic carbon, magnesium, mercury, and pH; lowest in sodium, titanium, and zirconium.
6	Floodplain Forest and Cedar Glade[1]	Higher in phosphorus.

[1] Distinctive from other vegetation-type areas.

[2] Distinctive from each other.

these aspects of its soil chemistry, but because cursory examination of the area revealed nothing obviously unusual about the local landscape, we have included arsenic and molybdenum data for the Pottersville soil samples as part of our summaries in table 6 and map figure 11.

In summary, the geochemical data presented in table 6 and figures 10 – 43 reveal a major pattern or trend of generally high concentrations of the elements that were studied in soils from the prairie vegetation-type areas which compose a region underlain largely by rocks of Pennsylvanian age and by glacial deposits, and of low concentrations in soils from forests of the Ozark uplands, especially in those from the vegetation-type area characterized by the presence of pine trees. Our decision to recognize the Glaciated Prairie and the Unglaciated Prairie as distinct vegetation-type areas for the purpose of geochemical studies seems to have been justified, as is shown by the differences in concentration of certain elements in the soils. Some of these chemical differences may reflect time differences in the effects of weathering on the two groups of soils, the unglaciated soils having had the longer period of weathering. Samples of soils from the Cedar Glade area are distinctly different in concentration of certain elements from soils sampled in other vegetation-type areas and reflect, in part, the strong influence of the carbonate parent materials (dolomite and limestone) of soils in this area.

Q-MODE FACTOR ANALYSIS

The distribution patterns in concentrations of many elements in the uncultivated soils of the State are similar (figs. 10 – 43). These patterns indicate that concentrations of the elements are not independent of each other and that the total chemical composition of the soil at any one locality might be resolved into some minimum number of more fundamental compositional variables or factors. To this end, the data from the stage 1b sampling were analyzed using procedures of *Q*-mode factor analysis as described by Miesch (1976).

The factor analysis procedure began with the conversion of all of the element data for each sample to percentages of the common oxides, except for fluorine, mercury, and organic carbon. These data were adjusted so that they summed to exactly 100 percent for each sample. Each chemical variable was then scaled to range from zero to one, and this transformed data matrix was normalized by dividing each row by the square root of the row sum of squares (Miesch, 1976). Finally, from the normalized data matrix we effectively computed a matrix of proportional similarity coefficients, cos θ (Klovan and Imbrie, 1971). The first 10 eigenvalues of this matrix and the corresponding percentages of the total variance that they represent are as follows:

Eigenvalue	*Cumulative percentage*	*Eigenvalue*	*Cumulative percentage*
244.0	81.6	1.9	96.9
20.2	88.3	1.6	97.1
9.3	91.5	1.4	97.6
8.1	94.2	1.3	98.1
5.0	95.9	1.2	98.5

These values indicate that 94 percent of the variability in the normalized data matrix can be represented in terms of four theoretical factors of some kind. However, as pointed out by Miesch (1976), the eigenvalues give no information about the degree to which a factor model will account for the variability in the original data in units of percent. For this purpose, a factor-variance diagram was constructed using the coefficients of determination derived by comparison of the original data with the data reproduced from factor models containing 2 to 10 factors (Miesch, 1976). The diagram showed that 14 of the 32 chemical constituents included were not being closely accounted for by any of the models containing up to 10 factors; 4-factor models accounted for less than one-half of their variances. The 14 constituents, in general, were those which display little variance between vegetation-type areas (As, B, organic C, Co, Cu, F, Hg, K, La, Mn, Ni, Pb, Se, and Y, table 5). Accordingly, these constituents were excluded from further computations. The factor-variance diagram was reconstructed using the remaining 18 constituents and is shown in figure 44. The diagram indicates that a *Q*-mode model containing four factors will account for about one-half or more of the variance in the original percentage data for each of the 18 constituents included. The inclusion of a fifth or additional factor would not lead to a significantly better model.

Composition loadings and composition scores were determined for the Varimax *Q*-mode model using the procedures outlined by Miesch (1976). This model has the form:

$$\hat{x}_{ij}=a_{i1}f_{1j}+a_{i2}f_{2j}+a_{i3}f_{3j}+a_{i4}f_{4j}, \qquad (10)$$

where $\hat{x}_{ij}$ is an approximation of the percentage concentration of the jth chemical constituent in the ith sample, the a's are composition loadings, and the f's are composition scores. The four composition loadings sum to unity for each sample and are of primary interest because each represents the proportion of an end-member "sample" or the importance of an end-member factor in the model.

The factor scores for the Varimax model are given in table 9. The computation procedure used in their

TABLE 9.—*Composition scores for the Varimax Q-mode model describing compositional variations in the uncultivated soils from Missouri*

Chemical variable	Composition scores			
	f_{1j}	f_{2j}	f_{3j}	f_{4j}
Al_2O_3	−142.8	−0.1	5.4	4.1
BaO	−.797	.010	−.018	.248
CO_2(in carbonate)	63.8	−1.4	18.9	−4.0
CaO	45.6	−1.9	16.6	−1.3
Cr_2O_3	−.137	.003	.004	−.014
Fe_2O_3	−74.3	1.3	2.5	−11.0
Ga_2O_3	−.0363	−.0002	.0015	−.0011
Li_2O	−.0896	.0015	.0052	−.0113
MgO	12.1	−.7	7.1	−1.1
Na_2O	−6.07	−.10	−.32	5.36
P_2O_5	.988	.022	.430	.464
SiO_2	211	102	50	108
SrO	−.142	−.002	.008	.055
TiO_2	−8.22	.54	−.28	−.56
V_2O_3	−.254	0	.008	−.020
Yb_2O_3	−.0050	.0003	0	−.0004
ZnO	−.0827	0	.0127	−.0005
ZrO_2	−.374	.049	−.034	−.040

derivation leads to a set of scores that sums to 100 for each factor. Because of the large positive scores for SiO_2, CO_2, and CaO on factor 1 (f_{1j}, table 9), most of the remaining scores on this factor are negative. Moreover, as will be shown, all of the sample composition loadings on factor 1 are also negative.

It is apparent from these scores that samples having large negative composition loadings on factor 1 are alumina-rich in comparison with other samples, and that samples having large positive loadings on factor 2 tend to be rich in silica and other constituents of resistate minerals, including titanium and zirconium, but in little else. Similarly, samples with large positive loadings on factor 3 tend to be relatively rich in carbonate minerals, and those with large positive loadings on factor 4 tend to be rich in sodium, alumina, and silica, and probably are feldspathic. These loadings for each sample are given to one significant figure in figures 45–48, and, as indicated by equation 10, when multiplied by the corrresponding scores in table 9 provide approximations of the original data.

TABLE 10.—*Chemical composition and mineralogy of soil samples with first and second highest absolute loadings on each of four factors in the factor model*

Constituent	Factor 1		Factor 2		Factor 3		Factor 4	
	Sample No.		Sample No.		Sample No.		Sample No.	
	U6	U22	U49	U38	C16	C37	D15	D32
Chemical composition [Concentrations in parts per million, except as indicated]								
Al, percent	9	6	3	3	2	2	3	3
Ba	500	700	500	200	100	150	300	700
C, carbonate, percent	<.01	.12	.08	<.01	9.12	6.40	.06	.01
Ca, percent	.2	.6	.1	.1	30	11	.6	.6
Cr	70	100	30	50	20	20	7	15
Fe, percent	6.4	4.2	1.4	2.4	.8	1.1	.8	1.0
Ga	30	30	7	7	7	5	5	10
Li	66	37	18	19	7	13	8	8
Mg, percent	.78	.60	.16	.15	.50	6.03	.15	.17
Na, percent	.39	.59	.16	.27	.06	.11	1.0	.96
P, percent	.03	.04	.01	.02	.08	.14	.04	.07
Si, percent	26	29	39	40	7	14	40	41
Sr	150	100	70	50	150	100	100	150
Ti, percent	.5	.5	.7	.5	.15	.07	.1	.15
V	150	150	70	70	30	30	20	20
Yb	3	5	3	3	2	1	<1	1
Zn	61	63	22	29	31	34	20	23
Mineralogy [Reduced to percentage of four major mineral groups; relative background is proportional to total iron content]								
Quartz	30	35	70	85	10	20	70	65
Clay minerals	65	60	25	<10	10	15	<10	15
Feldspars	5	5	5	10	0	1	20	15
Carbonates	0	0	0	0	80	65	0	5
Relative background	9.5	8	6	6.5	4	5.5	5	5.5

We have used the *Q*-mode analysis as a device for summarizing a complex set of multivariate data. This analysis leads us to conclude that variation in four factors can explain, to a great extent, the variation in the concentrations of the 18 elements in the soils that exhibit generally a high degree of variation across the State. What these factors may have been is a matter of interpretation; the main bases for our interpretation are the nature of the composition scores and the geographic variations in magnitudes of the composition loadings for each sample on each factor.

All four factors may be interpreted as reflecting the contributions of geologic parent materials to soils. The first factor (fig. 45) appears to reflect an aluminum-rich parent because samples with high negative loadings on this factor come from areas known to contain aluminum-rich parent rocks. Alternatively, this factor could represent maximum

TABLE 11.—*Components of logarithmic variance estimated for samples of sumac stems collected in sampling stages 1a and 1b from six vegetation-type areas in Missouri*

[First and second lines of data following each element give components derived from stages 1a and 1b sampling, respectively. Asterisk (*), significantly greater than zero at the 0.05 probability level. Leaders (. . .) in figure columns indicate no data available]

Ash, or element	Total $\log_{10}$ variance	Variance					
		Between areas		Between quadrangles		Between sites	
		Component, s^2_α	Percent of total	Component, s^2_β	Percent of total	Component, s^2_γ	Percent of total
Ash	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	0.00637	*0.00102	16	0.00014	2	0.00521	82
Al	.04251	0	<1	0	<1	.04251	100
	.11228	0	<1	.00636	6	.01592	94
B	.01331	0	<1	0	<1	.01331	100
	.01753	.00037	2	0	<1	.01716	98
Ba	.24802	*.14120	57	.02894	12	.07788	31
	.28873	*.19700	68	*.02281	8	.06892	24
Ca	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.00496	*.00087	17	0	<1	.00410	83
Cd	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.08319	*.02154	26	*.01736	21	.04430	53
Cr	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.09470	.00124	1	.00659	7	.08687	92
Cu	.03294	*.00965	29	.00614	19	.01705	52
	.02851	.00076	3	.00127	4	.02648	93
Fe	.03513	*.00735	21	0	<1	.02778	79
	.05992	.00078	1	.00341	6	.05572	93
K	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.10272	*.00204	16	0	<1	.01068	84
Mg	.02977	*.00667	22	.00219	7	.02091	70
	.03489	*.00265	7	.00176	5	.03048	87
Mn	.07130	*.02028	28	*.02703	38	.02399	34
	.05213	*.00557	11	*.00511	10	.04145	76
Na	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.04729	*.00221	5	.00110	2	.04399	93
Ni	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.22870	*.11777	51	*.01397	6	.09696	42
P	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.02357	*.01008	43	.00034	1	.01315	56
Pb	.05742	.00791	14	.00131	2	.04820	84
	.10481	*.01267	12	*.01796	17	.07417	71
Se	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.08687	*.03990	46	.00299	3	.04399	51
Sr	.12891	*.07927	61	.00058	<1	.04906	38
	.19599	*.13730	70	*.00671	3	.05198	27
Ti	.08968	0	<1	0	<1	.08968	100
	.14279	*.00592	7	*.01468	10	.11860	83
Zn	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	.04172	*.00943	23	.00043	1	.03186	76

B-horizon development—that is , the accumulation of clay minerals and the consequent increase of alumina and most other constituents compared to silica and carbonate minerals. According to the classical theory of soil genesis, the accumulation of clays and trace metals in this horizon results from the solubilization and movement of alumina from the A horizon and its deposition in the B horizon.

The second factor (fig. 46) seems to represent highly weathered silica-rich regoliths developed from a cherty residuum. This development occurs most commonly in the southern upland forests, even though several of the samples with the highest loadings on this factor were collected in the area mapped as Unglaciated Prairie vegetation-type area. The chemical data for many of the samples from the 7½-minute quadrangles in the southernmost part of this prairie type suggest, however, that we had collected the samples in a zone that is transitional between the prairie and the upland forests of the State.

The lithosols from the Cedar Glades in the south-central part of Missouri form a distinct group and are thought to be reflected by the third factor of the Varimax model (fig. 47). Soils of the Cedar Glade area are slightly alkaline, rich in organic material, and high in calcium-magnesium carbonate content which reflects the dolomitic soil parent that crops out abundantly in the area.

The fourth factor of the Varimax model (fig. 48) is interpreted to represent a feldspathic sand facies of the Mississippi River floodplain alluvium. These light soils (apparently, minor variants of the Floodplain Forest soils) are in strong contrast to the more representative heavy clayey soils more typically associated with the alluvial region.

The mineralogy and elemental chemical compositions of the two soil samples that have the highest loadings on each of the theoretical factors of the Varimax model are given in table 10.

The effects of alumina-rich parent materials (factor 1), as reflected in the mineralogy of samples U6 and U22 (table 10), are indicated by a relatively low quartz and carbonate mineral content and corresponding high concentrations of the clay minerals. The quartz parent (factor 2) is evident in the mineralogy of samples U49 and U38, as is the carbonate parent (factor 3) in samples C16 and C37. The importance of feldspars in the last type of parent material (factor 4) is clear from the mineralogy of the Floodplain Forest samples D15 and D32.

TABLE 12.—*Components of logarithmic variance estimated for buckbush from five vegetation-type areas in Missouri*

[Asterisk (*), significantly greater than zero at the 0.05 probability level]

Ash, or Element	Total log 10 variance	Between areas		Between quadrangles		Between sites	
		Component, s_α^2	Percent of total	Component, s_β^2	Percent of total	Component, s_γ^2	Percent of total
Ash	0.00588	*0.00029	5	*0.00077	13	0.00482	82
Al	.02352	*.00223	9	*.00209	9	.01920	82
B	.01564	0	<1	.0074	5	.01491	95
Ba	.09737	*.04896	50	*.01393	14	.03448	35
Ca	.00639	*.00116	18	.00040	6	.00483	76
Cd	.08621	*.02013	23	*.01269	15	.05339	62
Co	.04581	.00109	2	.00167	4	.04305	94
Cr	.03952	*.00458	12	*.00406	10	.03088	78
Cu	.02805	*.00154	5	.00041	1	.02610	93
Fe	.05707	*.00688	12	*.00776	14	.04243	74
K	.00547	.00003	<1	*.00091	17	.00453	83
Li	.02119	*.00184	9	.00087	4	.01847	87
Mg	.04117	*.00264	6	.00041	1	.03812	93
Mn	.08299	*.02380	29	.00470	6	.05450	66
Na	.01994	*.00520	26	*.00185	9	.01290	65
Ni	.03906	*.00727	19	.00116	3	.03064	78
P	.02094	*.00667	32	.00095	5	.01332	64
Pb	.08571	*.01294	15	*.01703	20	.05574	65
Se	.03596	*.01067	30	*.00074	2	.02455	68
Sr	.14452	*.09905	69	*.00768	5	.03779	26
Ti	.06022	*.00762	13	*.00211	4	.05048	84
V	.04188	*.00697	17	*.00301	7	.03191	76
Zn	.03765	*.00305	8	*.00919	24	.02541	67
Zr	.09196	*.01057	11	*.00718	8	.07421	81

TABLE 13.—*Components of logarithmic variance estimated for white oak from the Oak-hickory Forest and the Oak-hickory-pine Forest areas in Missouri*

[Asterisk (*), significantly greater than zero at the 0.05 probability level]

Element, or ash	Total $\log_{10}$ variance	Between areas		Between quadrangles		Between sites	
		Component, s_α^2	Percent of total	Component, s_β^2	Percent of total	Component, s_γ^2	Percent of total
Al	0.04174	0	<1	0	<1	0.04174	100
B	.01893	0	<1	.00117	6	.01775	94
Ba	.03428	.00167	5	.00494	14	.02767	81
Ca	.00092	0	<1	0	<1	.00092	100
Cd	.02314	0	<1	.00244	11	.02070	89
Co	.25501	.01098	4	.00321	1	.24082	94
Cr	.08416	0	<1	0	<1	.08416	100
Cu	.02461	0	<1	*.00472	19	.01988	81
Fe	.05029	0	<1	.00399	8	.04630	92
K	.01003	0	<1	.00069	7	.00934	93
Mg	.05356	0	<1	*.01738	32	.03618	68
Mn	.04975	.00052	1	0	<1	.04923	99
Na	.01492	.00083	6	.00028	2	.01381	92
Ni	.05580	0	<1	.00692	12	.04888	88
P	.02138	.00112	5	.00032	2	.01993	93
Pb	.07155	.00656	9	*.01920	27	.04579	64
Se	.02657	0	<1	.00162	6	.02495	94
Sr	.06203	.00356	6	*.00862	14	.04985	80
Ti	.05068	0	<1	.00107	2	.04961	98
Zn	.01718	.00015	1	.00135	8	.01567	91
Ash	.00785	.00017	2	*.00190	24	.00576	73

TABLE 14.—*Statistics used to assess adequacy of stage 1b sampling for distinguishing vegetation-type areas on the basis of plant analyses*

[Leaders (...) in figure columns indicate significant difference between areas were not demonstrated]

Element	Plant species							
	Sumac				Buckbush			
	s_α^2 (or N_v)	E_s	v_m	$v_m(0.95)$	s_α^2 (or N_v)	E_s	v_m	$v_m(0.95)$
Al	...	...	...	...	0.00223	0.00059	3.8	3.1
Ba	0.19700	0.00366	53.8	8.6	.04896	.00208	23.5	5.1
Ca	.00087	.00008	10.9	3.4	.00116	.00014	8.3	3.3
Cd	.02154	.00262	8.2	3.8	.02013	.00234	8.6	3.7
Cr	...	...	...	...	.00458	.00102	4.5	2.9
Cu	...	...	...	...	.00154	.00056	2.8	2.6
Fe	...	...	...	...	.00688	.00163	4.2	2.9
K	.00204	.00021	9.7	3.2	...	...	...	...
Li	...	...	...	...	.00184	.00046	4.0	2.9
Mg	.00265	.00079	3.4	2.9	.00264	.00084	3.1	2.4
Mn	.00557	.00134	4.2	3.0	.02380	.00137	17.4	4.0
Na	.00221	.00099	2.2	2.8	.00520	.00044	18.2	3.5
Ni	.11777	.00334	35.3	5.3	.00727	.00073	10.0	3.2
P	.01008	.00030	33.6	4.5	.00667	.00036	18.5	3.7
Pb	.01267	.00328	3.9	3.0	.01294	.00282	4.6	3.2
Se	.03990	.00118	33.8	5.1	.01067	.00057	18.7	3.8
Sr	.13730	.00171	80.3	7.0	.09905	.00152	65.2	8.7
Ti	.00952	.00384	2.5	3.0	.00762	.00122	6.2	3.2
V	...	...	...	...	.00697	.00094	7.4	3.2
Zn	.00943	.00068	13.9	3.5	.00305	.00143	2.1	2.8
Zr	...	...	...	...	.01057	.00220	4.8	2.9

The differences in the chemical compositions among the soil samples just described (table 10) are in accord with the differences among their mineralogical compositions. Samples U6 and U22 from the Unglaciated Prairie are thought to reflect the influence of alumina-rich parent materials (factor 1). Aluminum, iron, and many of the trace elements (barium, chromium, gallium, lithium, vanadium, ytterbium, and zinc) are highly concentrated in these soils. Samples U49 and U38 from the southernmost part of the Unglaciated Prairie, where sandstone outcrops are common, reflect a soil parent material rich in silicon, titanium, and zirconium (factor 2). The two kinds of carbonate parent materials common to the Cedar Glades—limestone and dolomite—are reflected in samples C16 and C37, respectively (factor 3). In addition to the high concentrations of carbonate carbon, calcium, and magnesium (in sample C37, likely derived from dolomite), phosphorus appears to be fairly abundant in soils from the glades. Finally, samples D15 and D32 from the Floodplain Forest represent a variant of the typically clayey alluvial soils (factor 4) that is characteristically high in silicon and sodium. Sodium seems to be the principal element that distinguishes this factor from the others, particularly from factor 2.

CHEMICAL COMPOSITION AND VARIABILITY OF SELECTED NATIVE PLANTS

Although a large part of the stage 1b sampling of plants was directed toward a description of regional geochemical patterns exhibited by two widely occurring shrubs, sumac and buckbush, studies were also made of seven tree species: white oak, post oak, willow oak, sweetgum, shagbark hickory, cedar, and shortleaf pine. Stems or stems and leaves were collected, insofar as possible, at each of 5 sites in 10 quadrangles, in the vegetation-type areas where the species are indigenous and, to some extent, characteristic. Sumac was collected in all six vegetation-type areas in the State. Buckbush was collected in five areas only, because of its scarcity in the Floodplain Forest area. White oak and shagbark hickory were collected only in the Oak-hickory Forest and the Oak-hickory-pine Forest areas. Cedar and post oak were collected in the Cedar Glade area, and willow oak and sweetgum only in the Floodplain Forest area.

Of all species studied, only sumac was sampled in both stages 1a and 1b of the sampling plan.

Estimated components of chemical variability in sumac, for the three geographic levels of the sampling design, are listed in table 11. A comparison of the estimated logarithmic variance components based on analyses of the sumac samples collected in both 1a and 1b sampling stages indicates that these estimates are reasonably reproducible except those for copper and iron. Estimates between areas for these two elements differ by an order of magnitude. Because the stage 1b results are based on more intensive sampling than those of stage 1a, we accept the variance estimates from the 1b sampling as more valid.

Geographic components of variance for stem ash of buckbush and white oak are listed in tables 12 and 13, respectively. Although a number of elements in stem ash exhibit significantly different mean concentrations between the vegetation-type areas in Missouri, the most important component for most elements is clearly the local one. This fact indicates that, compositionally, individuals of a single species growing within a few miles of each other (within the same 7½-minute quadrangle) tend to be as chemically different as individuals growing at opposite sides of the State.

The most notable exceptions to this local-variation tendency are barium, nickel, and strontium in stem ash of sumac, and barium and strontium in stem ash of buckbush, all of which exhibit more than half of their total variance at statewide scales (between vegetation-type areas). In addition to these elements, only cadmium, phosphorus, and selenium in sumac stem ash and manganese, phosphorus, selenium, and sodium in buckbush stem ash exhibit more than a fourth of their total variance between areas. No significant differences in elemental composition could be demonstrated in white oaks collected from the two upland forest areas. These results contrast sharply to

TABLE 15.—*Mean chemical composition and chemical variation in sumac stems from six vegetation-type areas in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (. . .) in figure colums, no data available. The highest and lowest mean concentrations of these elements, where tested and found to be significantly different at the 0.05 probability level, shown in **boldface** and *italic*, respectively. Because of insufficient data, differences in concentrations of Co, F, I, Li, Mo, and Zr were not tested]

Element, or ash	Vegetation type																	
	Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Cedar Glade			Oak-hickory Forest			Oak-hickory-pine Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al.........	1,100	2.55	48:48	1,300	2.09	50:50	1,100	2.29	49:49	1,000	1.92	49:49	1,200	2.11	50:50	1,300	1.99	49:49
B.........	230	1.31	48:48	230	1.44	50:50	230	1.33	49:49	220	1.37	49:49	200	1.26	50:50	210	1.38	49:49
Ba........	3,500	1.84	48:48	2,600	1.60	50:50	2,600	1.78	49:49	*270*	2.35	49:49	3,400	2.33	50:50	**4,500**	2.00	49:49
Ca........	240,000	1.20	48:48	260,000	1.14	50:50	260,000	1.14	49:49	**290,000**	1.12	49:49	*240,000*	1.20	50:50	270,000	1.11	49:49
Cd........	4.4	2.09	48:48	3.1	1.88	50:50	4.2	1.83	49:49	1.7	1.48	49:49	2.8	1.63	50:50	2.2	1.60	49:49
Co........	.75	2.80	23:48	.65	1.88	18:50	.78	2.10	23:49	.71	1.42	16:49	1.1	1.75	35:50	.97	2.17	30:49
Cr........	3.3	3.28	37:48	2.6	1.96	40:50	2.5	2.16	36:49	2.2	2.05	31:49	2.7	1.95	40:50	3.1	1.87	43:49
Cu........	110	1.40	48:48	110	1.41	50:50	100	1.46	49:49	86	1.58	49:49	89	1.43	50:50	97	1.51	49:49
F.........	.5	...	7:9	.5	...	5:8	.5	...	9:11	.76	1.67	10:11	.5	...	5:9	.5	...	5:8
Fe........	1,100	1.98	48:48	1,300	1.52	50:50	1,300	1.74	49:49	1,000	1.68	49:49	1,100	1.89	50:50	1,200	1.66	49:49
I..........	4.8	1.10	9:9	4.6	1.16	9:9	4.6	1.18	11:11	4.3	1.18	11:11	4.6	1.11	9:9	4.0	1.24	8:8
K..........	130,000	1.34	48:48	130,000	1.26	50:50	130,000	1.24	49:49	*100,000*	1.32	49:49	**130,000**	1.20	50:50	120,000	1.22	49:49
Li.........	<4	...	1:48	<4	...	0:50	<4	...	2:49	<4	...	0:48	<4	...	0:50	<4	...	1:49
Mg........	**29,000**	1.48	48:48	22,000	1.54	50:50	23,000	1.40	49:49	22,000	1.69	49:49	20,000	1.43	50:50	*20,000*	1.50	49:49
Mo........	.91	3.38	6:48	.76	4.27	7:50	<5	...	3:49	3.3	2.80	21:49	<5	...	3:50	<5	...	4:49
Mn........	760	1.74	48:48	550	1.68	50:50	640	1.62	49:49	*470*	1.62	49:49	690	1.60	50:50	770	1.58	49:49
Na........	**310**	1.64	48:48	250	1.60	50:50	*220*	1.88	49:49	230	1.60	48:48	230	1.46	50:50	280	1.57	49:49
Ni.........	**17**	2.51	48:48	11	2.15	48:50	11	1.93	47:49	*.81*	3.56	13:49	4.0	2.82	36:50	3.9	2.68	35:49
P..........	**23,000**	1.27	48:48	20,000	1.20	50:50	17,100	1.24	49:49	*12,000*	1.45	49:49	18,000	1.30	50:50	14,000	1.34	49:49
Pb........	*26*	2.28	34:48	32	1.82	42:50	28	2.11	38:49	42	2.17	43:49	30	2.36	37:50	61	2.23	46:49
Se........	**.027**	1.98	47:48	.022	1.83	49:50	.013	1.62	39:49	*.01*	...	25:48	*.01*	...	28:50	*.01*	...	34:49
Sr........	3,400	1.62	48:48	3,500	1.49	50:50	**3,700**	1.46	49:49	*400*	1.72	49:49	2,700	2.19	50:50	3,100	1.79	49:49
Ti.........	98	2.54	48:48	120	1.65	50:50	120	1.99	49:49	*94*	1.77	49:49	130	2.15	50:50	170	1.89	49:49
Zn........	770	1.63	48:48	**860**	1.44	50:50	820	1.42	49:49	520	1.59	49:49	660	1.41	50:50	*500*	1.56	49:49
Zr.........	4.1	3.49	6:48	<20	...	4:50	<20	...	4:49	<20	...	4:49	11	1.85	11:50	<20	...	13:49
Ash.......	35,000	1.19	48:48	**42,000**	1.19	50:50	38,000	1.18	49:49	36,000	1.18	49:49	36,000	1.18	50:50	*34,000*	1.18	49:49

TABLE 16.—*Mean chemical composition and chemical variation in buckbush stems from five vegetation-type areas in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (. . .), no data available. The highest and lowest mean concentrations of these elements, where tested and found to be significantly different at the 0.05 probability level, are shown in **boldface** and *italic*, respectively. Because of insufficient data, differences in concentrations of F, Ga, I, La, Mo, Y, and Yb were not tested]

Element, or ash	Vegetation type														
	Glaciated Prairie			Unglaciated Prairie			Cedar Glade			Oak-hickory Forest			Oak-hickory-pine Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al	13,000	1.35	47:47	**14,000**	1.44	48:48	10,000	1.46	50:50	12,000	1.33	49:49	*10,000*	1.40	41:41
B	180	1.37	47:47	170	1.29	48:48	180	1.35	50:50	170	1.35	49:49	180	1.29	41:41
Ba	2,700	1.52	47:47	2,500	1.48	48:48	1,200	1.75	50:50	3,800	1.63	49:49	4,500	1.87	41:41
Ca	*150,000*	1.11	47:47	150,000	1.12	48:48	**180,000**	1.15	50:50	150,000	1.22	49:49	150,000	1.27	41:41
Cd	13	1.91	47:47	**14**	2.08	48:48	*6.2*	1.43	50:50	12	1.69	49:49	12	1.86	41:41
Co	4.0	1.43	47:47	4.8	1.76	47:48	4.4	1.42	50:50	4.7	1.68	49:49	5.4	1.91	41:41
Cr	20	1.52	47:47	**22**	1.49	48:48	*14*	1.38	50:50	21	1.57	49:49	19	1.72	41:41
Cu	190	1.61	47:47	200	1.46	48:48	160	1.32	50:50	180	1.45	49:49	160	1.40	41:41
F	1.6	1.49	11:11	1.4	2.56	3:3	1.1	1.79	5:5	1.4	1.64	13:13	1.3	1.45	7:7
Fe	7,600	1.74	47:47	**9,300**	1.64	48:48	5,600	1.44	50:50	6,900	1.58	49:49	*5,600*	1.96	41:41
Ga	2.8	1.54	11:47	2.4	1.73	9:48	<5	. . .	2:50	2.7	1.51	9:49	1.5	2.24	5:41
I	4.7	1.11	11:11	5.4	1.10	7:7	4.7	1.16	8:8	5.1	1.13	16:16	4.6	1.16	10:10
K	160,000	1.15	47:47	160,000	1.16	48:48	150,000	1.16	50:50	150,000	1.21	49:49	150,000	1.24	41:41
La	<70	. . .	0:47	<70	. . .	0:48	<70	. . .	1:50	34	1.48	5:49	43	1.39	8:41
Li	**5.3**	1.37	42:47	5.2	1.38	41:46	*4*	. . .	31:47	4.5	1.43	34:46	*4*	. . .	26:39
Mg	35,000	1.56	47:47	38,000	1.51	48:48	**47,000**	1.55	50:50	36,000	1.65	49:49	*34,000*	1.59	41:41
Mn	*4,900*	2.03	47:47	5,100	1.88	48:48	6,300	1.61	50:50	10,000	1.62	49:49	**10,000**	1.55	41:41
Mo	2.0	2.48	11:47	<5	. . .	4:48	6.5	2.68	34:50	1.4	2.49	7:49	1.6	3.12	9:41
Na	**970**	1.40	47:47	960	1.28	46:46	*640*	1.27	47:47	820	1.36	44:44	770	1.27	39:39
Ni	**12**	1.51	47:47	12	1.49	48:48	*7.5*	1.45	50:50	11	1.49	49:49	12	1.62	41:41
P	**26,000**	1.30	47:47	24,000	1.40	48:48	*17,000*	1.28	50:50	21,000	1.27	49:49	17,000	1.32	41:41
Pb	*200*	1.76	47:47	210	1.91	48:48	310	1.85	50:50	260	1.88	49:49	**420**	1.84	41:41
Se	.043	1.45	47:47	.038	1.49	46:46	*.023*	1.33	49:49	.032	1.47	46:46	.031	1.47	39:39
Sr	1,800	1.43	47:47	1,700	1.46	48:48	340	1.52	50:50	1,500	1.96	49:49	1,500	1.72	41:41
Ti	980	1.57	47:47	**1,200**	1.76	48:48	*710*	1.51	50:50	1,200	1.73	49:49	1,000	1.91	41:41
V	22	1.48	47:47	**23**	1.55	48:48	*14*	1.52	50:50	19	1.50	49:49	18	1.63	41:41
Y	17	1.16	14:47	16	1.28	17:48	<20	. . .	5:50	15	1.45	16:49	17	1.39	17:41
Yb	1.6	1.18	11:47	1.7	1.21	18:48	<2	. . .	1:50	1.4	1.42	13:49	1.5	1.51	13:41
Zn	1,400	1.48	47:47	**1,800**	1.79	48:48	*1,200*	1.40	50:50	1,400	1.41	49:49	1,400	1.53	41:41
Zr	69	1.78	47:47	85	1.71	48:48	*44*	1.68	48:50	79	2.16	49:49	66	2.32	41:41
Ash	**27,000**	1.19	47:47	27,000	1.19	48:48	*24,000*	1.12	50:50	26,000	1.19	49:49	25,000	1.24	41:41

those of a similar analysis of the uncultivated soils (table 5) in which 24 of 35 constituents exhibited more than a fourth of their total variance between vegetation-type areas.

The relative stabilities of the means for those elements in tables 11 and 12 for which statistically significant differences between vegetation-type areas were found can be assessed by again using the relation in equation 7. The within-area mean variance (E_s, equation 9) was again used to compute the stability index, v_m. In spite of the small proportions of the total variance that tend to occur between vegetation-type areas, the generally large values of v_m in table 14, compared to the corresponding critical v_m, indicate that, with the exception of sodium and titanium in sumac and of zinc in buckbush, the available data are sufficient to distinguish at the 95-percent confidence level the major areas of the State classified by the elemental composition of sumac and buckbush stem ash.

Results of the analyses of stem, or stem and leaf, material for nine species that were studied are summarized in tables 15 – 20. The geometric mean (*GM*) for each vegetation-type area represents the most probable concentration of the element in a randomly selected sample from that area. For those elements in which the detection ratio is less than unity, the mean logarithms were computed using procedures developed by Cohen (1959) and described for the Missouri studies by Miesch (1976).

The analysis of variance and Duncan's multiple range test demonstrate the presence of some geographic patterns in the chemical composition of sumac samples (figs. 49 – 63). The strongest pattern (table 21) indicates that sumacs from the Cedar Glade vegetation-type area are chemically unique, being characterized by generally low concentrations of the elements that were studied. A second pattern indicates that sumacs from the Floodplain Forest area are distinctly high in magnesium, nickel, and phosphorus. A third pattern results solely from the high lead concentrations in samples of sumac from the Oak-hickory-pine Forest area.

As shown in the summary tables 15 and 16, barium and strontium in sumac and buckbush show the most marked differences in concentrations between vegetation-type areas. The differences approach an order of magnitude in sumacs sampled from the Cedar

Glade areas compared to sumacs sampled elsewhere in the State. Large differences also occur, moreover, in barium and strontium contents between buckbush sampled in the Cedar Glade area and buckbush from other areas.

In contrast to the low barium and strontium levels in plants sampled in the Cedar Glade area, molybdenum appears to be more concentrated in these samples. The detection ratios and estimated means (tables 15 and 16) support this observation, even though tests of significance were not made owing to the highly censored data. The higher molybdenum concentrations in both sumac and buckbush from the Cedar Glade area probably reflect the high soil pH of the area, because the molybdenum concentrations in the soils do not appear to differ to any great extent among vegetation-type areas (table 6), and because the pH of the soil from the Cedar Glade area—typically, 7.3—is significantly higher than the pH of soils collected from other areas in the State (fig. 43). These observations suggest that the higher molybdenum levels in Cedar Glade sumacs reflect differences in availability of molybdenum among vegetation-type areas, rather than differences in total amounts of this element that are present in soils; Sauchelli (1969) reported that the availability of molybdenum to plants increases with soil pH of 6.5 or higher.

Of further interest are the lanthanide-accumulating properties of shagbark hickory, as demonstrated by the lanthanum, yttrium, cerium, and neodymium values that were found. In addition, shortleaf pine was found to be a marked concentrator of the trace metals aluminum and silver (table 20).

CORRESPONDENCE BETWEEN THE ELEMENTAL COMPOSITION OF SELECTED PLANT SPECIES AND THAT OF ASSOCIATED UNCULTIVATED SOILS

The correspondence between the elemental composition of sumac stem ash and soils within each vegetation-type area was examined by means of correlation coefficients (table 22).

The concentrations of certain elements in soils, expressed as total rather than as available concentrations, are often assumed to determine the amounts that the plants will absorb, unless the

TABLE 17.—*Mean chemical composition and chemical variation in species characteristic of the Floodplain Forest in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (. . .), no data available]

Element, or ash	Species, and plant part sampled					
	Sweetgum stems			Willow oak stems		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio
Al	1,800	1.85	47:47	2,400	1.89	46:46
B	160	1.47	47:47	220	1.34	46:46
Ba	2,000	1.61	47:47	2,700	1.57	46:46
Ca	270,000	1.14	47:47	280,000	1.12	46:46
Cd	6.0	2.00	47:47	8.3	1.85	46:46
Co	1.5	2.36	37:47	2.3	2.00	44:46
Cr	3.9	1.84	44:47	6.0	1.90	46:46
Cu	130	1.90	47:47	210	1.61	46:46
F	.66	1.58	11:14	.77	1.72	9:12
Fe	1,300	1.68	47:47	2,500	1.59	46:46
I	4.1	1.20	14:14	4.6	1.15	12:12
K	41,000	1.59	47:47	78,000	1.37	46:46
Li	<4	. . .	14:47	4.0	1.54	46:46
Mg	27,000	1.85	47:47	34,000	2.08	46:46
Mn	6,300	2.11	47:47	14,000		
					1.54	46:46
Na	670	1.57	47:47	840	1.77	46:46
Ni	50	1.93	47:47	130	1.32	46:46
P	9,600	1.63	47:47	21,000	1.85	46:46
Pb	65	2.09	45:47	120		
Se	.065	2.36	47:47	.032	2.02	45:45
Sr	2,000	1.51	47:47	1,800	1.36	46:46
Ti	120	2.02	47:47	190	1.72	46:46
Zn	790	1.53	47:47	440	1.59	46:46
Zr	6.7	2.30	6:47	<20	. . .	10:46
Ash	46,000	1.43	47:47	24,000	1.29	46:46

TABLE 18.—*Mean chemical composition and chemical variation in species characteristic of the Cedar Glade area in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (. . .), no data available]

Element, or ash	Species, and plant part sampled					
	Cedar, stems and leaves			Post oak, stems		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio
Al	4,100	2.07	50:50	2,600	1.87	50:50
B	160	1.33	50:50	180	1.41	50:50
Ba	320	2.50	49:49	660	2.31	50:50
Ca	310,000	1.09	50:50	320,000	1.11	50:50
Cd	1.5	1.52	50:50	2.3	1.51	50:50
Co	1.2	1.48	45:50	.95	1.97	30:50
Cr	7.5	1.76	50:50	4.9	1.97	49:50
Cu	54	1.63	50:50	130	1.49	50:50
F	1.6	1.58	11:11	1.1	1.69	6:8
Fe	2,800	1.66	50:50	1,900	1.57	50:50
I	5.0	1.18	11:11	4.2	1.19	8:8
K	63,000	1.26	50:50	44,000	1.38	50:50
Li	<4	. . .	5:49	<4	. . .	5:49
Mg	30,000	1.81	50:50	31,000	2.02	50:50
Mn	1,700	2.21	50:50	3,200	2.36	50:50
Mo	3.4	2.43	22:50	<5	. . .	0:50
Na	220	1.46	49:49	420	1.46	49:49
Ni	5.6	2.89	41:50	8.6	1.71	49:50
P	13,000	1.25	50:50	9,400	1.44	50:50
Pb	100	2.06	50:50	81	1.87	50:50
Se	.021	1.36	50:50	.020	1.56	46:49
Sr	340	1.63	50:50	320	1.53	50:50
Ti	330	1.67	50:50	220	1.75	50:50
V	2.6	3.08	17:50	<5	. . .	5:50
Zn	310	1.27	50:50	300	1.43	50:50
Zr	24	1.40	30:50	16	1.47	20:50
Ash	60,000	1.16	50:50	42,000	1.31	50:50

elements are present in toxic quantities. The correlation coefficients given in table 22, and the diagrams in figure 64 which provide a graphical summary of the coefficients, contradict this assumption, for the most part. There appears to be very little influence of element concentrations in soils on plant uptake for most trace elements under ordinary ("natural") conditions. No significance tests of the correlation coefficients are given, because a critical *r* value cannot be established where a nested sampling design has been used and where the bivariate frequency distributions are censored. Based on a conservative estimate of 8 degrees of freedom (*N* minus 2, where *N* is the 10 independent quadrangles that were sampled), the critical *r* at the 95-percent confidence level is 0.63 if the bivariate distribution is not censored, therefore none of the correlations is significant. Because variation among quadrangles for most elements is low and for many elements not even significant, a realistic estimate of the degree of freedom for this test probably would be greater than eight. But even when the maximum possible degrees of freedom of 48 is used, the critical *r* at the 95-percent confidence level is 0.27, and only a few of the correlations in table 25 are significant. Nickel in sumac from the the glaciated prairie exhibits the highest correlation with soil values, but even here only about 25 percent of the total variation can be explained by the variation of nickel in the soil of the area.

TABLE 19.—*Mean chemical composition and chemical variation in species characteristic of the Oak-hickory Forest in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (...), no data available]

Element, or ash	Species, and plant part sampled					
	White oak, stems			Shagbark hickory, stems		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio
Al	1,900	1.62	50:50	2,900	2.27	19:19
B	190	1.47	50:50	190	1.48	19:19
Be	<2	...	0:50	1.5	1.21	3:19
Ba	4,200	1.58	50:50	7,700	2.38	19:19
Ca	330,000	1.08	50:50	340,000	1.07	19:19
Cd	4.1	1.39	50:50	18	1.80	19:19
Co	2.0	2.09	45:50	5.9	2.07	18:19
Cr	3.5	1.85	46:50	2.9	1.83	17:19
Cu	130	1.51	50:50	94	1.53	19:19
F	.50	...	10:12	.78	1.54	3:4
Fe	1,400	1.88	50:50	1,300	1.67	19:19
I	4.6	1.22	12:12	4.2	1.12	4:4
K	51,000	1.29	50:50	34,000	1.31	19:19
La	<70	...	0:50	110	1.70	16:19
Li	<4	...	17:50	4.0	...	10:19
Mg	18,000	1.86	50:50	25,000	2.11	19:19
Mn	12,000	1.74	50:50	8,300	1.89	19:19
Na	380	1.33	50:50	280	1.55	19:19
Ni	21	1.80	50:50	61	2.42	19:19
P	12,000	1.42	50:50	8,300	1.43	19:19
Pb	100	1.85	50:50	100	1.66	19:19
Se	.018	1.43	48:50	.022	1.52	19:19
Sr	1,800	1.59	50:50	3,200	2.03	19:19
Ti	160	1.68	50:50	110	1.92	19:19
Y	<20	...	1:50	23	1.69	14:19
Yb	<2	...	0:50	1.6	1.19	4:19
Zn	320	1.31	50:50	1,500	1.65	19:19
Zr	<20	...	12:50	7.6	1.97	2:19
Ash	36,000	1.28	50:50	53,000	1.29	19:19

The effects of unusual concentrations of a metal in the environment on the content of the metal in plants are believed to be illustrated by the lead levels that we found in plant samples from the Oak-hickory-pine Forest area. This area supports extensive lead mining (Weigel, 1965), and has been an important center of lead production since 1720 (Kiilsgaard and others, 1967). Lead concentrations in plant samples from this area (tables 15, 16, and 20) are notably higher than those in plants sampled elsewhere in Missouri (tables 15, 16, and 19), yet lead concentrations in the soils from the area are lower than those found in soils from any of the other five vegetation-type areas (fig. 24). Moreover, the slight indication of a bimodal frequency distribution for concentrations of lead in sumac (fig. 52)—suggesting two distinct populations or sources—and the higher lead concentrations in sumac stem ash from plants growing adjacent to mining operations strongly suggest that lead levels in plants from this area are reflecting an unusual source of lead. This source seems likely to be related, in some undetermined manner, to activities associated with lead mining in this area.

The importance of soil alkalinity in controlling the molybdenum concentrations in the vegetation of the Cedar Glade area has already been discussed. This soil property appears to be an important factor in contributing to the distinctiveness of the trace element chemistry in plants from this area. There is evidence of a strong soil pH control on the barium and strontium levels in the ash of sumac and buckbush, as is demonstrated by the following table of correlation coefficients between log concentrations of these elements in plant ash and pH values for soils from the Cedar Glade area.

	Barium		*Strontium*	
Plant species	*r*	*Number of Pairs*	*r*	*Number of Pairs*
Sumac	-0.71	49	-0.68	49
Buckbush	-.53	50	-.58	50
Post oak	-.49	50	-.49	50
Cedar	-.59	50	-.49	50

The degree to which pH affects barium and strontium mobility in soils was demonstrated experimentally by Bowen and Dymond (1956). They stated (p. 361), "Acid solutions generally extract more of the alkaline earth metals [barium and strontium] than do neutral ones, and the amounts of these metals

TABLE 20.—*Mean chemical composition and chemical variation in species characteristic of the Oak-hickory-pine Forest in Missouri*

[*GM*, geometric mean, in parts per million; *GD*, geometric deviation; ratio, number of samples in which detected to total number of samples; leaders (...), no data avaliable]

Element, or ash	Species, and plant part sampled								
	White oak, stems			Shagbark hickory, stems			Shortleaf pine, stems and leaves		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Ag	<1	...	0:49	<1	...	0:7	0.50	2.53	14:49
Al	1,900	1.57	49:49	3,600	1.76	7:7	39,000	1.67	49:49
B	190	1.26	49:49	190	1.11	7:7	230	1.34	49:49
Ba	5,000	1.44	49:49	11,000	1.56	7:7	1,200	1.90	49:49
Be	<2	...	0:49	2.0	2.18	4:7	<2	...	0:49
Ca	340,000	1.06	49:49	350,000	1.04	7:7	130,000	1.31	49:49
Cd	3.9	1.44	49:49	20	1.60	7:7	14	1.61	49:49
Co	2.7	2.20	47:49	7.4	1.93	7:7	9.7	1.75	49:49
Cr	3.4	1.95	47:49	2.9	1.92	6:7	13	1.60	49:49
Cu	140	1.34	49:49	100	1.25	7:7	160	1.44	49:49
F	.71	1.49	10:11	...	...	...	.84	1.41	4:4
Fe	1,600	1.43	49:49	1,600	1.57	7:7	5,300	1.59	49:49
I	4.6	1.12	11:11	...	...	...	4.9	1.18	4:4
K	49,000	1.22	49:49	29,000	1.21	7:7	110,000	1.35	49:49
La	<70	...	0:49	270	2.20	7:7	<70	...	0:49
Li	<4	...	8:49	4.6	1.52	4:7	<4	...	19:48
Mg	16,000	1.50	49:49	22,000	1.63	7:7	34,000	1.40	49:49
Mn	13,000	1.57	49:49	12,000	1.42	7:7	14,000	1.57	49:49
Na	340	1.30	49:49	320	1.33	7:7	580	1.45	48:48
Ni	20	1.63	49:49	70	2.13	7:7	51	1.82	49:49
P	11,000	1.35	49:49	8,900	1.45	7:7	23,000	1.24	49:49
Pb	140	1.72	49:49	190	1.65	7:7	250	1.70	49:49
Se	.019	1.43	48:49	.027	1.45	7:7	.062	1.71	49:49
Sr	2,300	1.88	49:49	5,100	1.56	7:7	570	1.85	49:49
Ti	150	1.68	49:49	120	1.57	7:7	620	2.04	49:49
V	<5	...	0:49	<5	...	0:7	10	2.12	41:49
Y	<20	...	1:49	46	2.11	7:7	<20	...	4:49
Yb	<2	...	0:49	...	...	4:7	1.4	1.23	6:49
Zn	350	1.39	49:49	1,600	1.24	7:7	1,200	1.41	49:49
Zr	<20	...	10:49	<20	...	0:7	29	2.62	36:49
Ash	36,000	1.14	49:49	51,000	1.17	7:7	27,000	1.23	49:49

TABLE 21.—*Geographic patterns of variation in chemical elements in ash of sumac stems from Missouri*

Geographic pattern No.	Vegetation type [1]	Variation in chemical elements
1	Cedar Glade	Highest in calcium; lowest in barium, nickel, phosphorus, potassium, strontium, and zinc.
2	Floodplain Forest	Highest in magnesium, nickel, and phosphorus.
3	Oak-hickory-pine Forest.	Highest in lead; lowest (with sumacs from the Cedar Glade area) in zinc.

[1] Sumacs sampled in each vegetation type are distinctive from sumacs of other vegetation types.

extracted from soils rich in carbonates are particularly sensitive to the pH of the extractant."

Similarly strong relationships between soil pH and plant concentrations could not be demonstrated for 19 other elements that were tested. Factors other than soil chemistry, including pH, must, therefore, be considered in attempting to explain element cycling in the geochemical system of the Cedar Glade vegetation-type area.

SUMMARY AND CONCLUSIONS

1. The investigation of the geochemical characteristics of native vegetation and associated soils in Missouri indicated that nearly every element detected in the B horizon of uncultivated soils exhibits statistically significant amounts of variation between the vegetation-type areas as mapped in this report.

2. *Q*-mode components analysis of the soil chemistry suggests the presence of four factors that have contributed to the observed chemical variation. These factors reflect, in general, the strong differences between the vegetation-type areas in: (1) presence of a clay-rich parent material, or degree of B-horizon development, or both, (2) presence of quartz sand or cherty residuum parent material, or both, (3) presence

TABLE 22.—*Correlation coefficients for the concentrations of selected elements in sumac stems and in associated soils from six vegetation-type areas in Missouri*

[*r*, product-moment correlation coefficient between logarithms of concentrations; *N*, number of pairs used in computation of *r*. Where *N* is less than 50, the bivariate frequency distribution is censored]

Element	Vegetation type											
	Floodplain Forest		Glaciated Prairie		Unglaciated Prairie		Cedar Glade		Oak-hickory Forest		Oak-hickory-pine Forest	
	r	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*
Al......	-0.11	48	0.05	50	0.09	49	0.09	49	0.00	50	0.30	49
B.......	.07	44	−.08	49	.10	49	−.01	42	.10	49	−.18	48
Ba......	−.05	48	.33	50	−.16	49	.35	49	.16	50	.30	49
Ca......	.06	48	.26	50	.25	48	.30	48	−.11	46	.04	27
Cr......	−.01	37	.18	40	−.40	36	.24	31	−.01	40	.09	43
Cu......	.14	48	.19	50	.00	49	.15	49	.06	50	.12	49
Fe......	.12	48	−.08	50	−.02	49	.20	49	−.13	50	.24	49
K	.20	48	−.07	50	−.16	49	.05	49	−.03	50	−.06	49
Mg.....	−.06	48	.22	50	.05	49	−.03	49	−.05	50	.02	49
Mn.....	.25	47	.02	50	−.02	49	.14	49	.35	50	−.01	49
Na.....	−.21	48	.12	50	−.04	49	.09	48	−.26	50	.12	49
Ni......	.14	46	.53	48	.03	46	.17	13	.02	34	−.19	33
P.......	.14	47	.06	44	.08	46	−.07	49	.33	40	.13	41
Pb......	−.24	33	.17	42	−.11	38	.06	43	.21	37	.45	45
Se......	.32	40	.45	48	−.05	39	−.04	23	.05	27	.26	31
Sr......	−.04	48	.27	50	.10	49	−.29	49	.25	50	.18	49
Ti......	.42	48	.11	50	.08	49	.11	49	−.13	50	.20	49
Zn......	−.12	48	.12	50	−.35	49	.14	49	.15	50	.21	49

of carbonate parent material, and (4) presence of feldspathic sand parent material.

3. Two native shrub species, sumac and buckbush, that were sampled throughout most of the State were used to estimate the effects of local soil chemistry on plant chemistry. Although both species exhibit statistically significant differences between vegetation-type areas for a number of elements, the observed differences are less marked in plant ash than in samples of the B horizons of uncultivated soils from the same areas. Species differences generally are much more pronounced than differences attributed to location. The most prominent effects of location on plant chemistry are found in the Cedar Glade area in south-central Missouri, but the effect is more likely related to soil pH than to trace element composition of the soil.

4. Summary tables of the chemical composition of stem ash in sumac and buckbush and in seven native trees characteristic of one or two specific vegetation-type areas give estimates of typical element concentrations and estimates of the expected variability in these materials.

5. Correlations between the elemental composition of sumac stem ash and the B, or equivalent, horizon of the supporting soils in each of the six vegetation-type areas were found to be uniformly low, only rarely exceeding 10 percent common variance in the two materials. This result supports earlier studies (Shacklette and others, 1970) in Georgia in which the chemical composition in the ash of selected vegetables and native plants was found to only weakly reflect, at best, the chemical composition of the associated soils.

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FIGURES 10–64

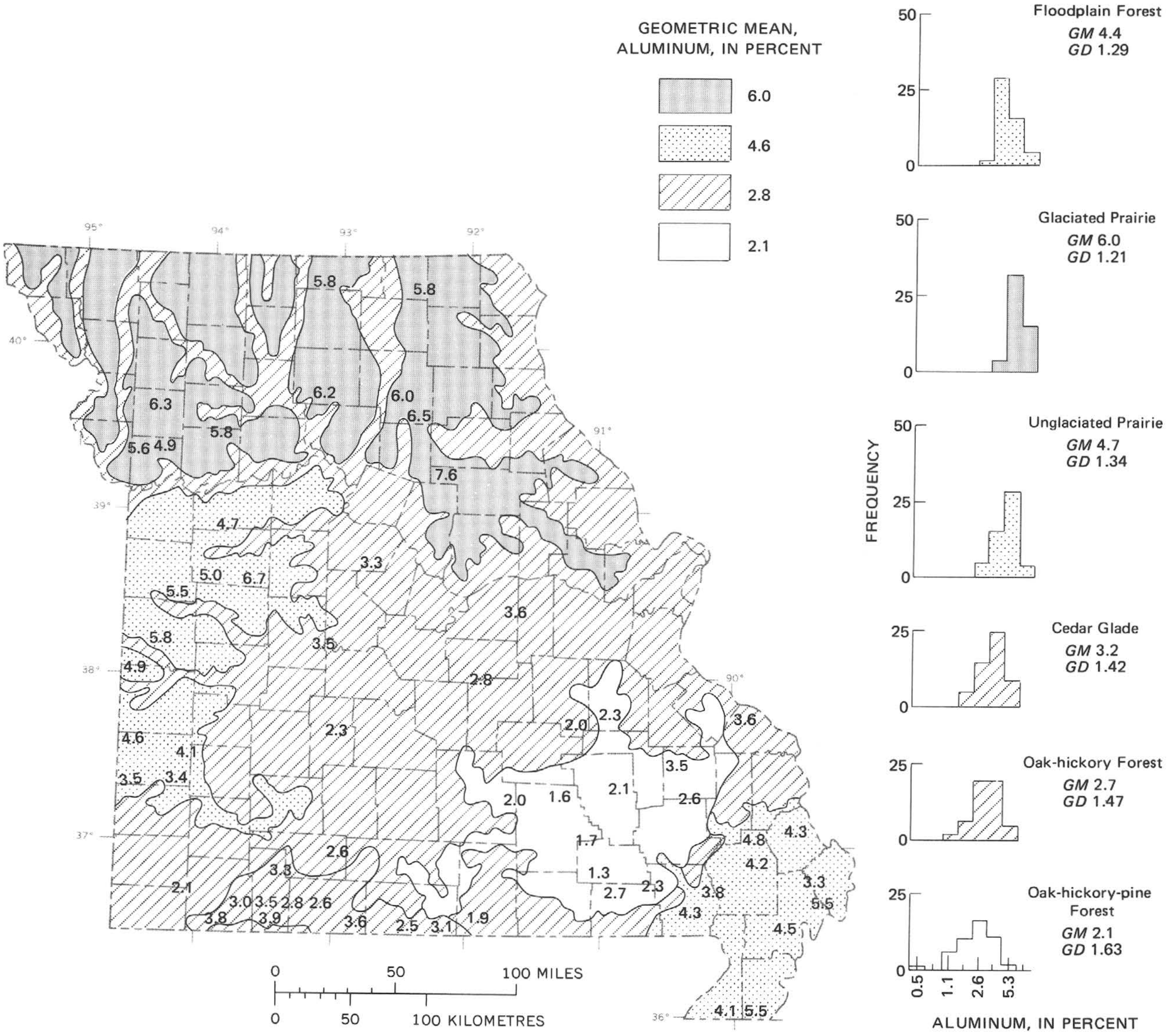


FIGURE 10. —Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of aluminum in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of aluminum in five samples from a 7½-minute quadrangle.

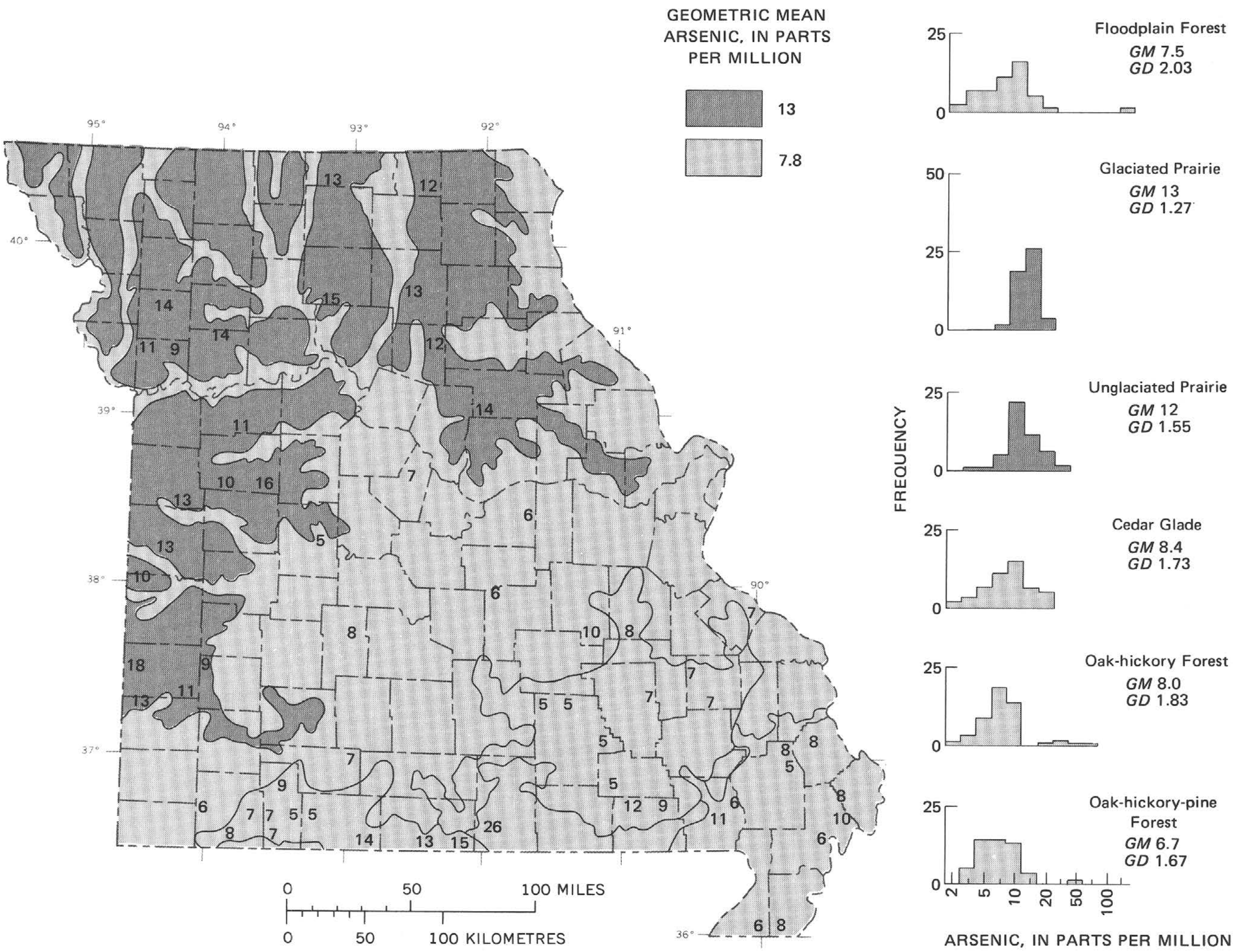


FIGURE 11.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of arsenic in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of arsenic in five samples from a 7½-minute quadrangle.

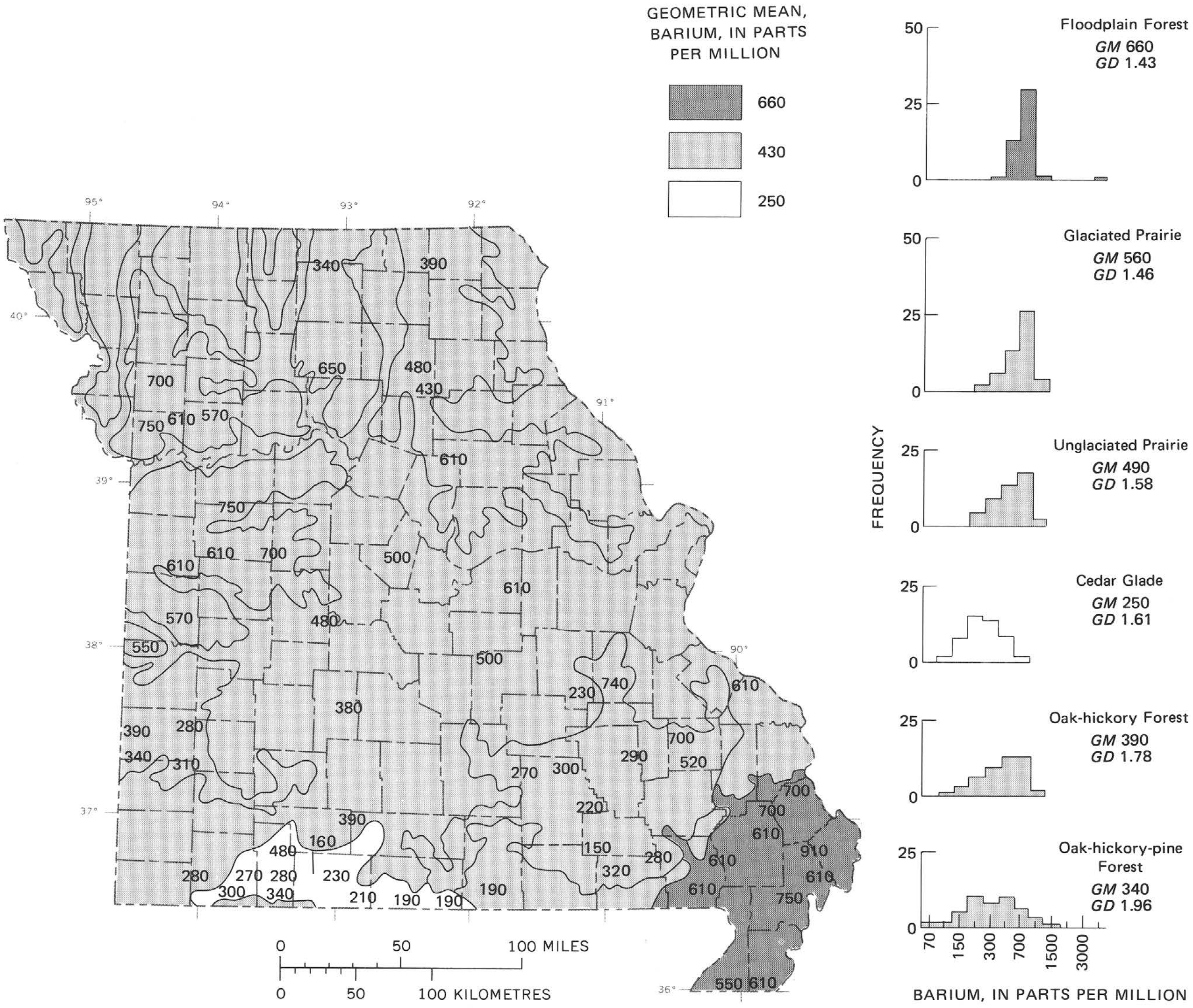


FIGURE 12.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of barium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of barium in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

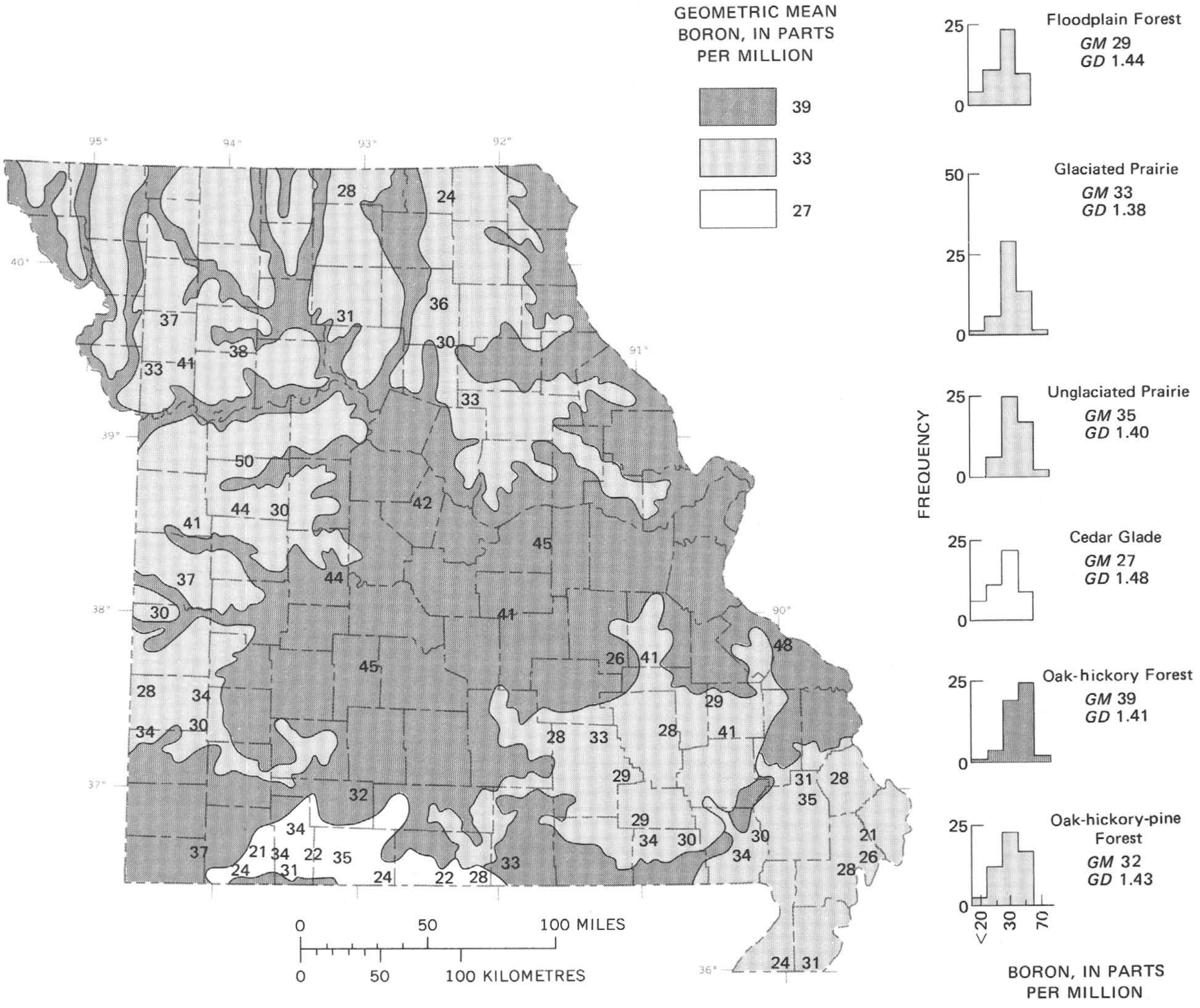


FIGURE 13.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of boron in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of boron in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

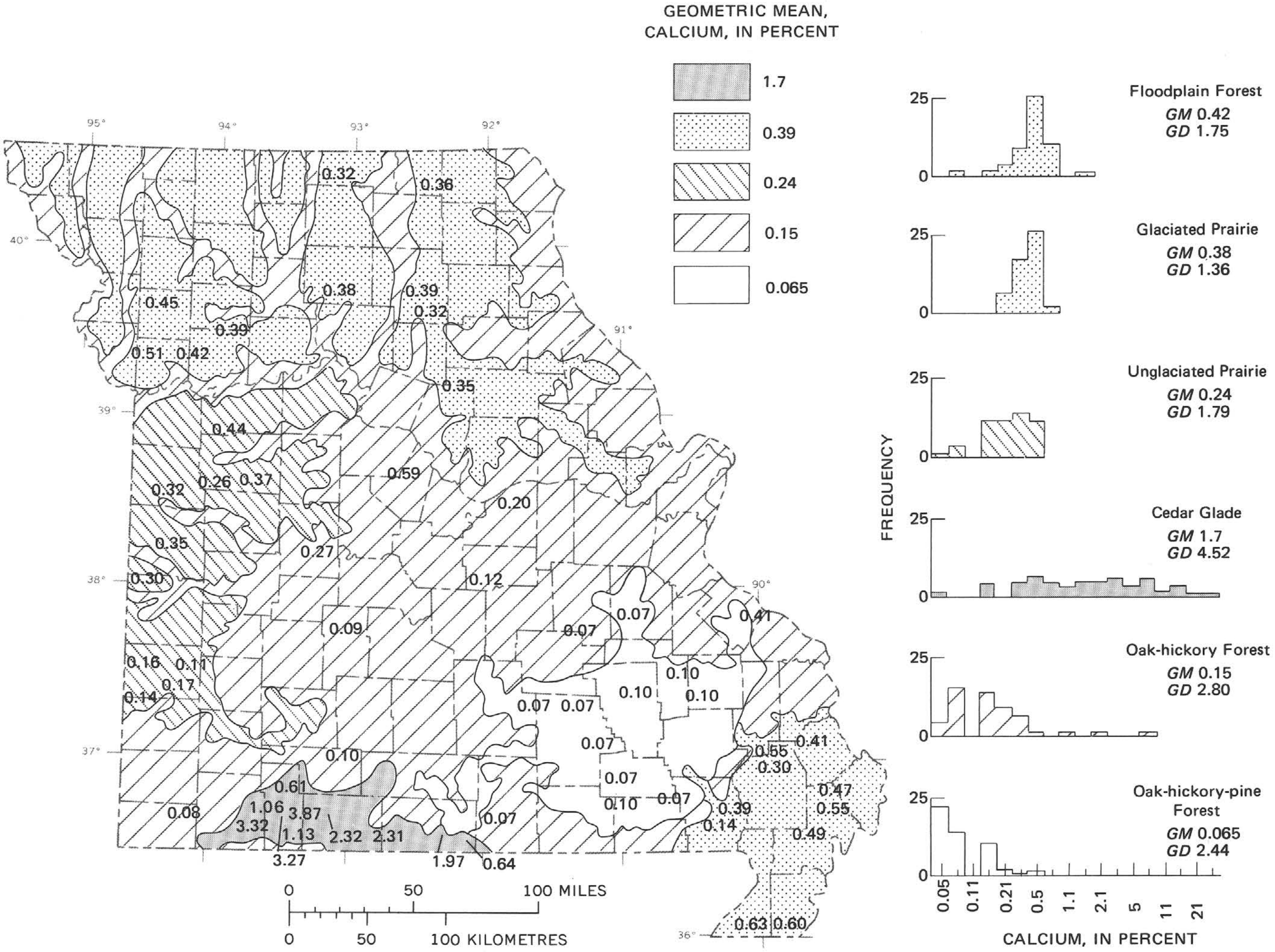


FIGURE 14—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of calcium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of calcium in five samples from a 7½-minute quadrangle.

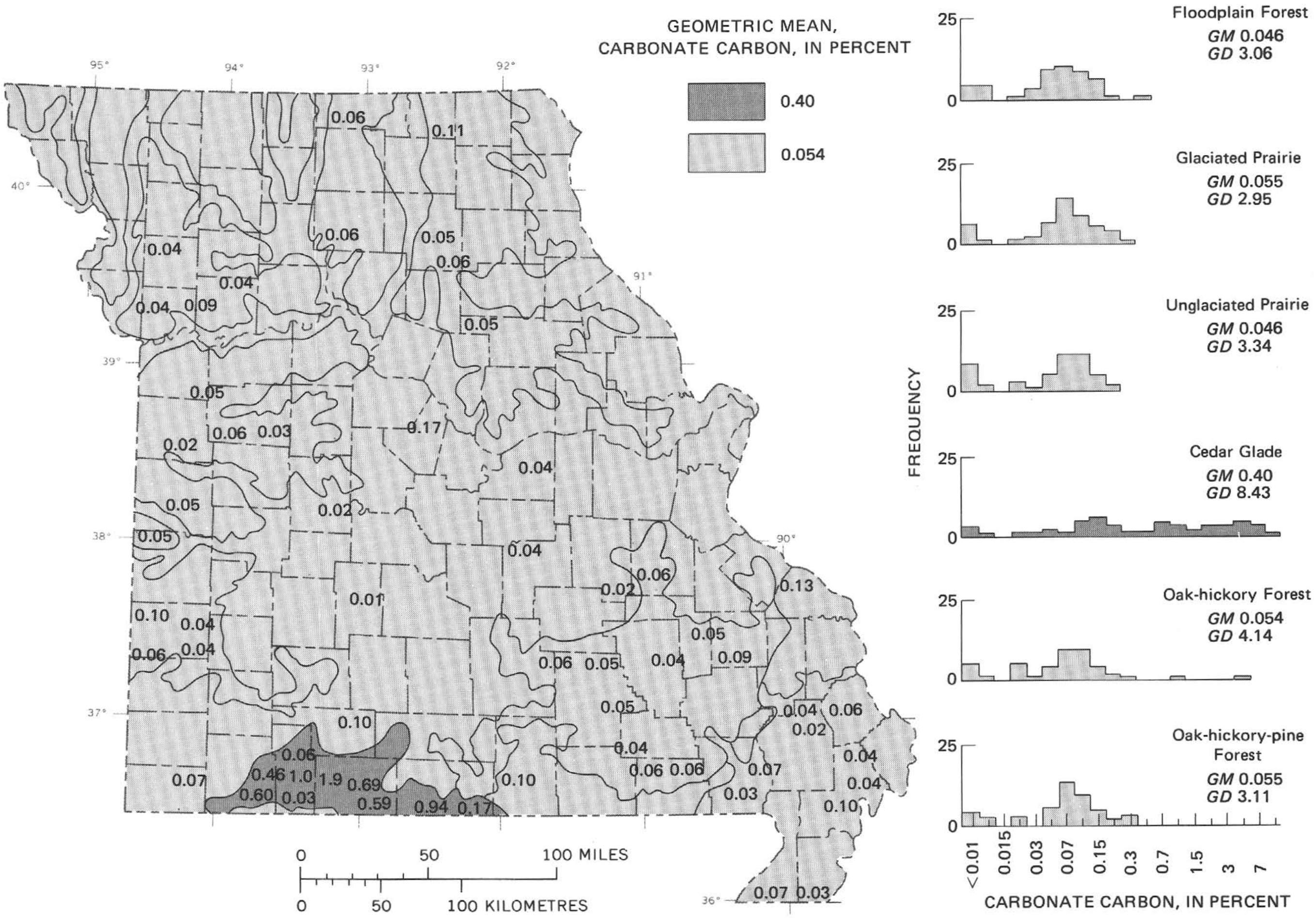


FIGURE 15.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of carbonate carbon in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of carbonate carbon in five samples from a 7½-minute quadrangle.

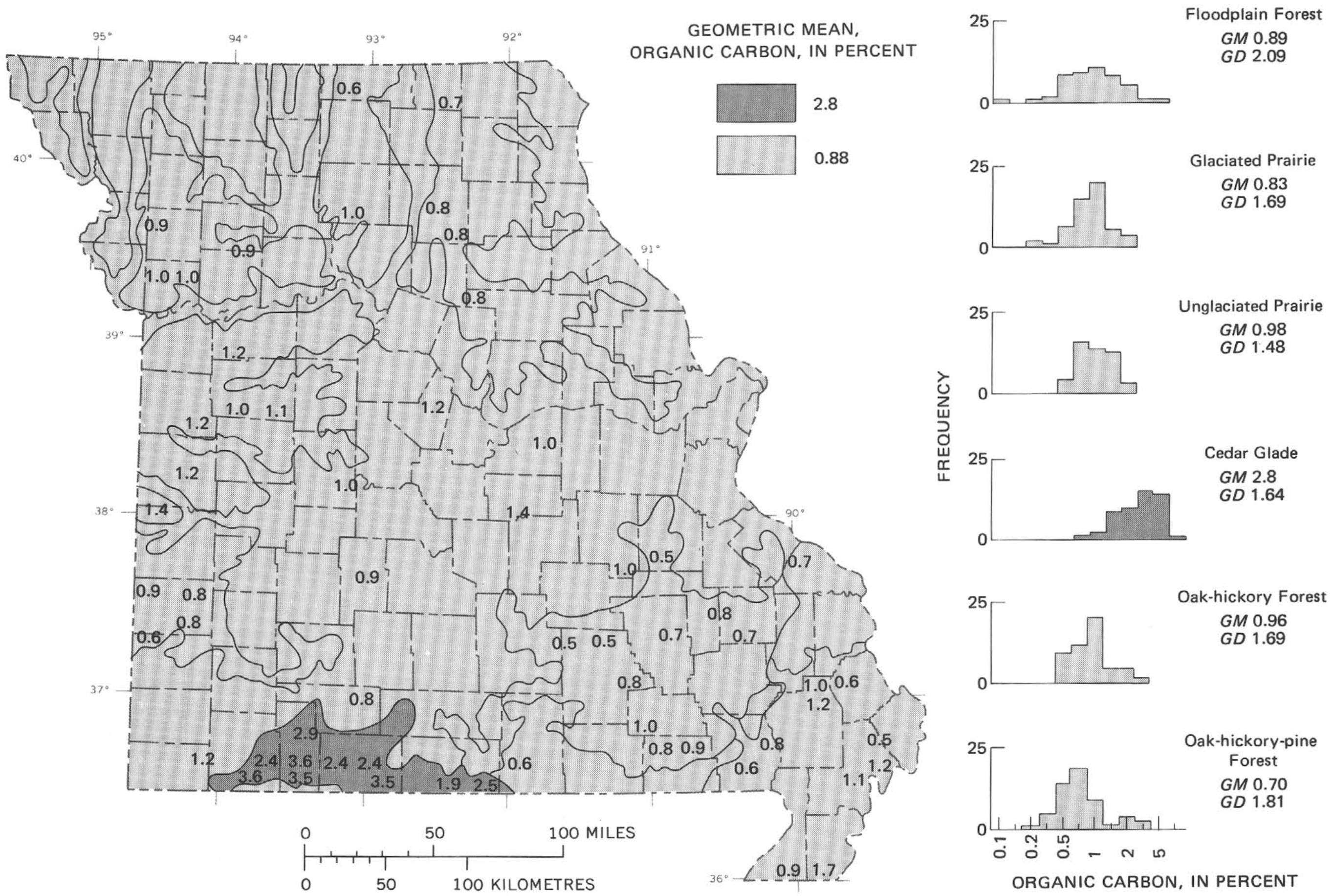


FIGURE 16.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of organic carbon in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of organic carbon in five samples from a 7½-minute quadrangle.

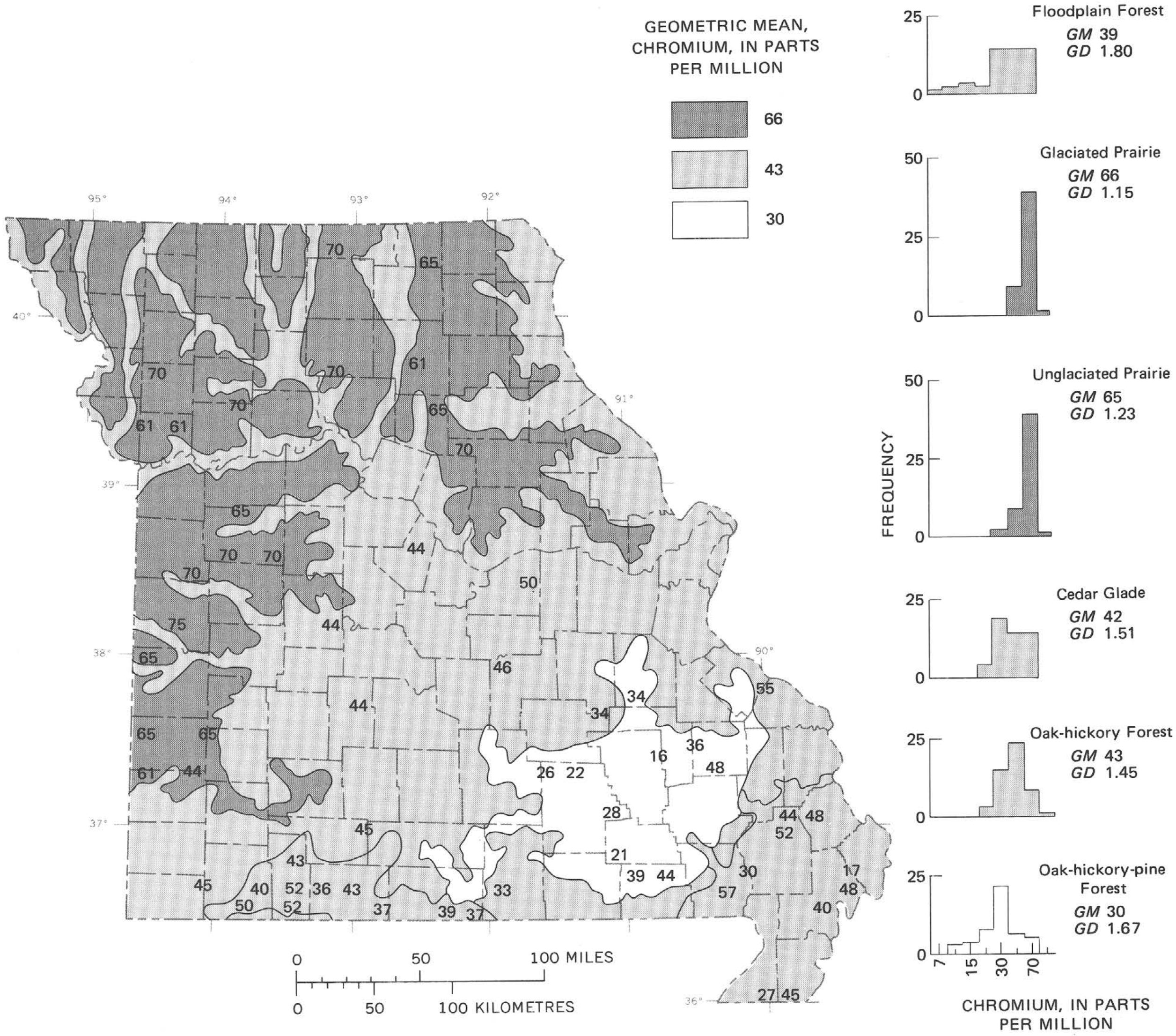


FIGURE 17.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of chromium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of chromium in five samples from a 7½-minute quadrangle.

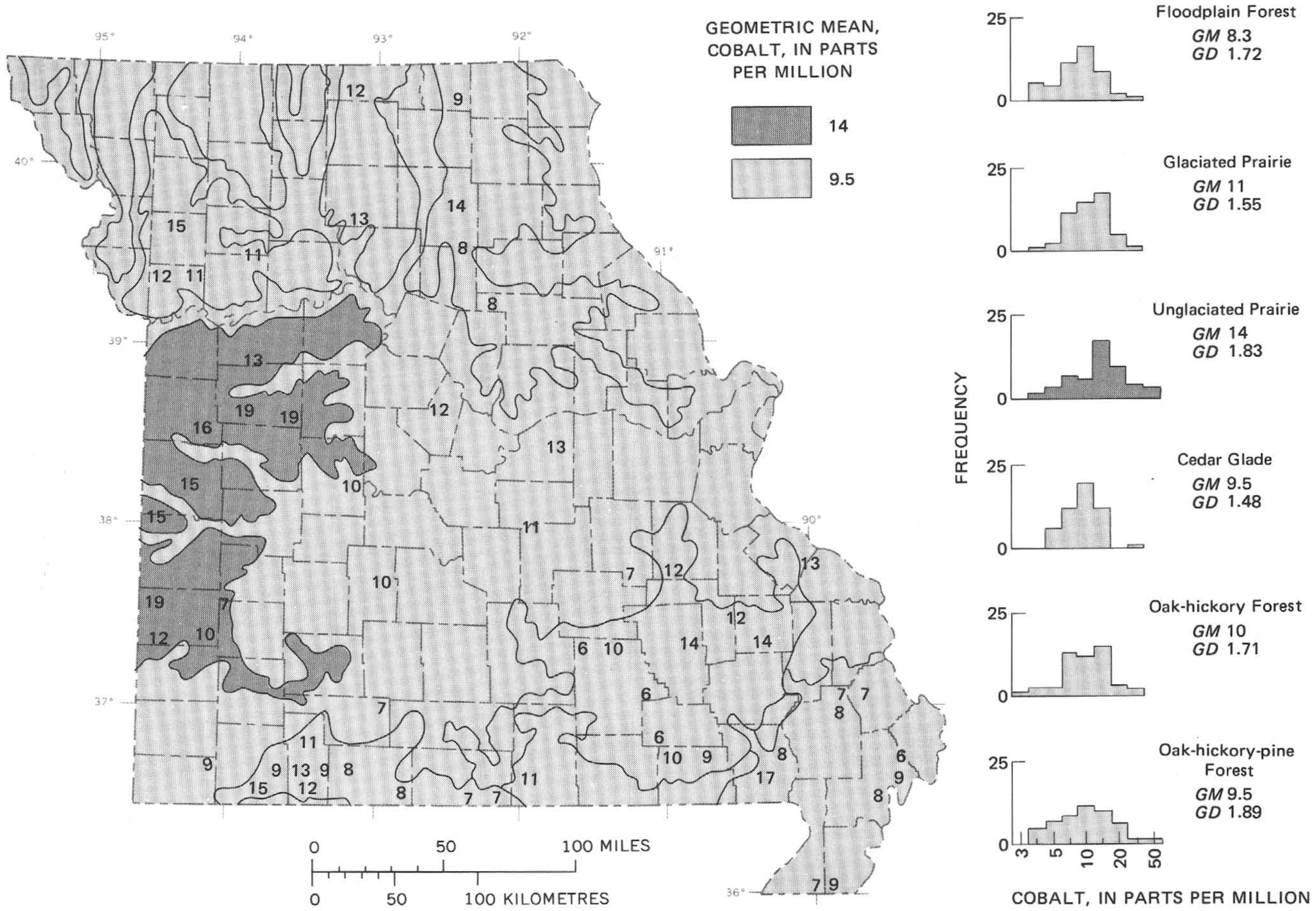


Figure 18.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of cobalt in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of cobalt in five samples from a 7½-minute quadrangle.

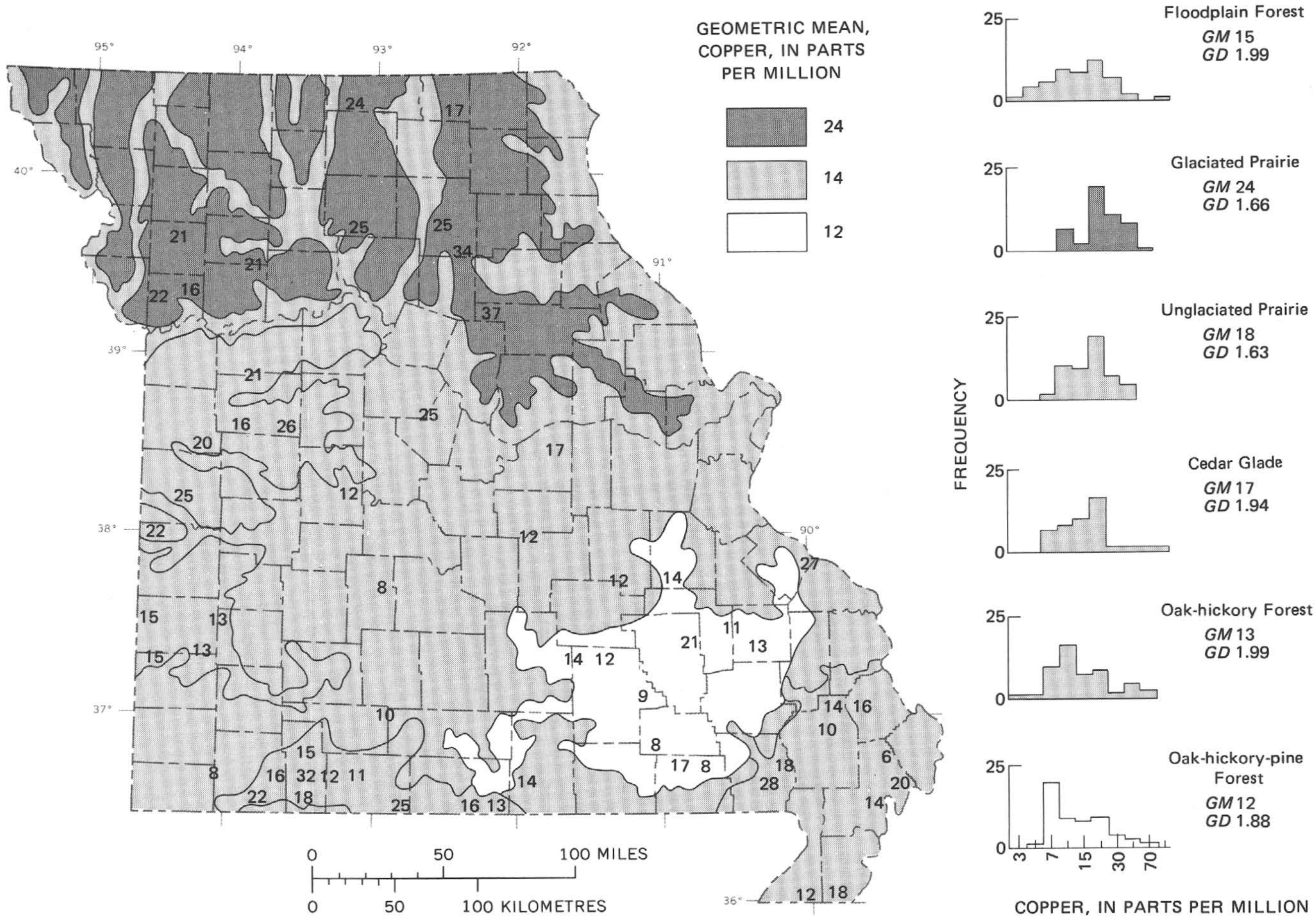


FIGURE 19.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of copper in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of copper in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

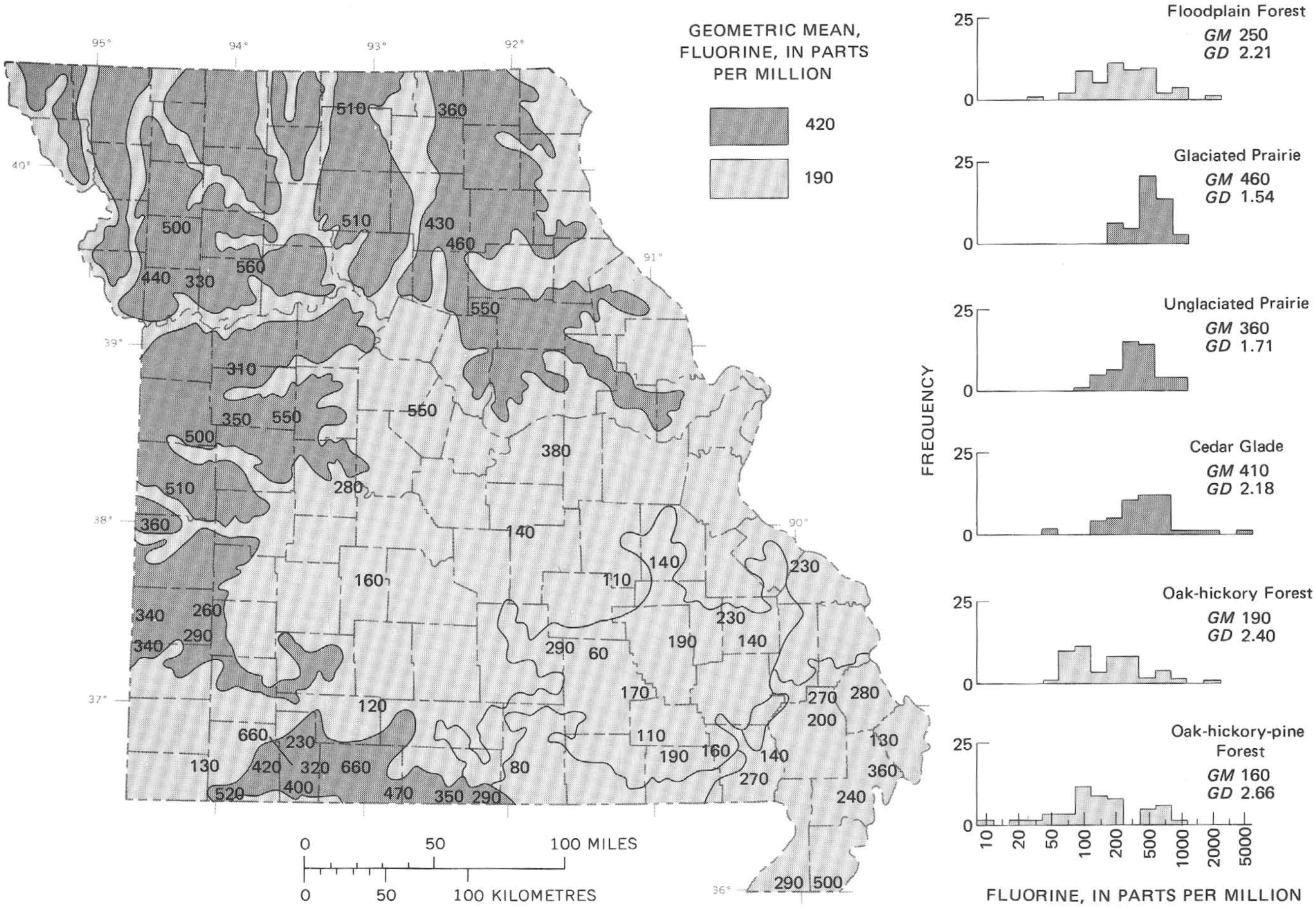


FIGURE 20.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of fluorine in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of fluorine in five samples from a 7½-minute quadrangle.

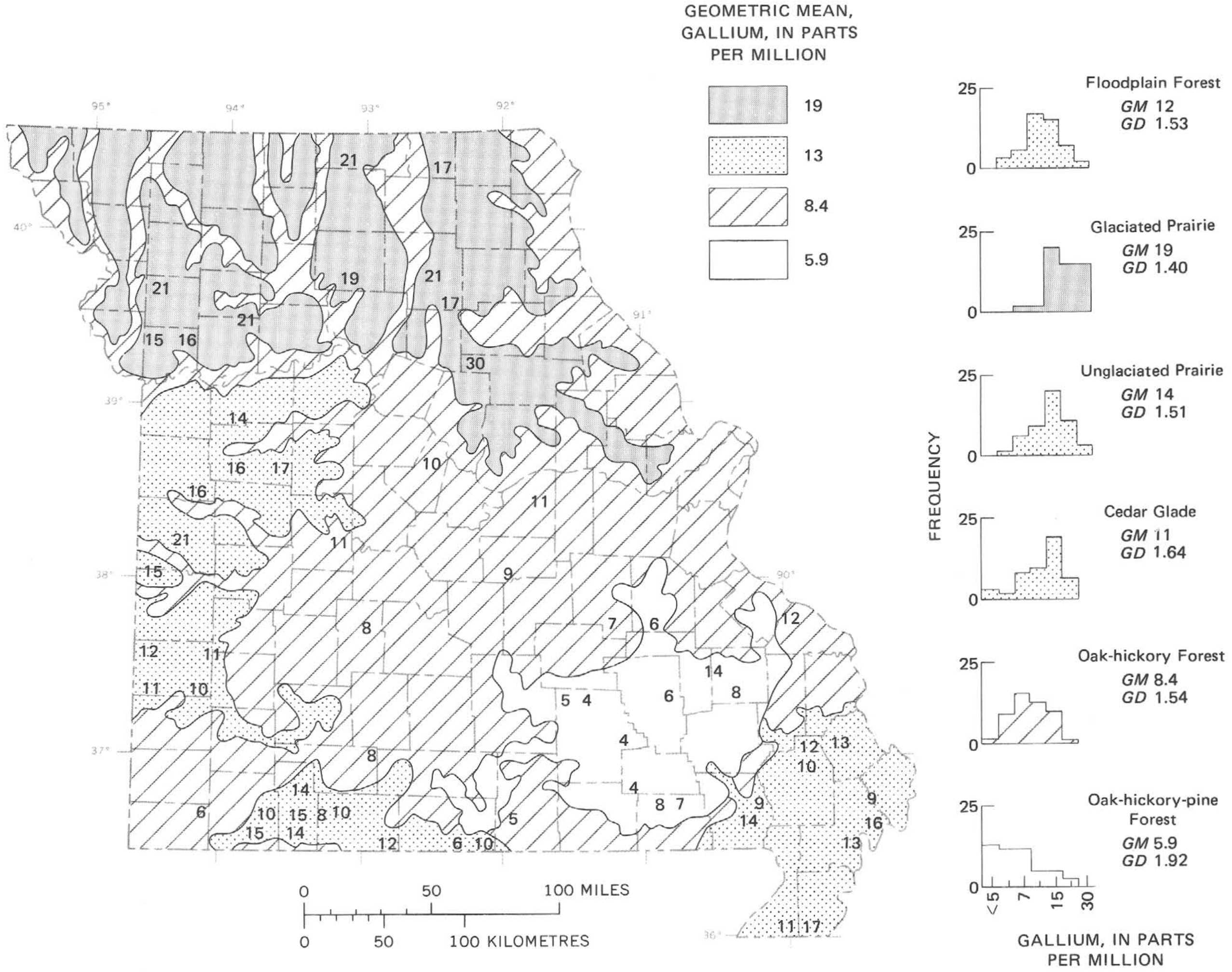


FIGURE 21.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of gallium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of gallium in five samples from a 7½-minute quadrangle.

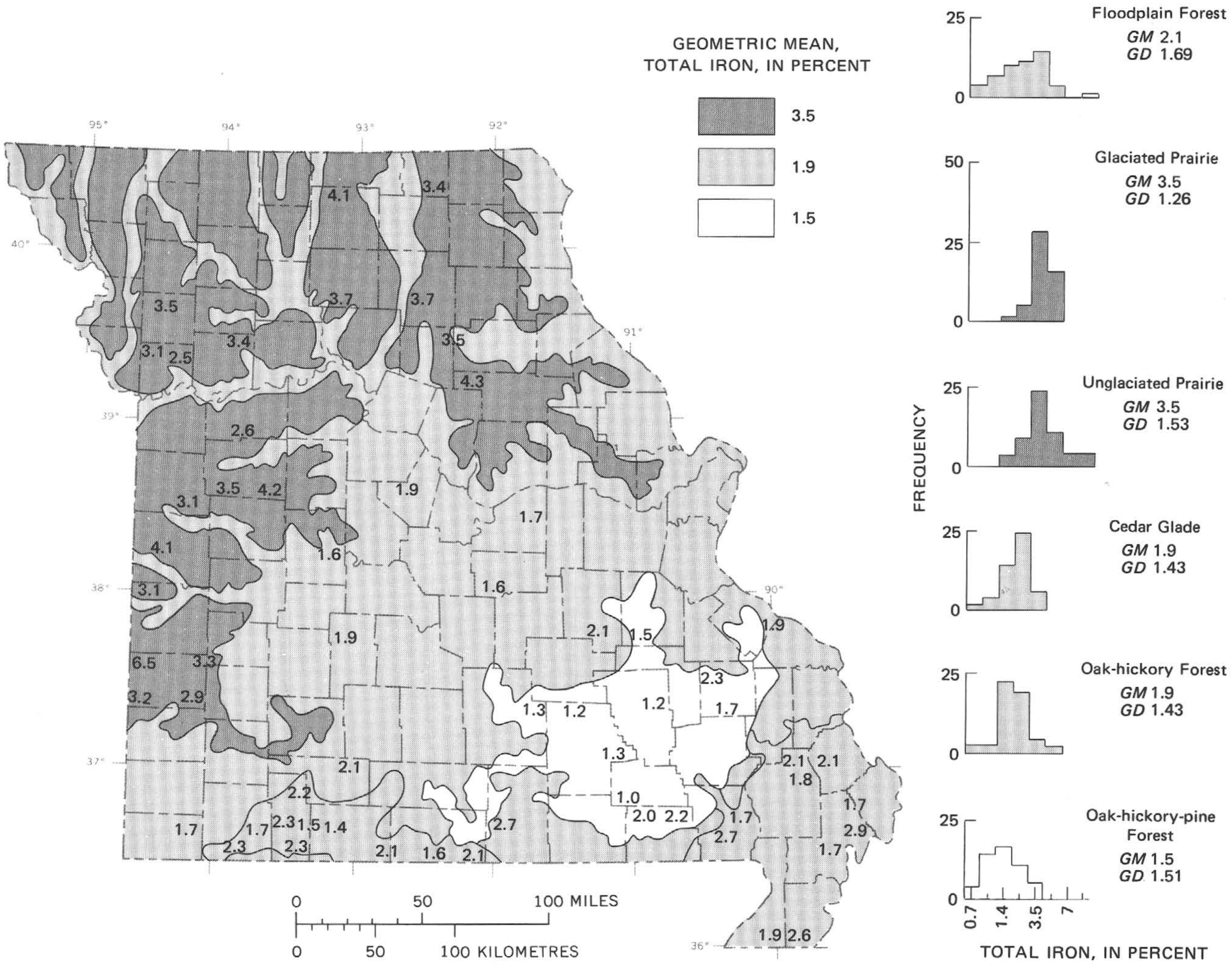


FIGURE 22.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of iron in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of iron in five samples from a 7½-minue quadrangle.

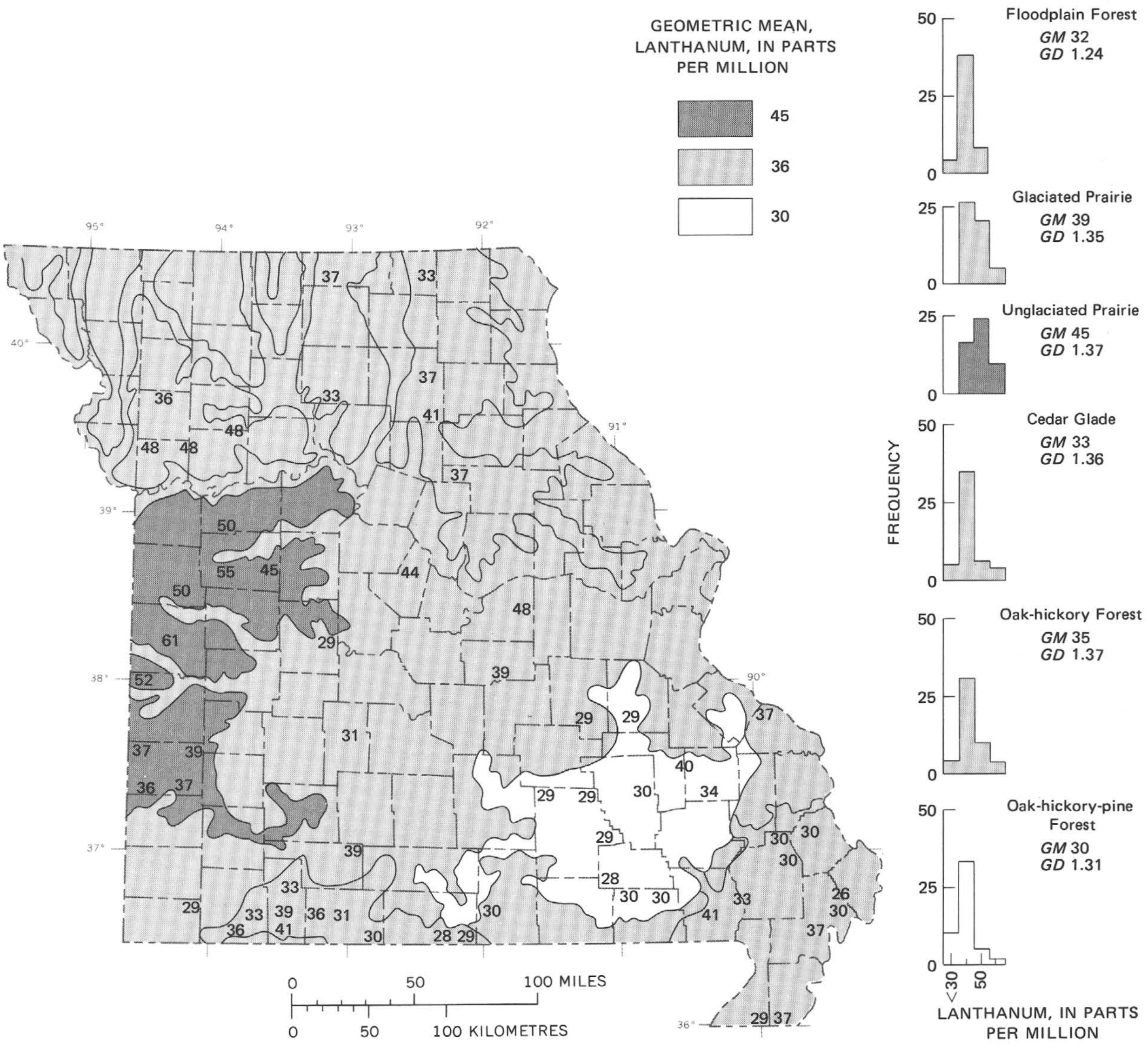


FIGURE 23.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of lanthanum in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of lanthanum in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

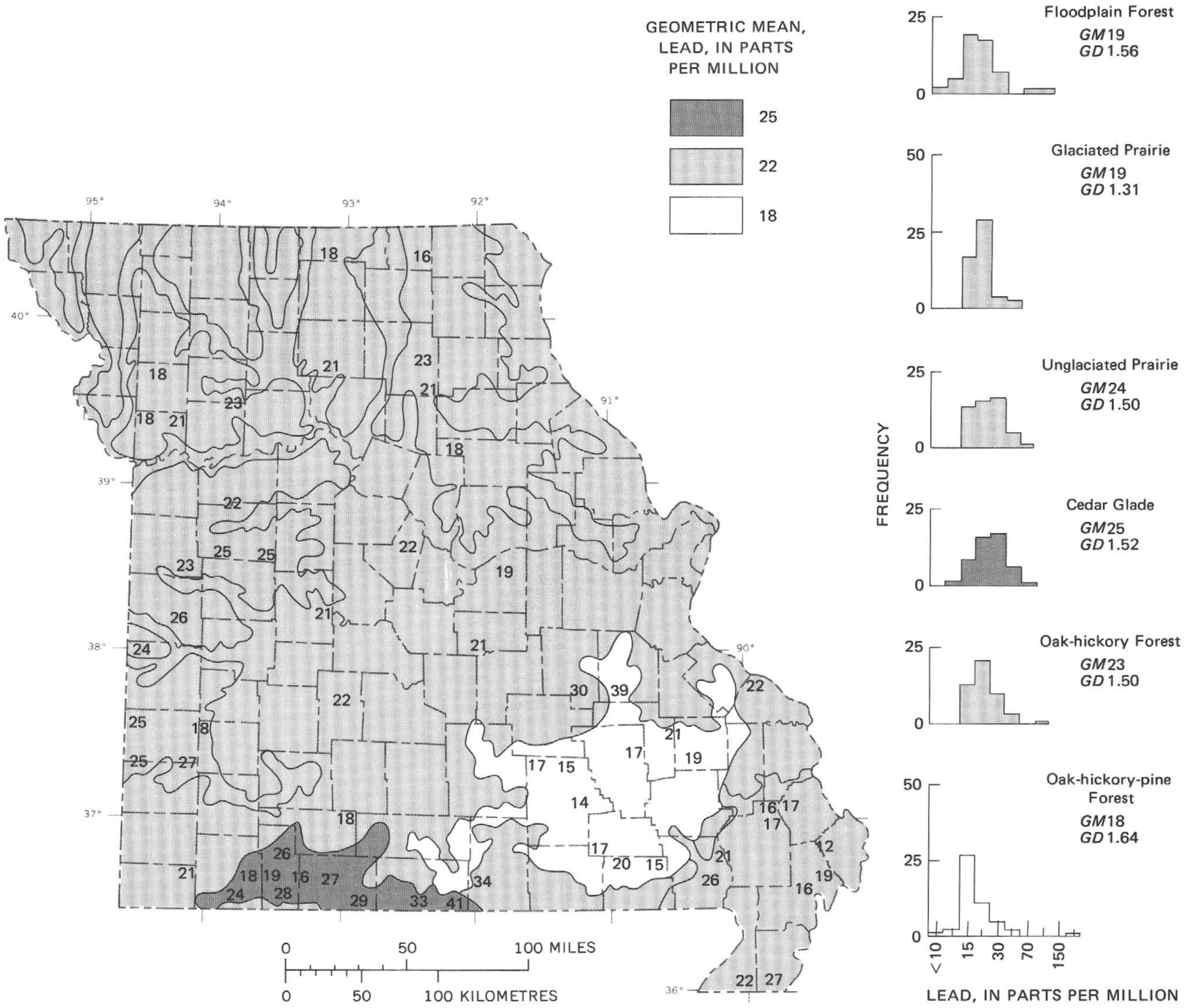


FIGURE 24.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of lead in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of lead in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

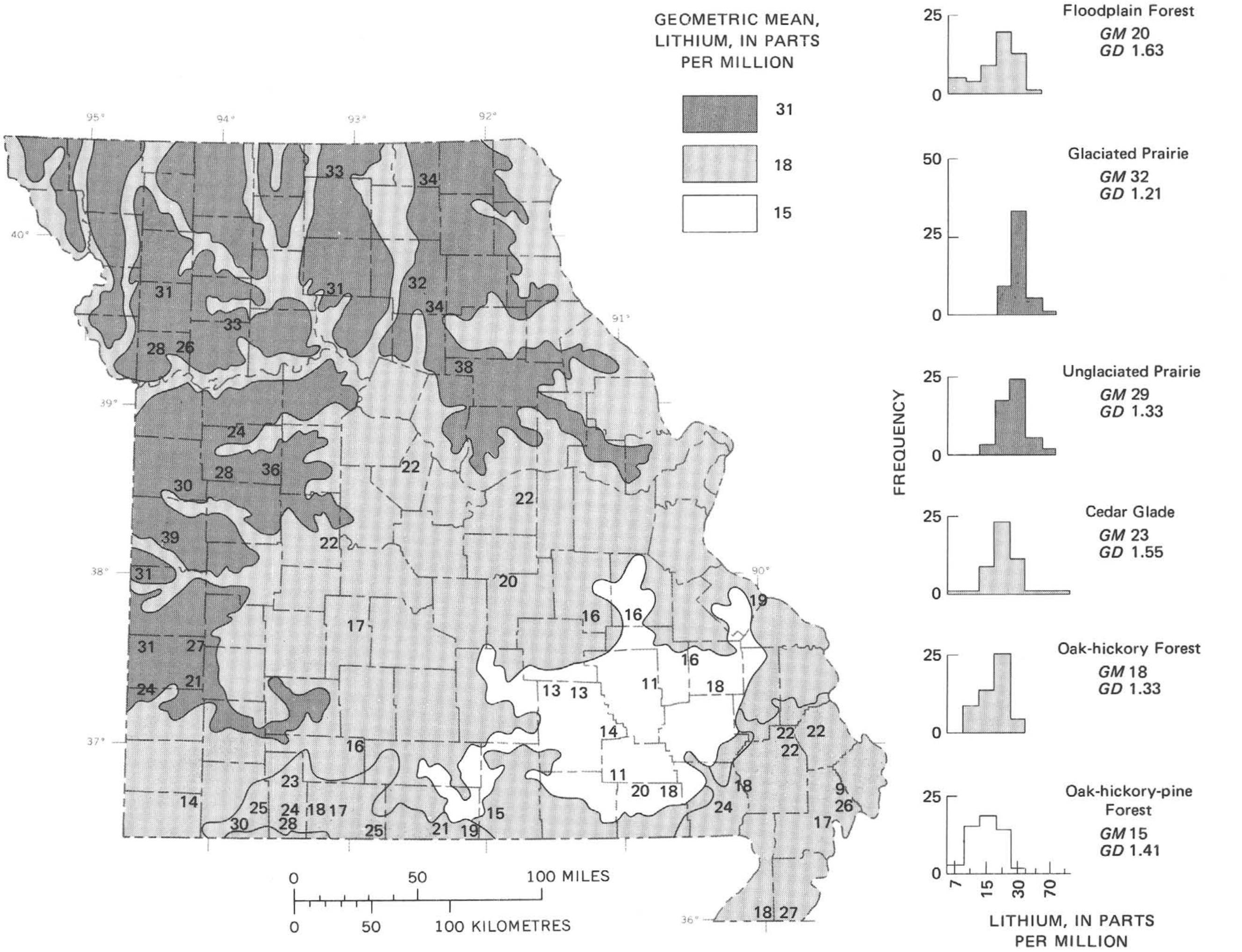


FIGURE 25.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of lithium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of lithium in five samples from a 7½-minute quadrangle.

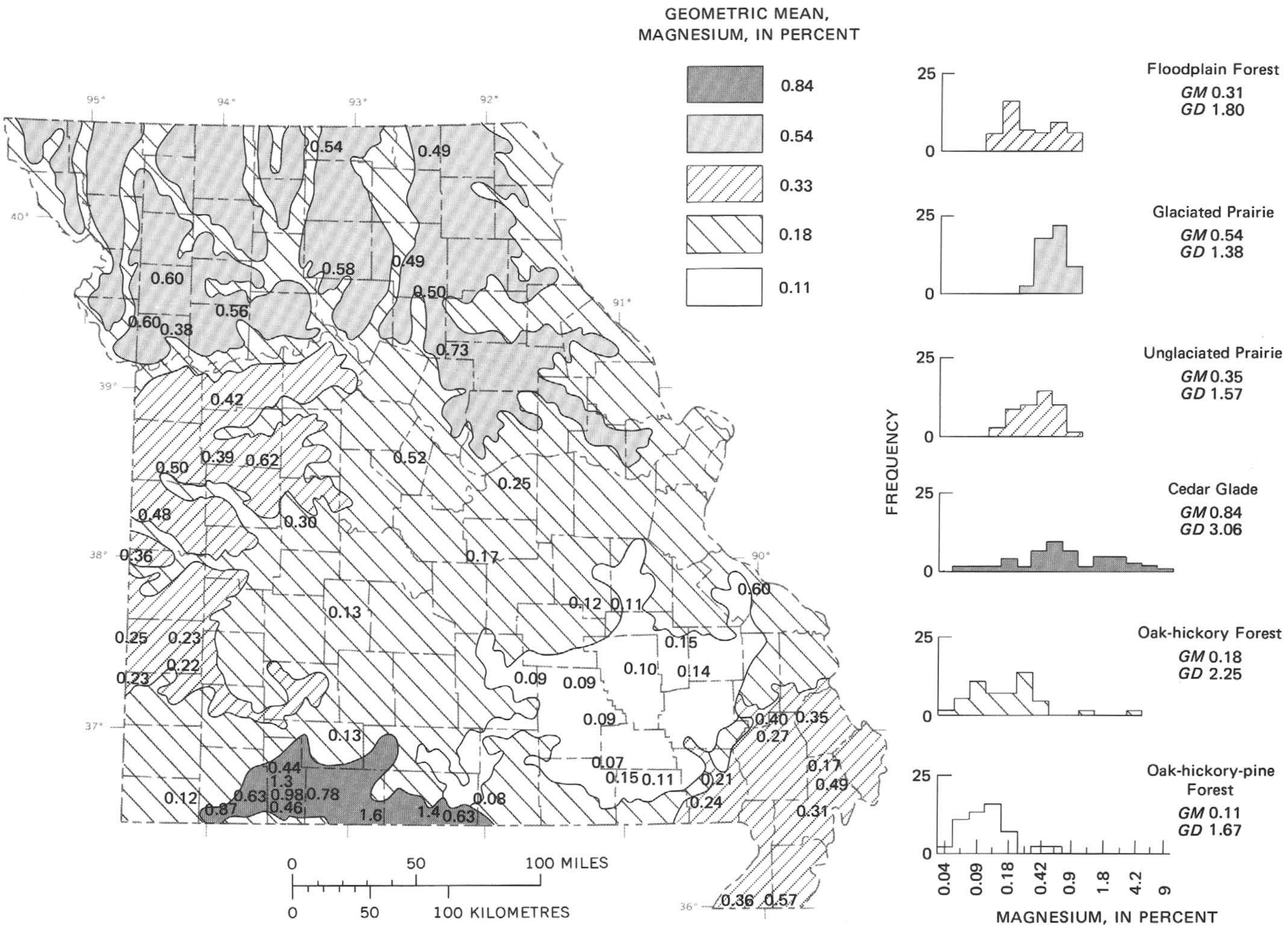


FIGURE 26.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of magnesium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of magnesium in five samples from a 7½-minute quadrangle.

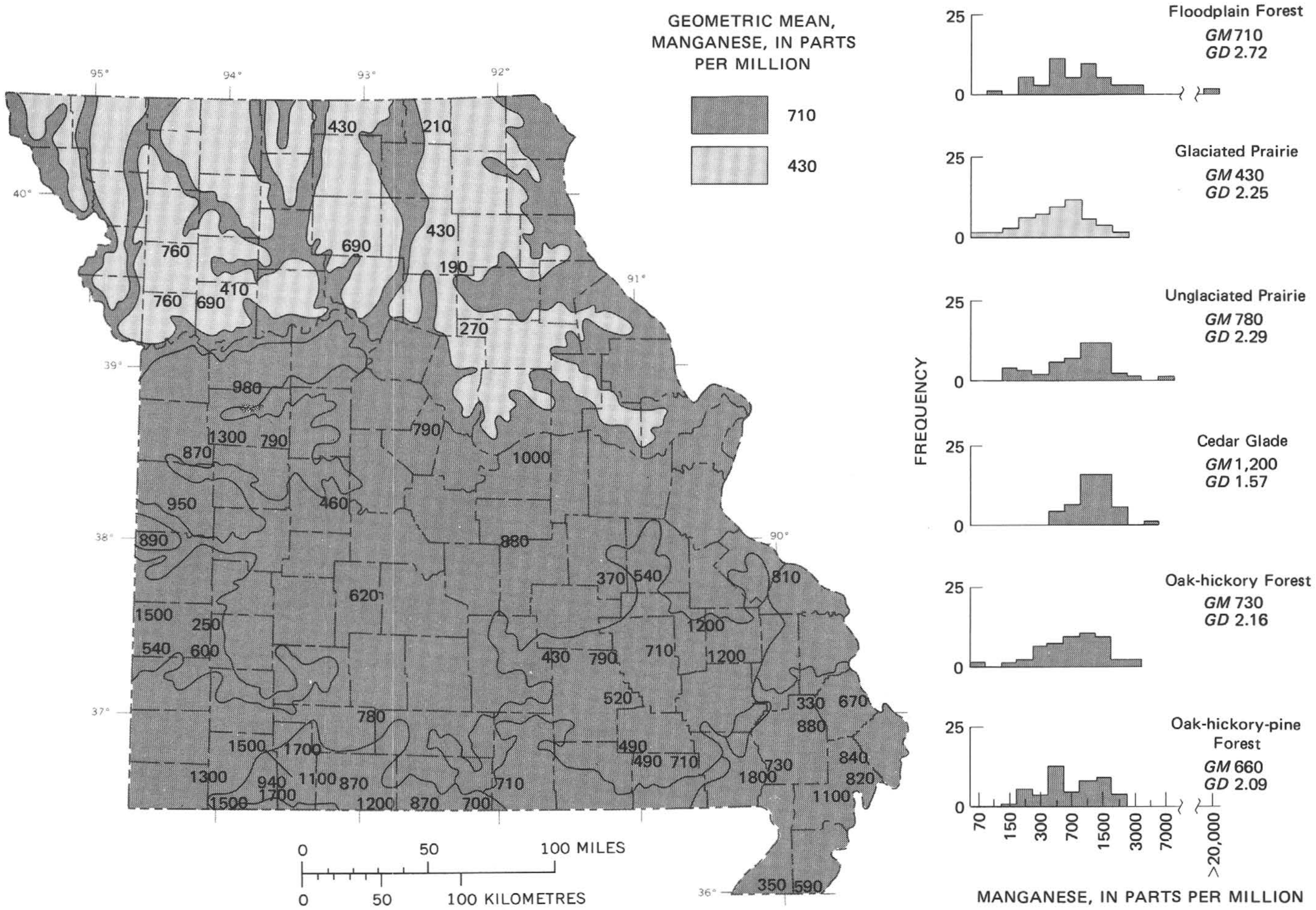


FIGURE 27.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of manganese in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of manganese in five samples from a 7½-minute quadrangle.

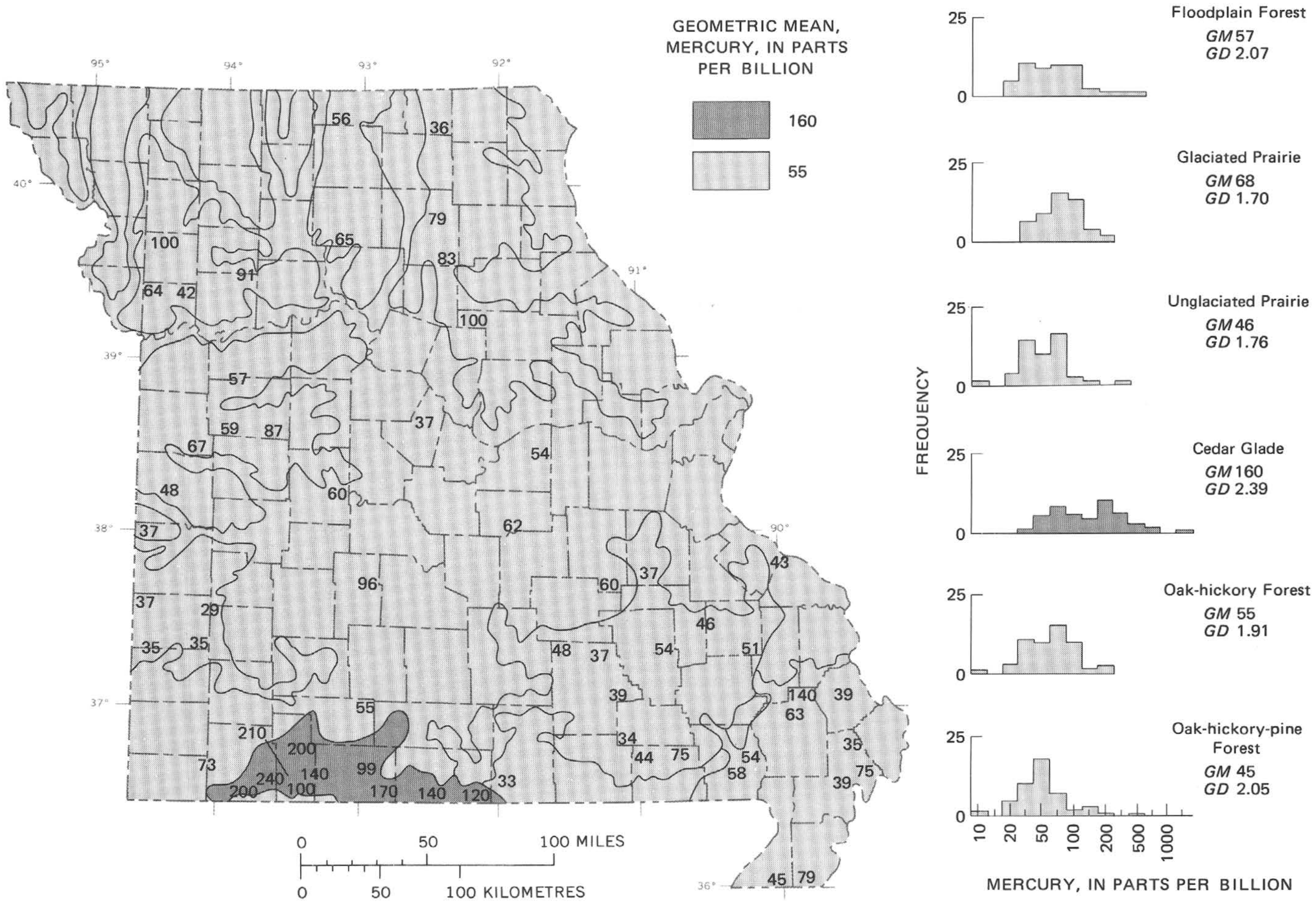


FIGURE 28.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of mercury in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of mercury in five samples from a 7½-minute quadrangle.

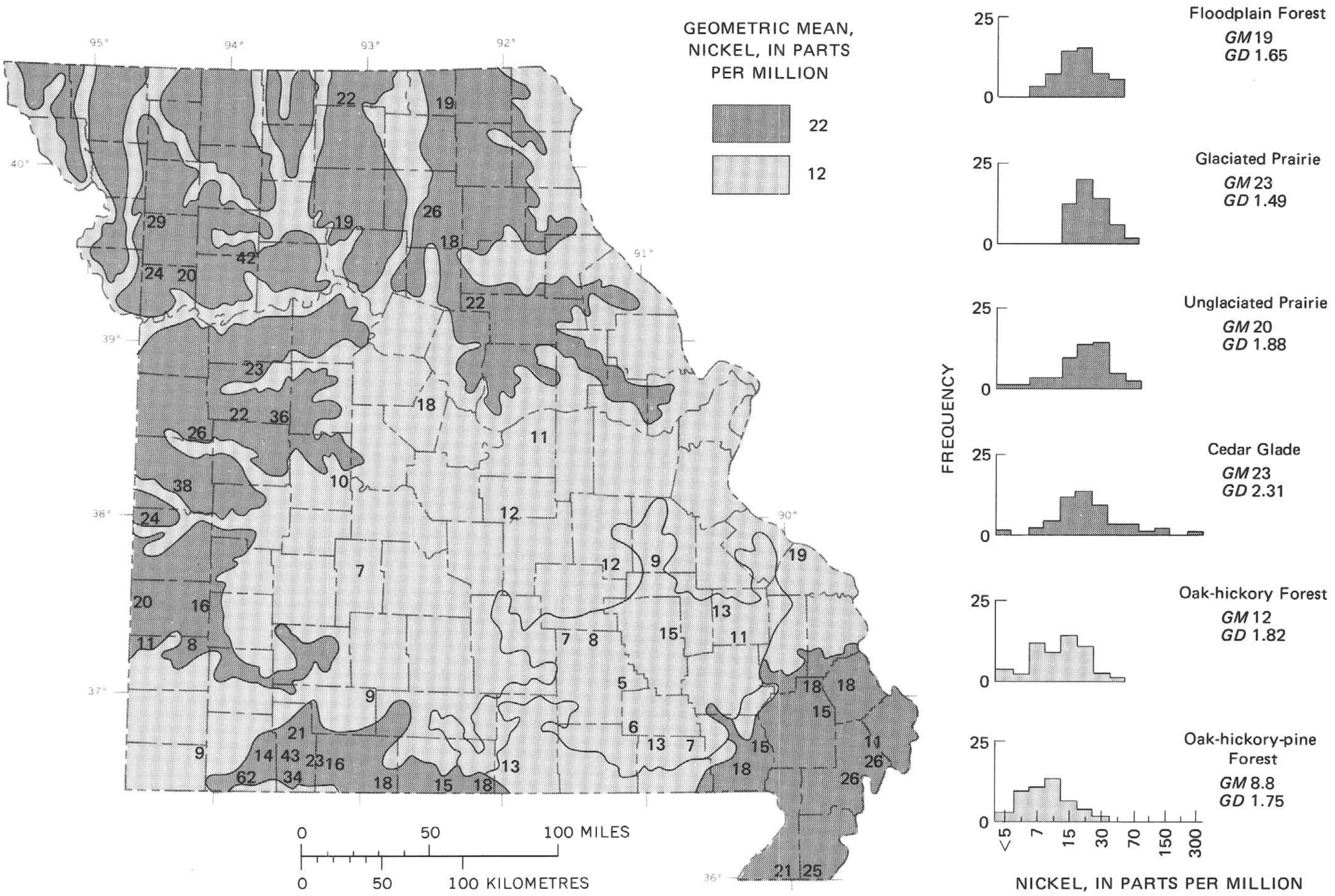


FIGURE 29.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of nickel in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of nickel in five samples from a 7½-minute quadrangle.

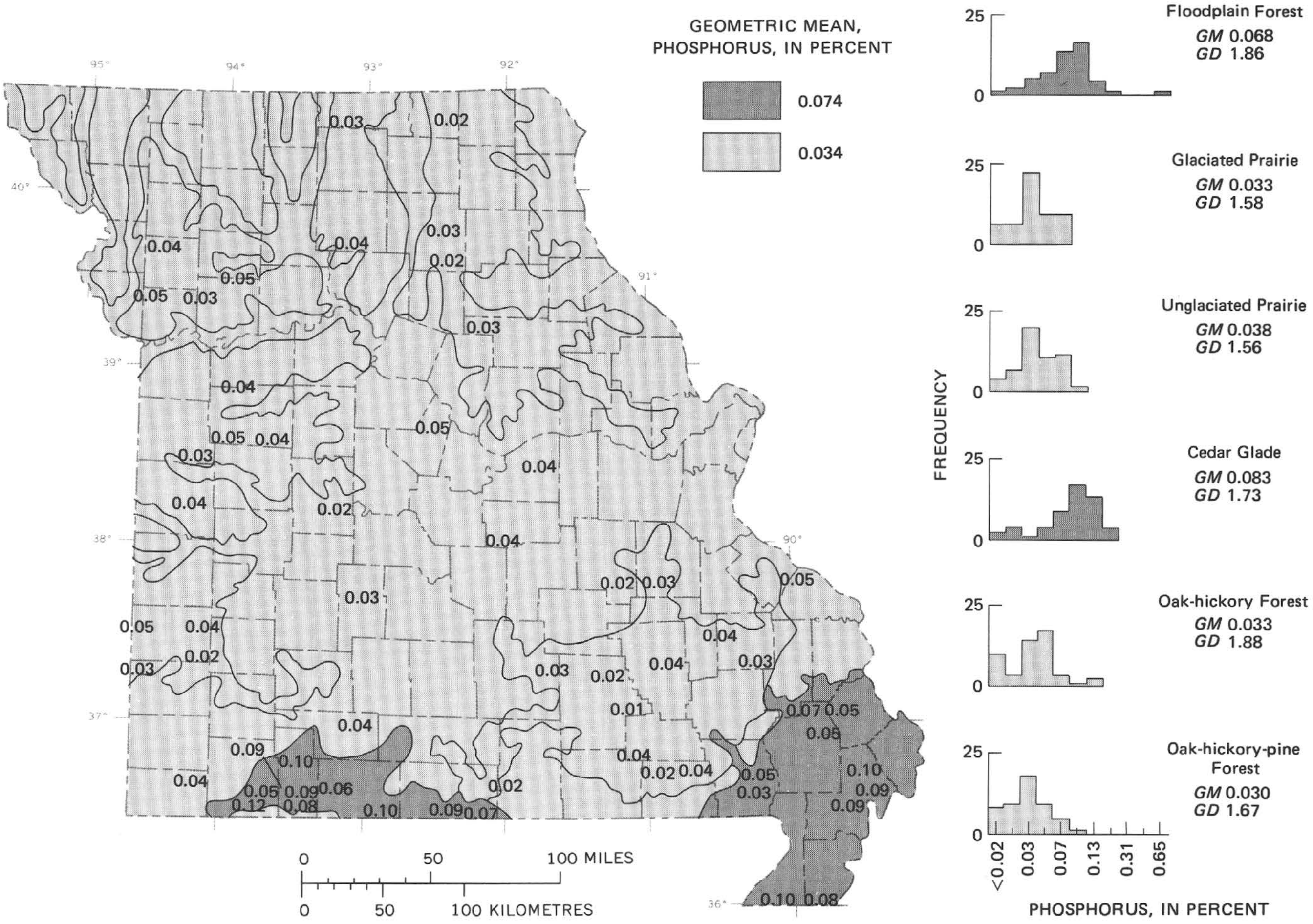


FIGURE 30.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of phosphorus in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of phosphorus in five samples from a 7½-minute quadrangle.

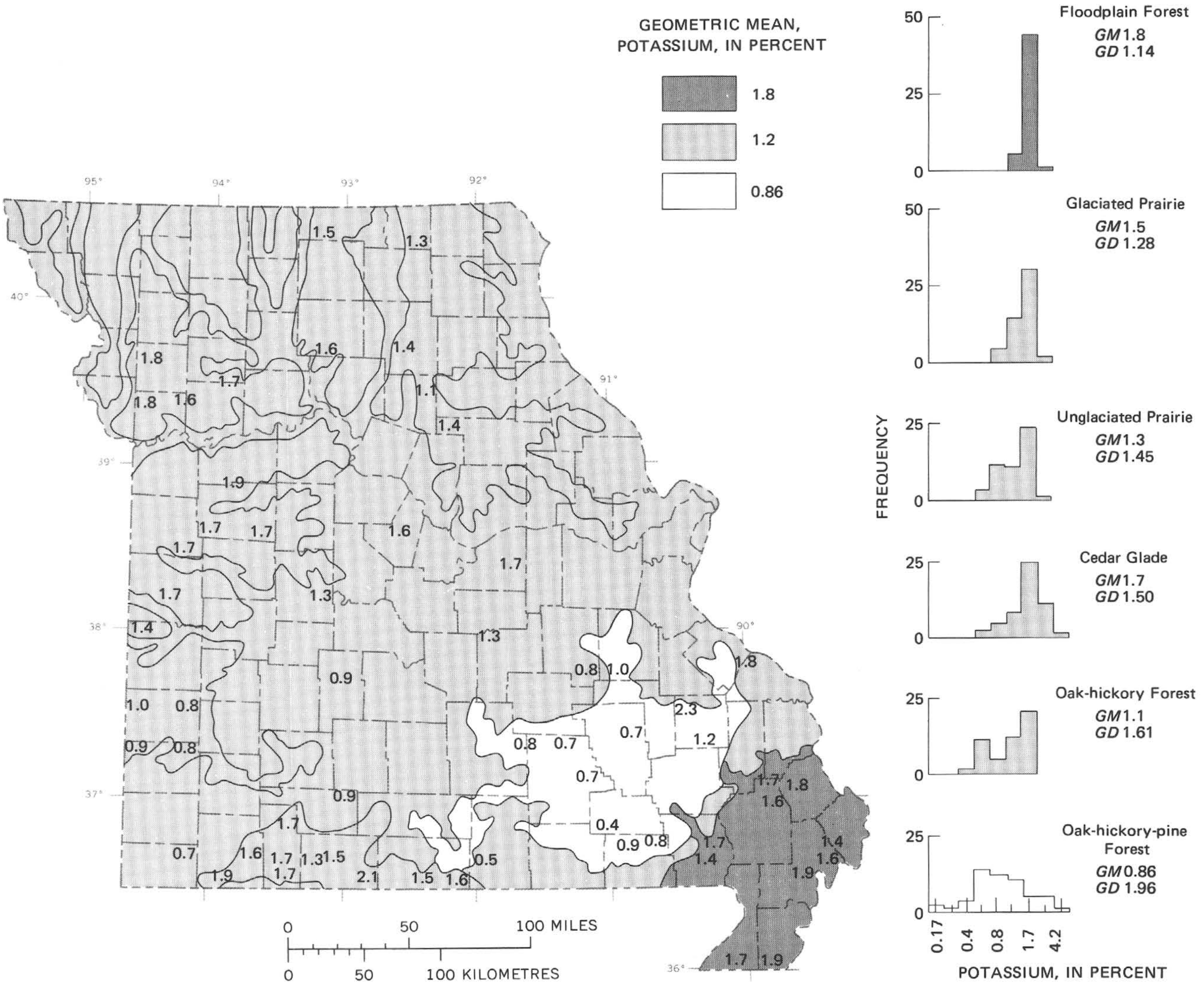


FIGURE 31.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of potassium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of potassium in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

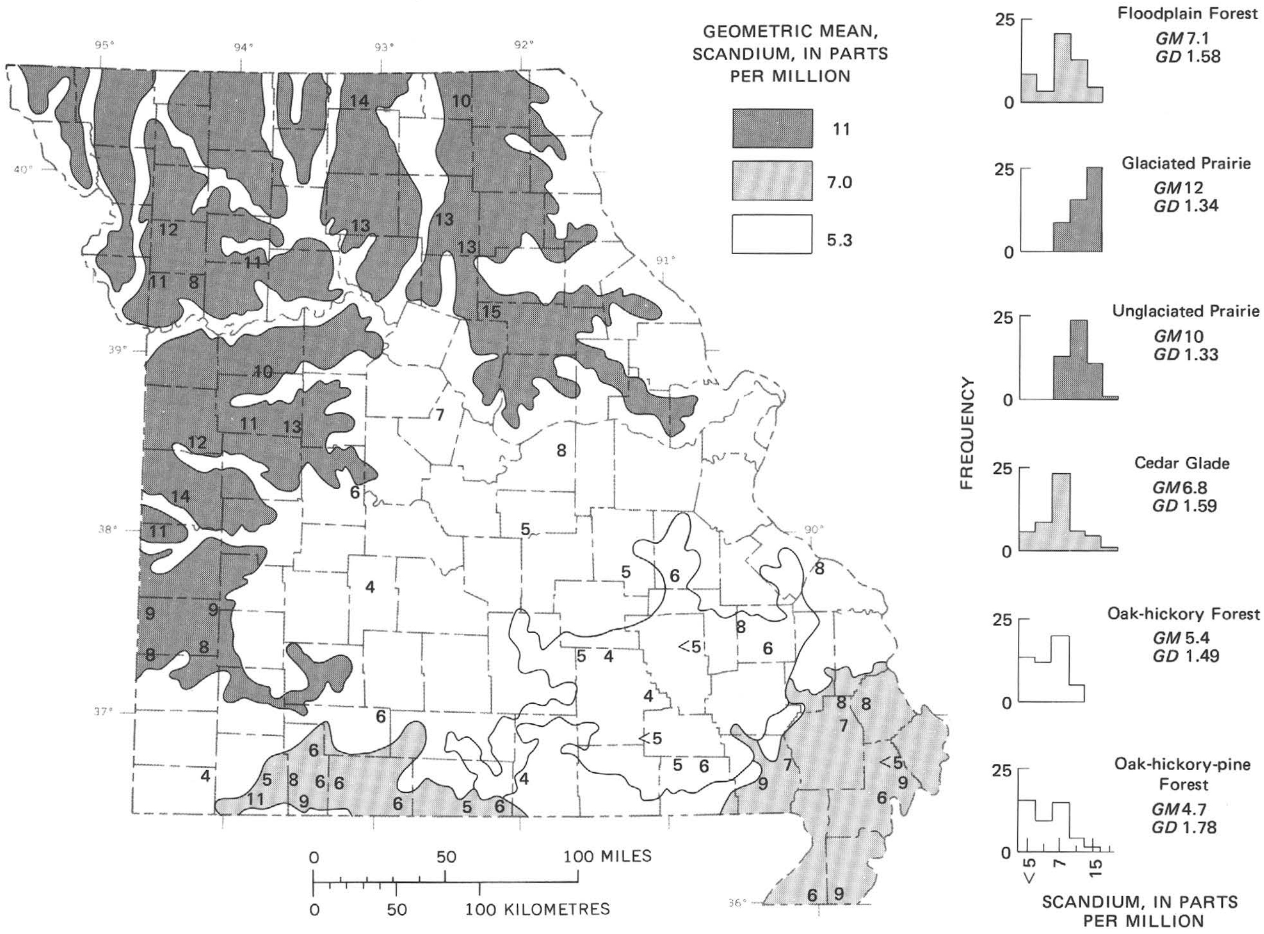


FIGURE 32.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of scandium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of scandium in five samples from a 7½-minute quadrangle.

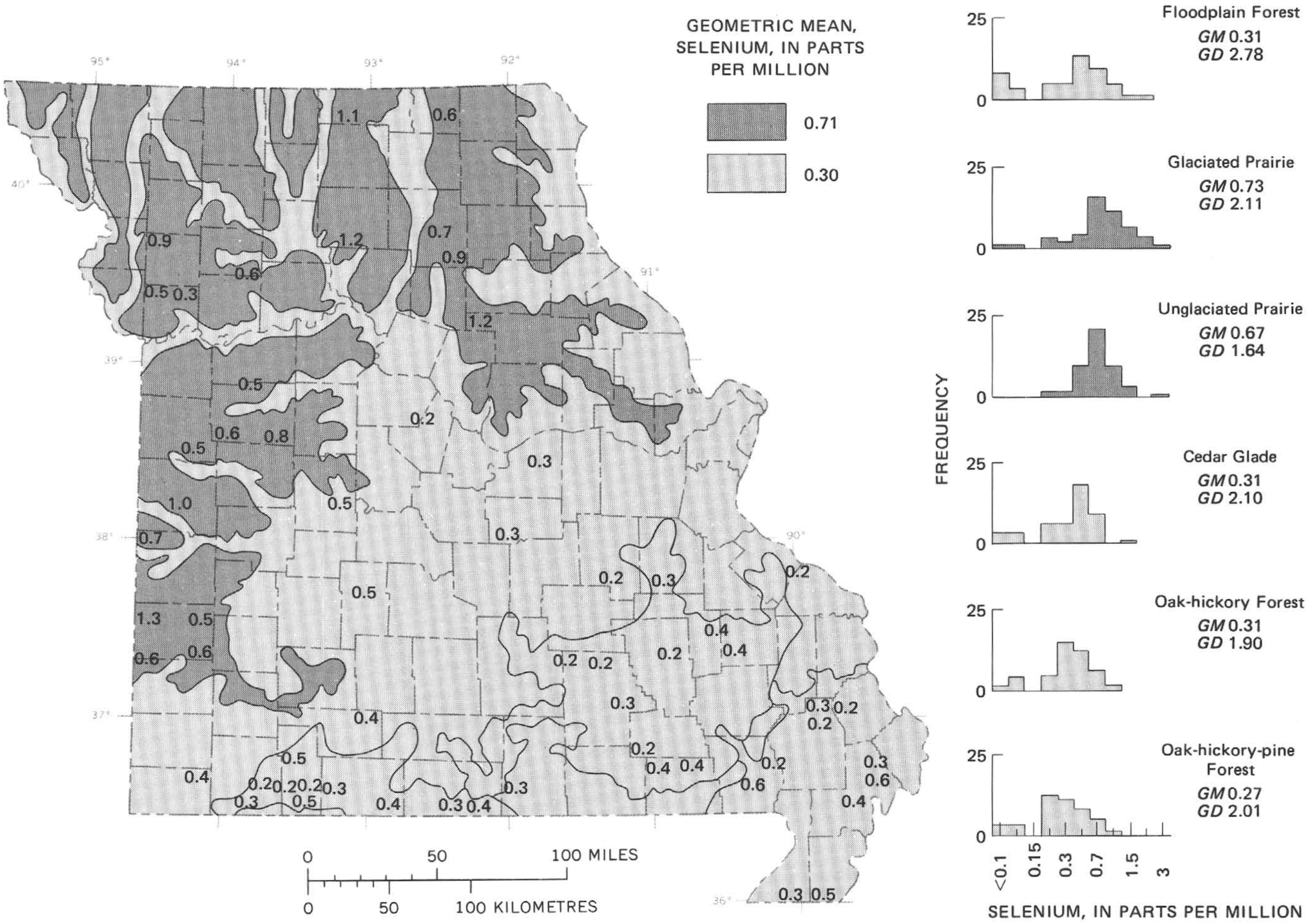


FIGURE 33.—Vegetation-type areas (modified from Küchler, 1964) according to average concentration of selenium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of selenium in five samples from a 7½-minute quadrangle.

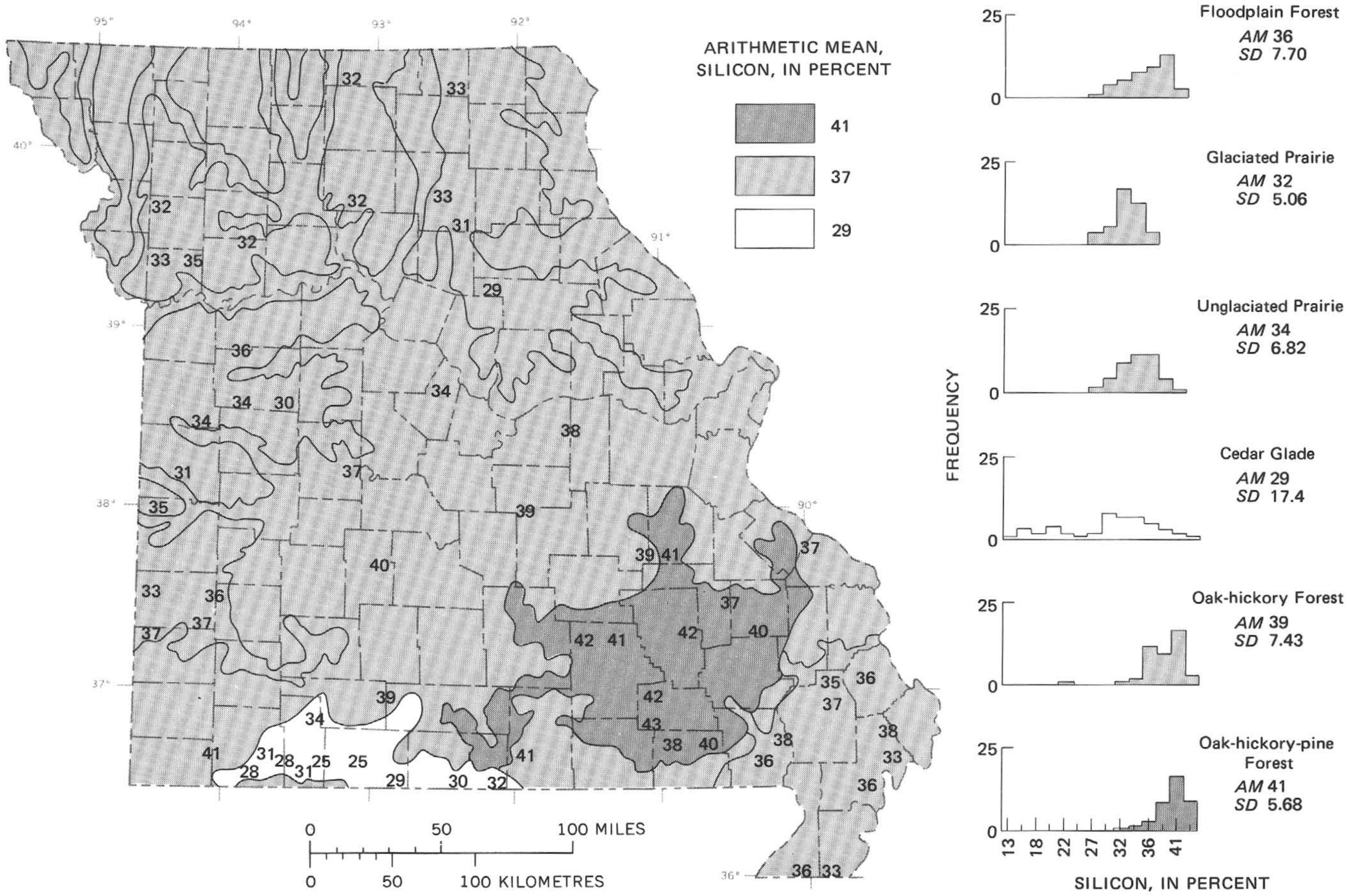


FIGURE 34.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of silicon in uncultivated soils from Missouri. Each number on the map is the arithmetic mean concentration of silicon in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

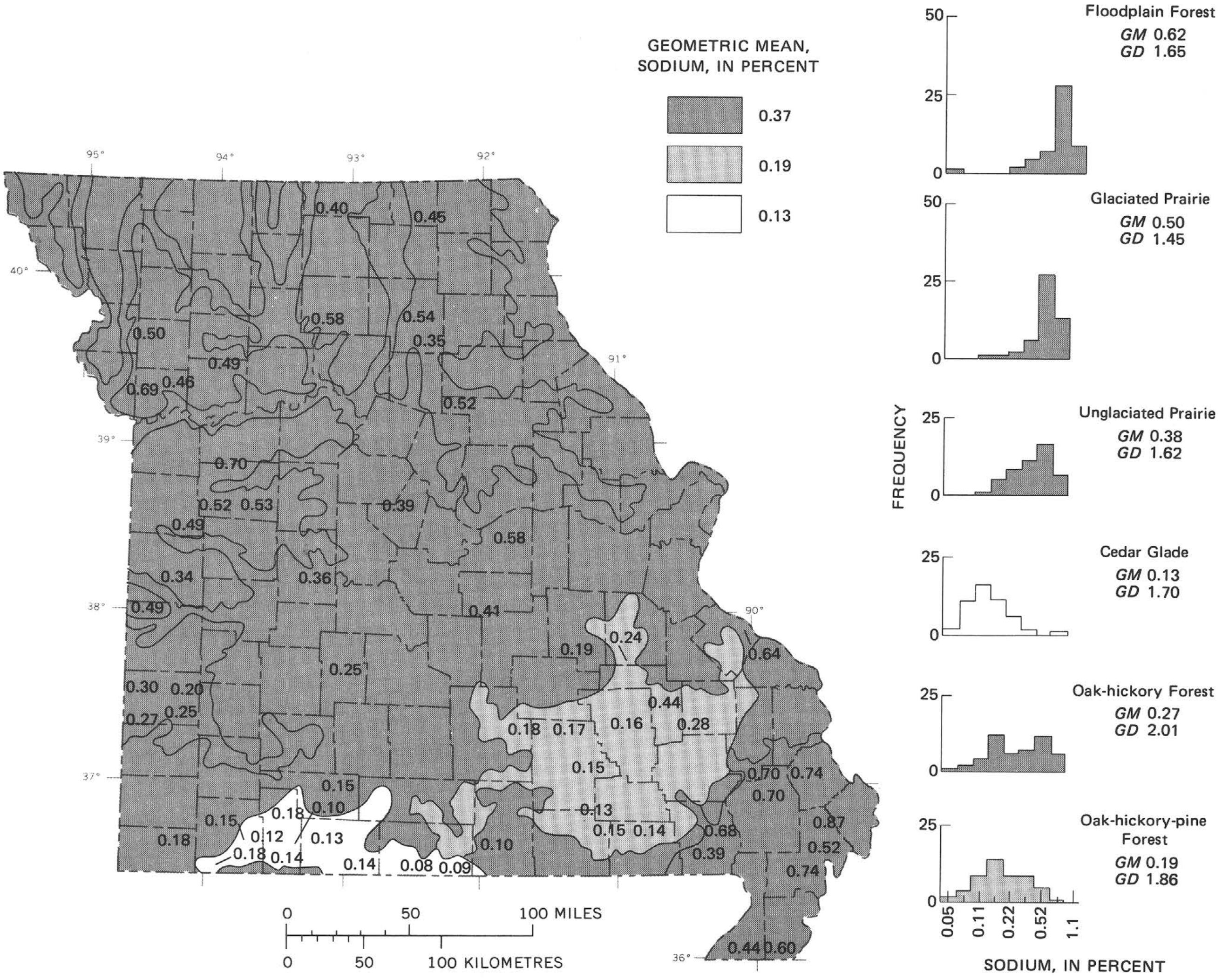


FIGURE 35.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of sodium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of sodium in five samples from a 7½-minute quadrangle.

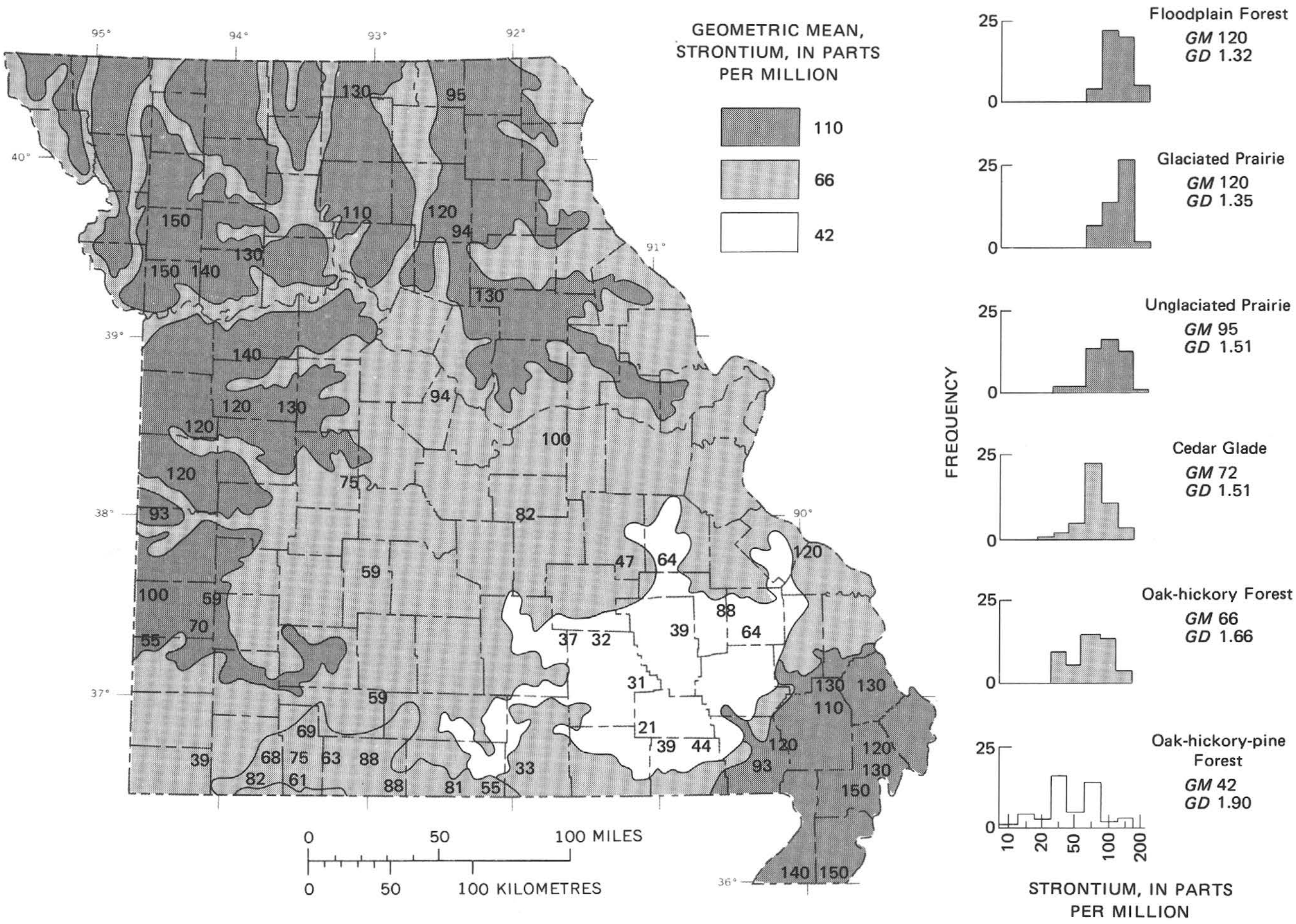


FIGURE 36.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of strontium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of strontium in five samples from a 7½-minute quadrangle.

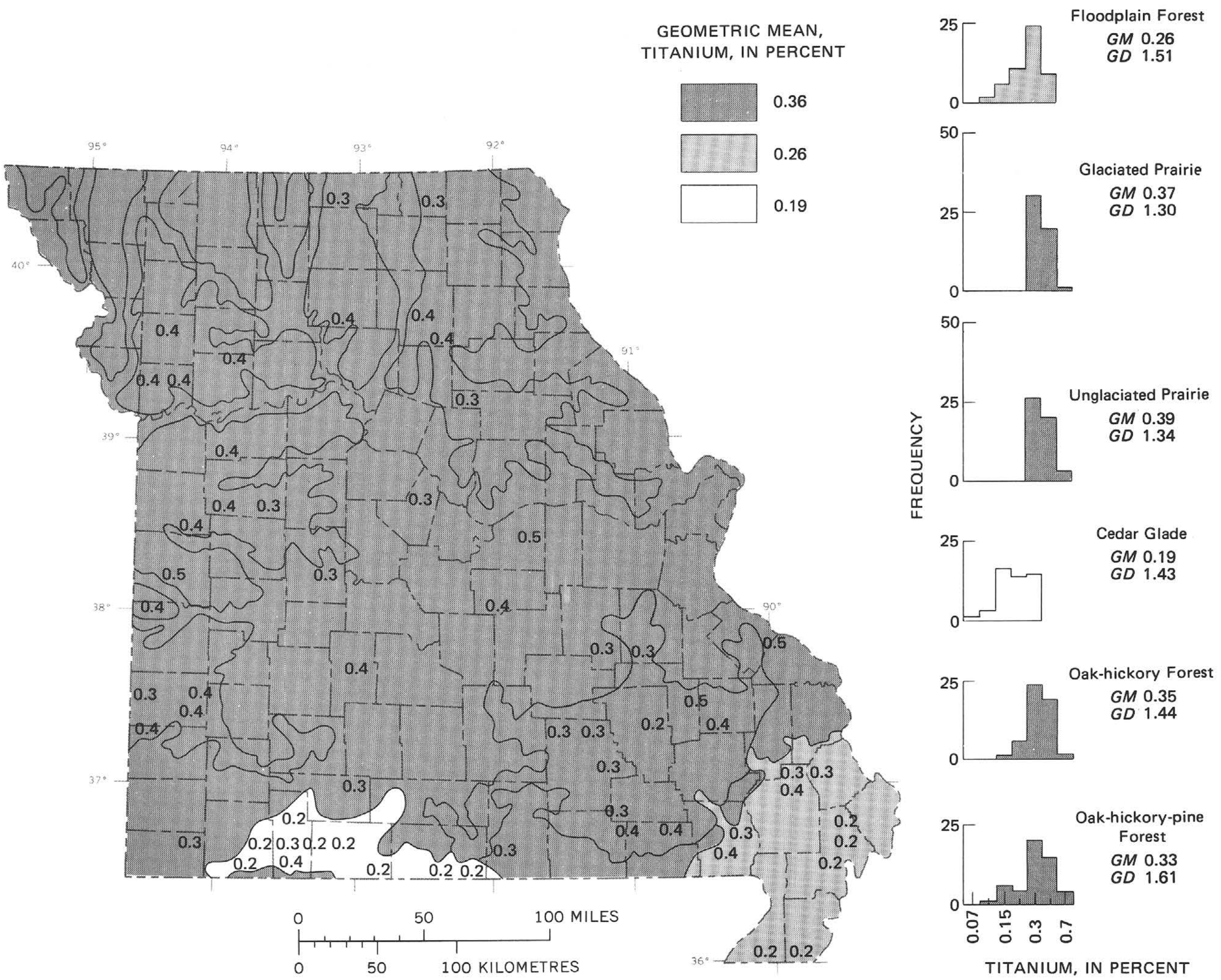


FIGURE 37.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of titanium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of titanium in five samples from a 7½-minute quadrangle.

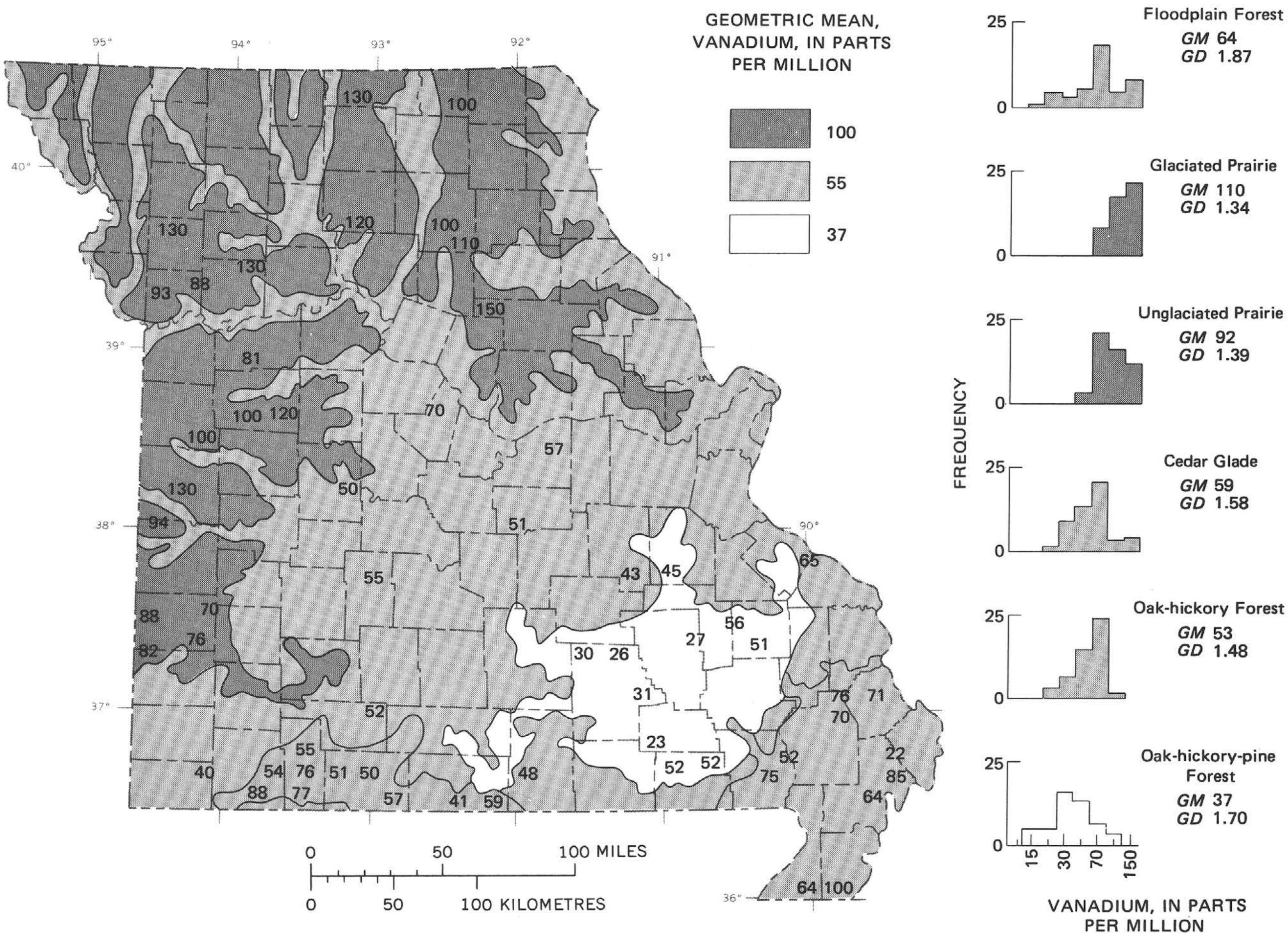


FIGURE 38.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of vanadium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of vanadium in five samples from a 7½-minute quadrangle.

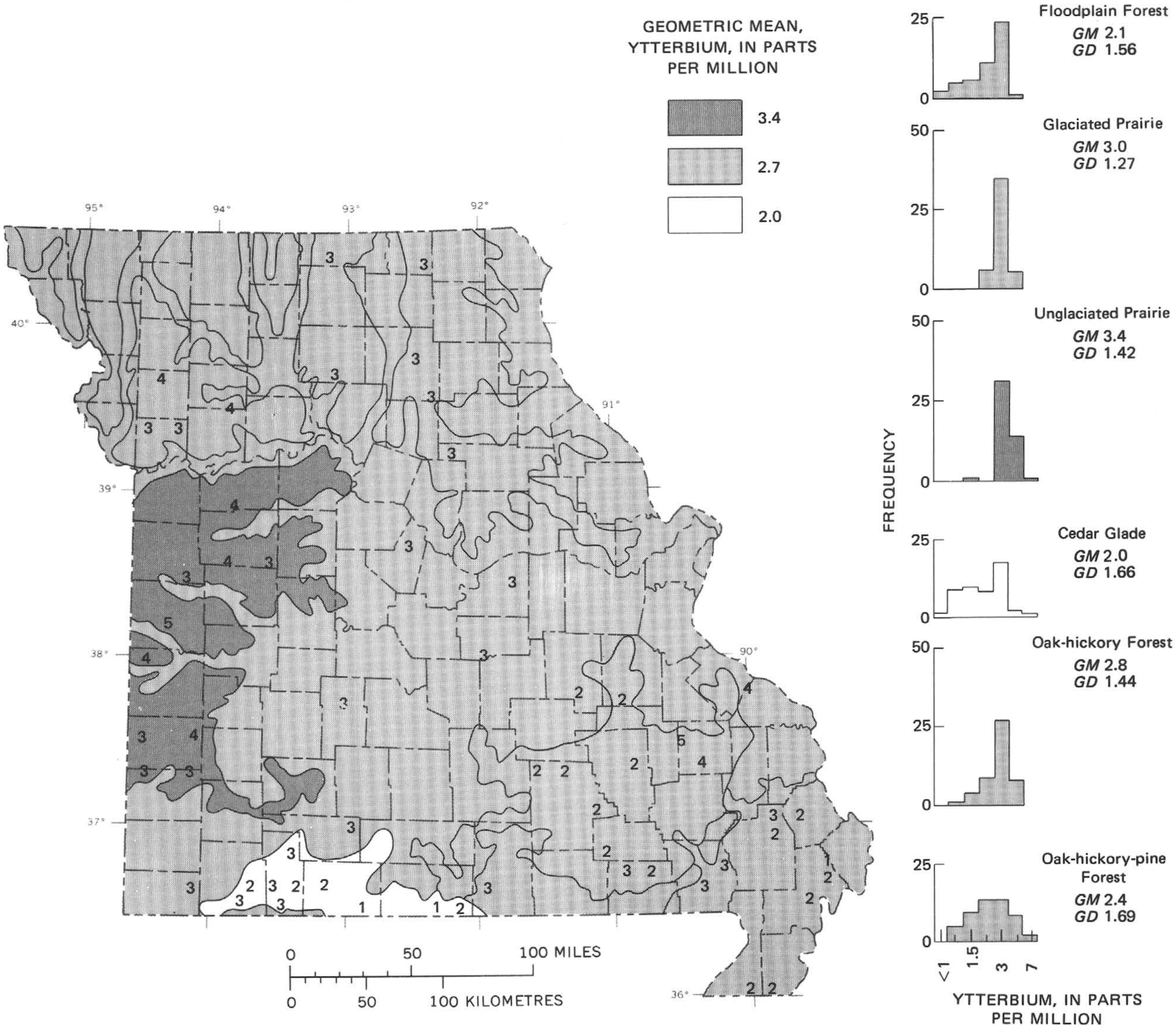


FIGURE 39.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of ytterbium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of ytterbium in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

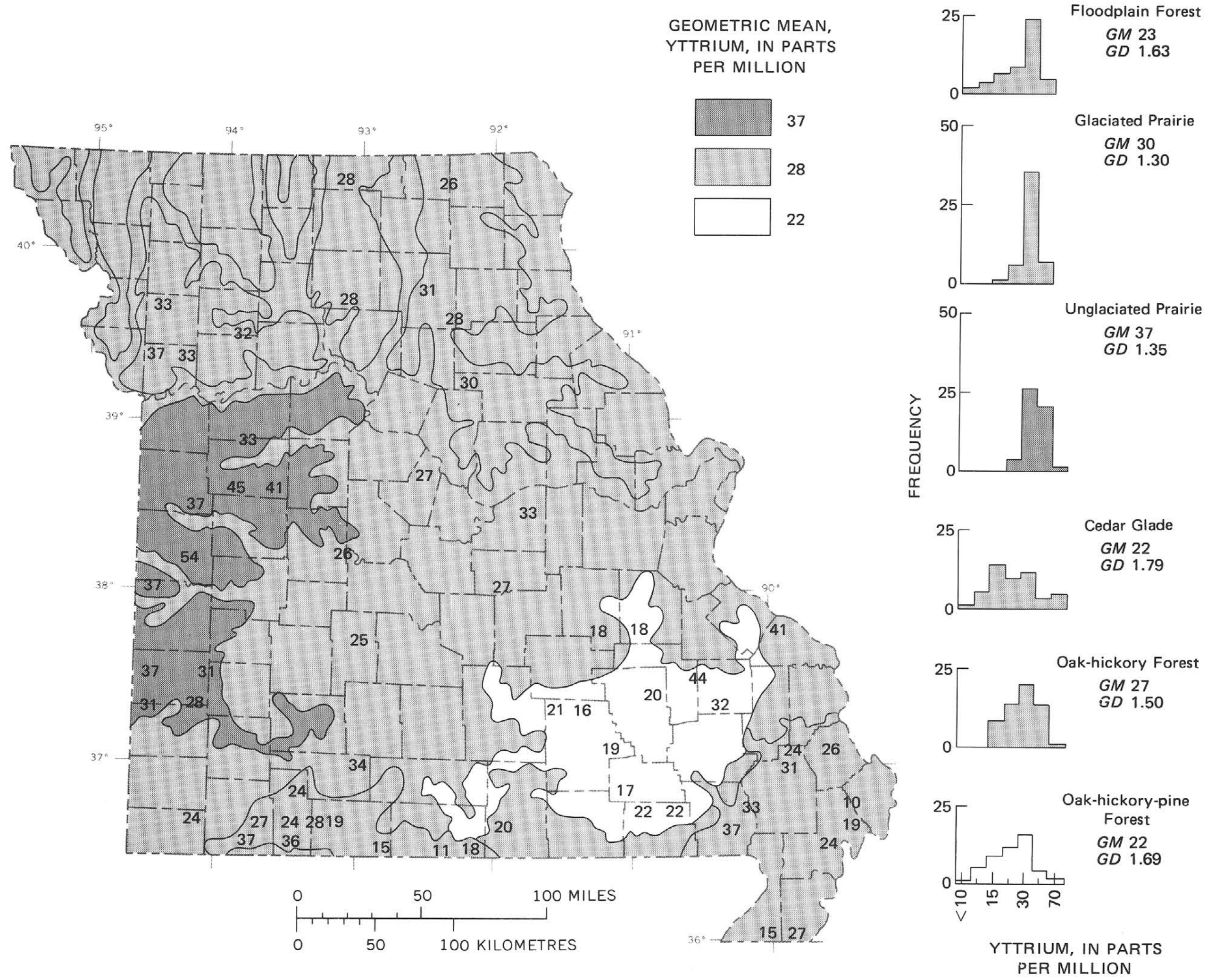


FIGURE 40.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of yttrium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of yttrium in five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are signigicantly different.

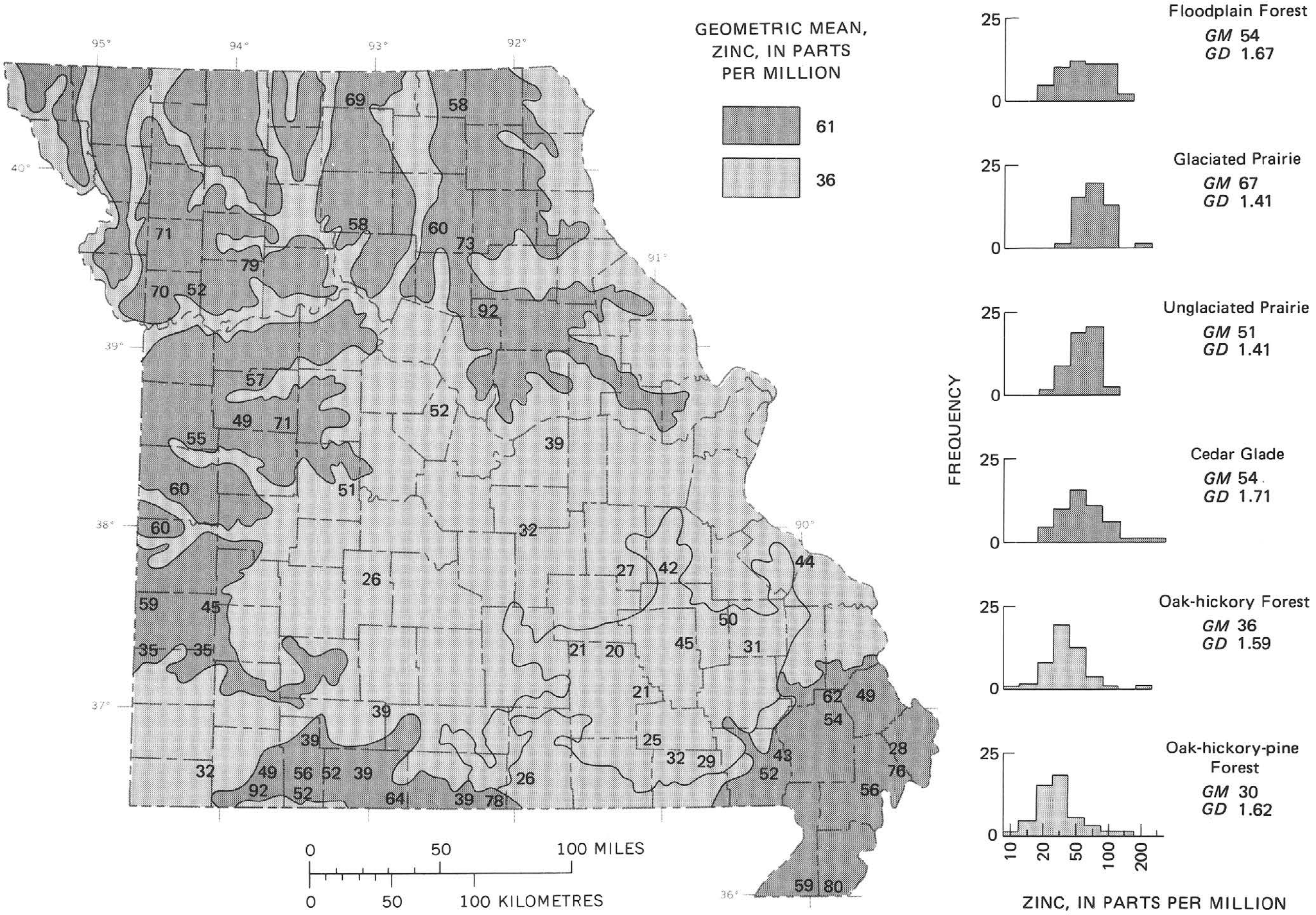


FIGURE 41.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of zinc in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of zinc in five samples from a 7½-minute quadrangle.

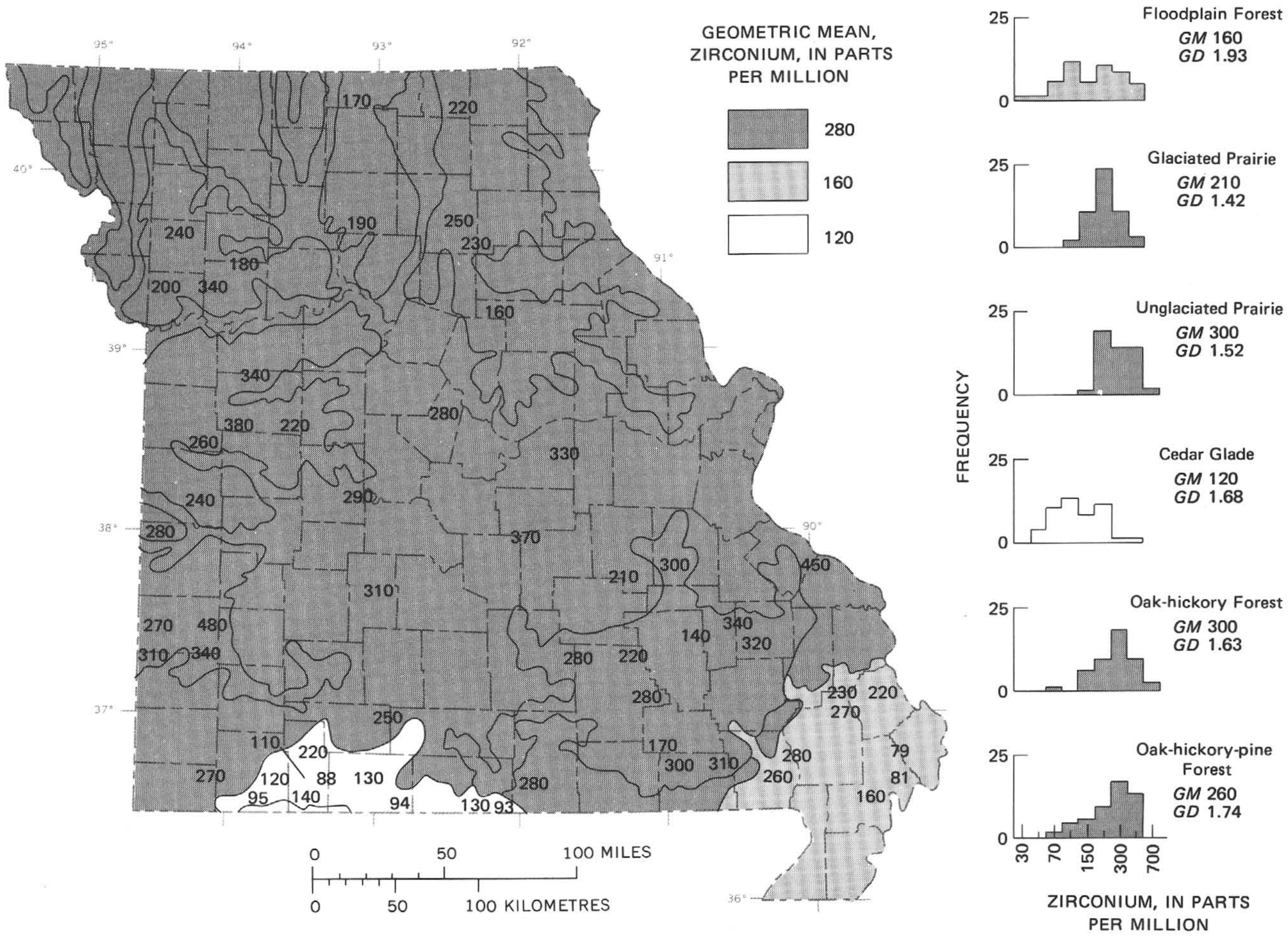


FIGURE 42.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of zirconium in uncultivated soils from Missouri. Each number on the map is the geometric mean concentration of zirconium in five samples from a 7½-minute quadrangle.

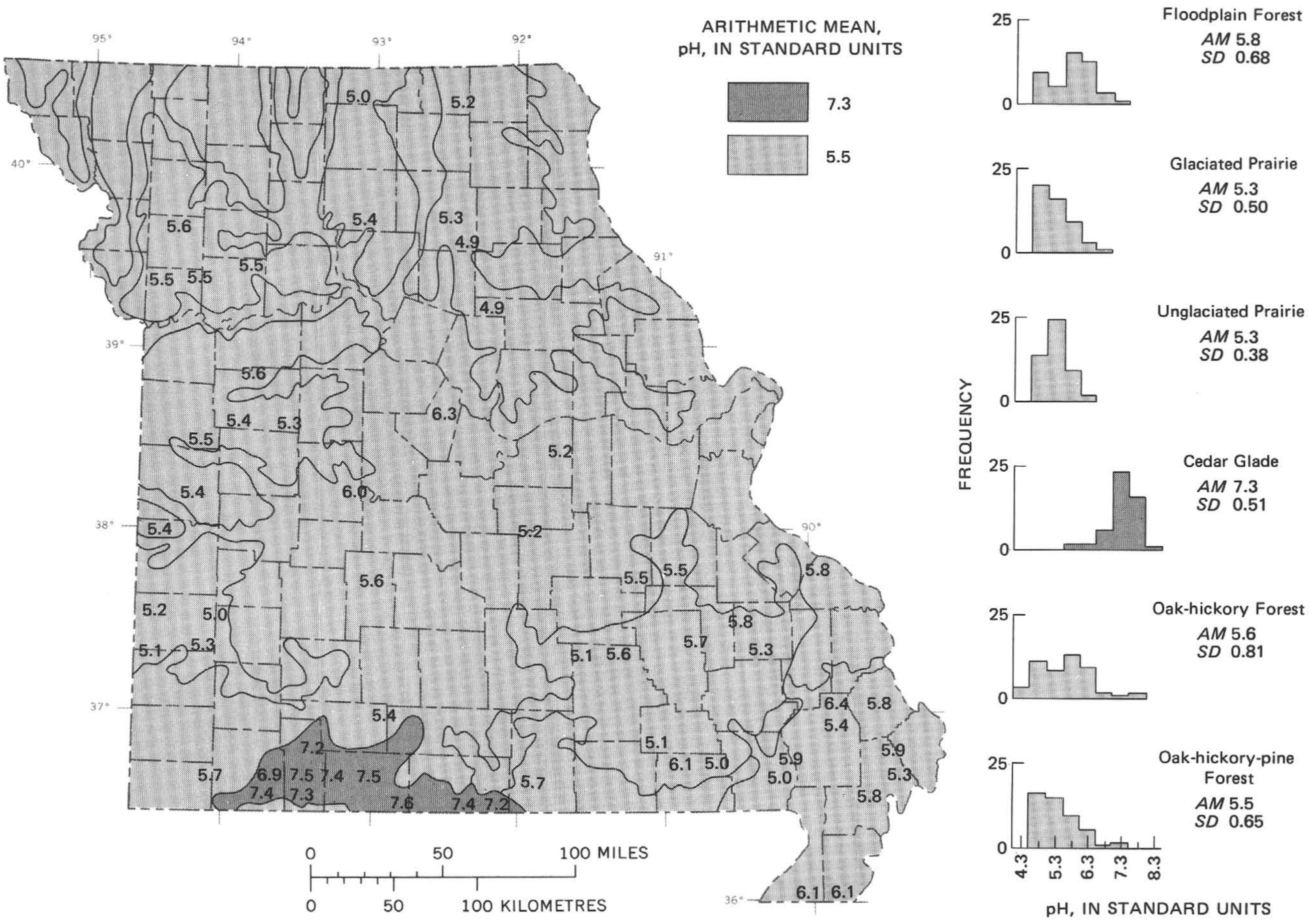


FIGURE 43.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of pH standard units in uncultivated soils from Missouri. Each number on the map is the arithmetic mean concentration of pH standard units in five samples from a 7½-minute quadrangle.

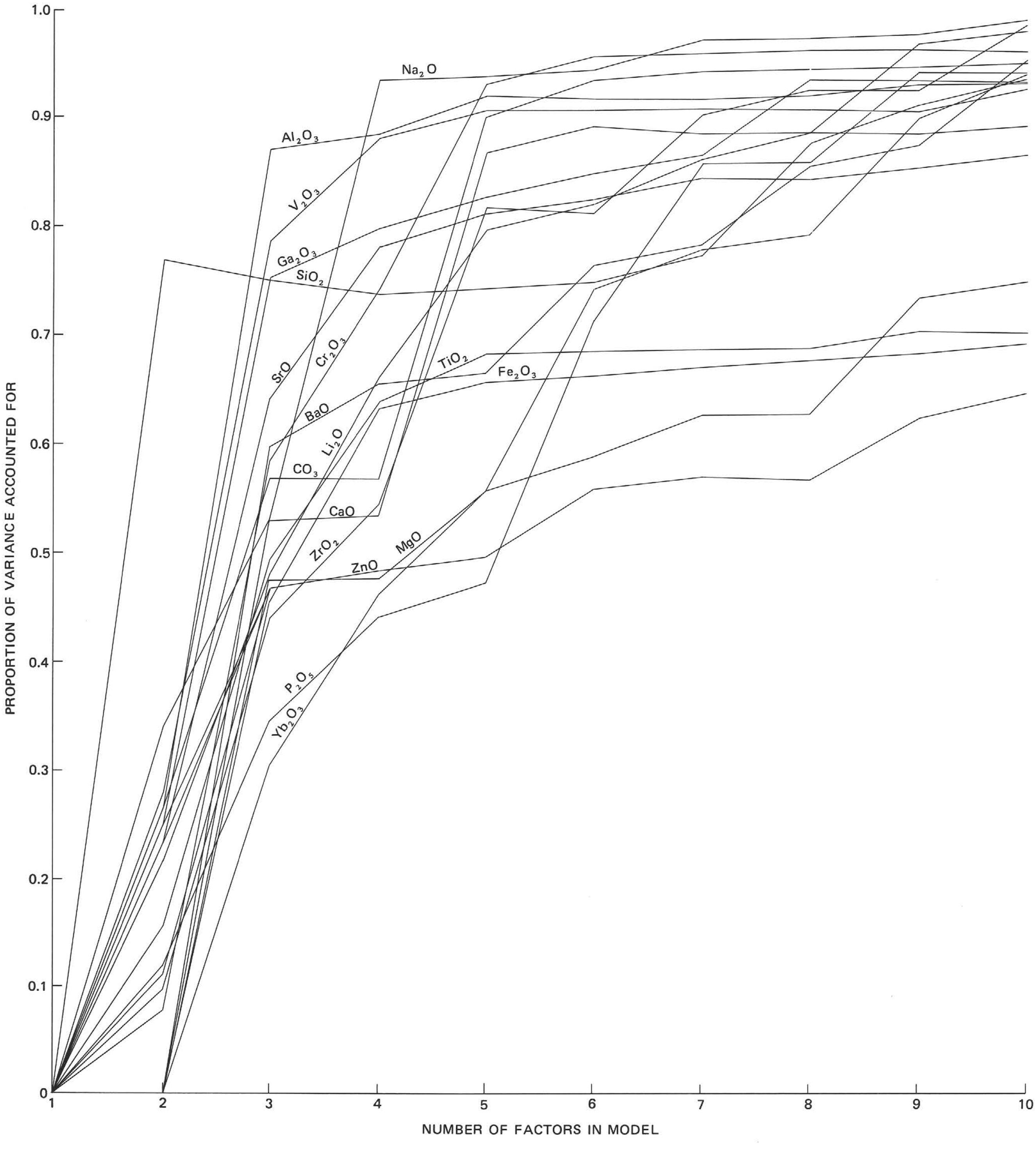


FIGURE 44.—Factor variance diagram for uncultivated soils of Missouri.

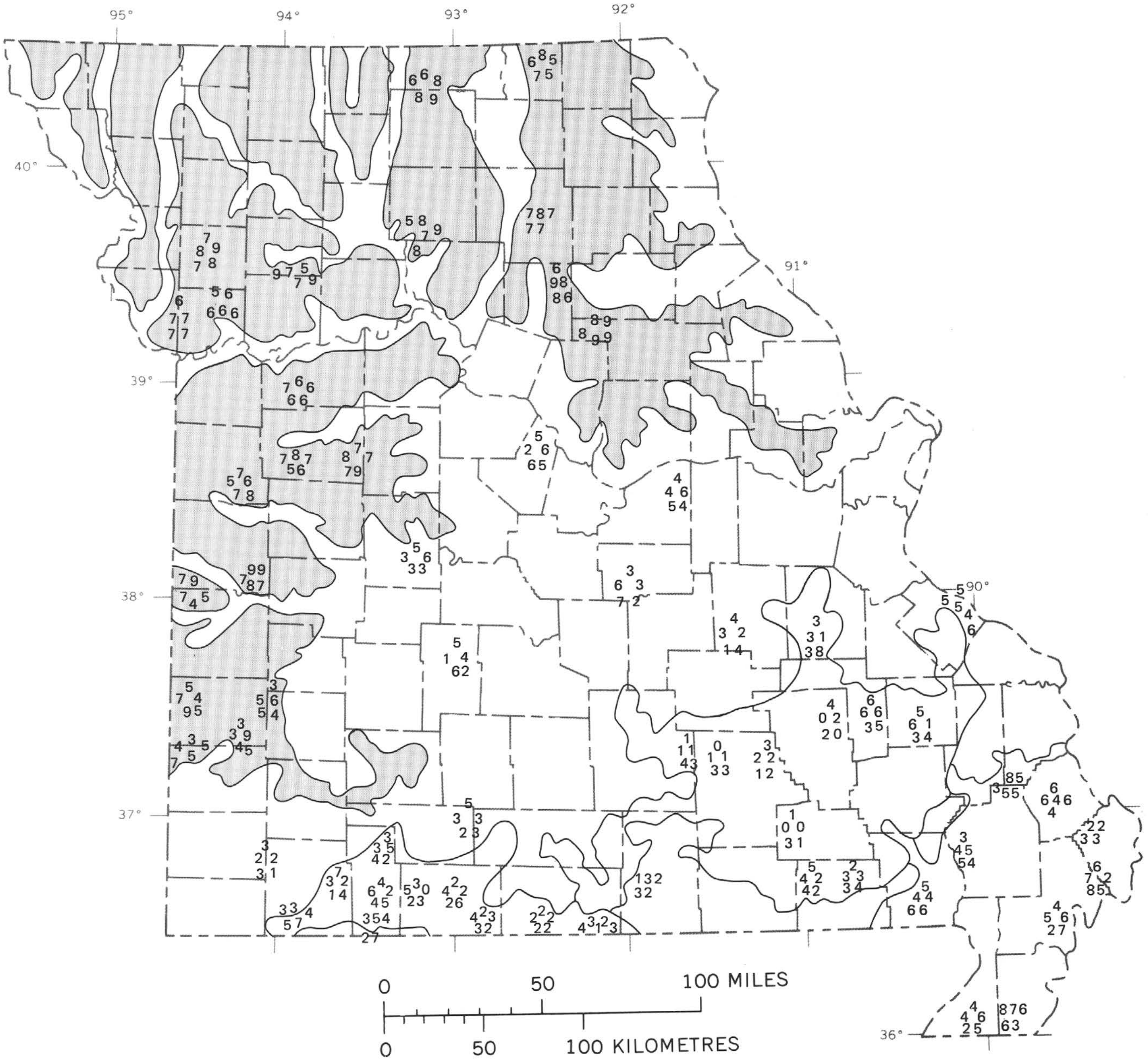


FIGURE 45.—Dominance of alumina-rich parent materials in soils, as indicated by composition loadings based on soil chemistry, in vegetation-type areas of Missouri (modified from Küchler, 1964). Loadings (a_{i1}x −100), shown as figures on the map, generally are highest in the prairie areas (shaded).

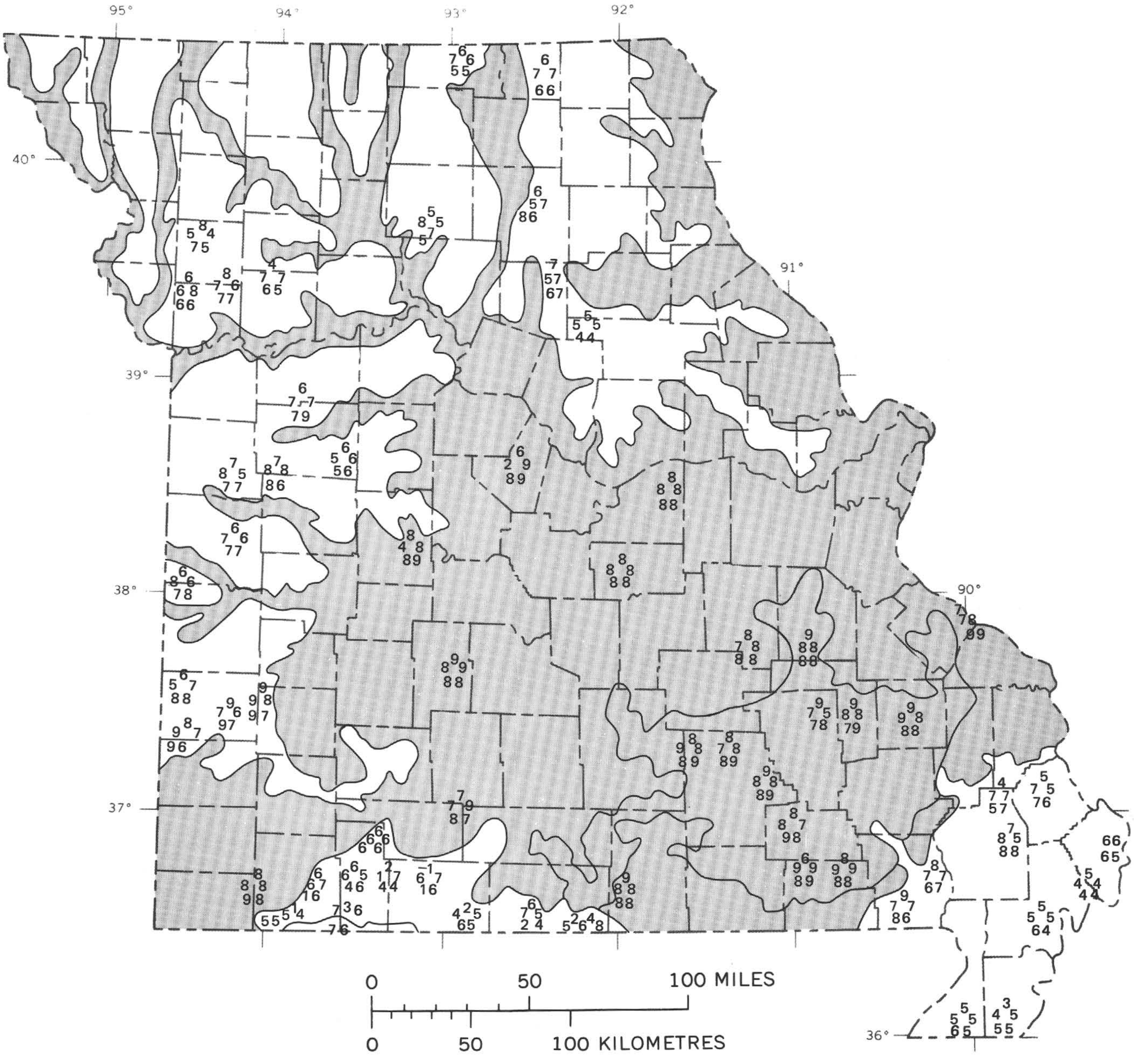


FIGURE 46.—Dominance of quartz sand parent material in soils, as indicated by composition loadings based on soil chemistry, in vegetation-type areas of Missouri (modified from Küchler, 1964). Loadings (a_{i2}x10), shown as figures on the map, generally are highest in the Oak-hickory Forest and Oak-hickory-pine Forest areas (shaded).

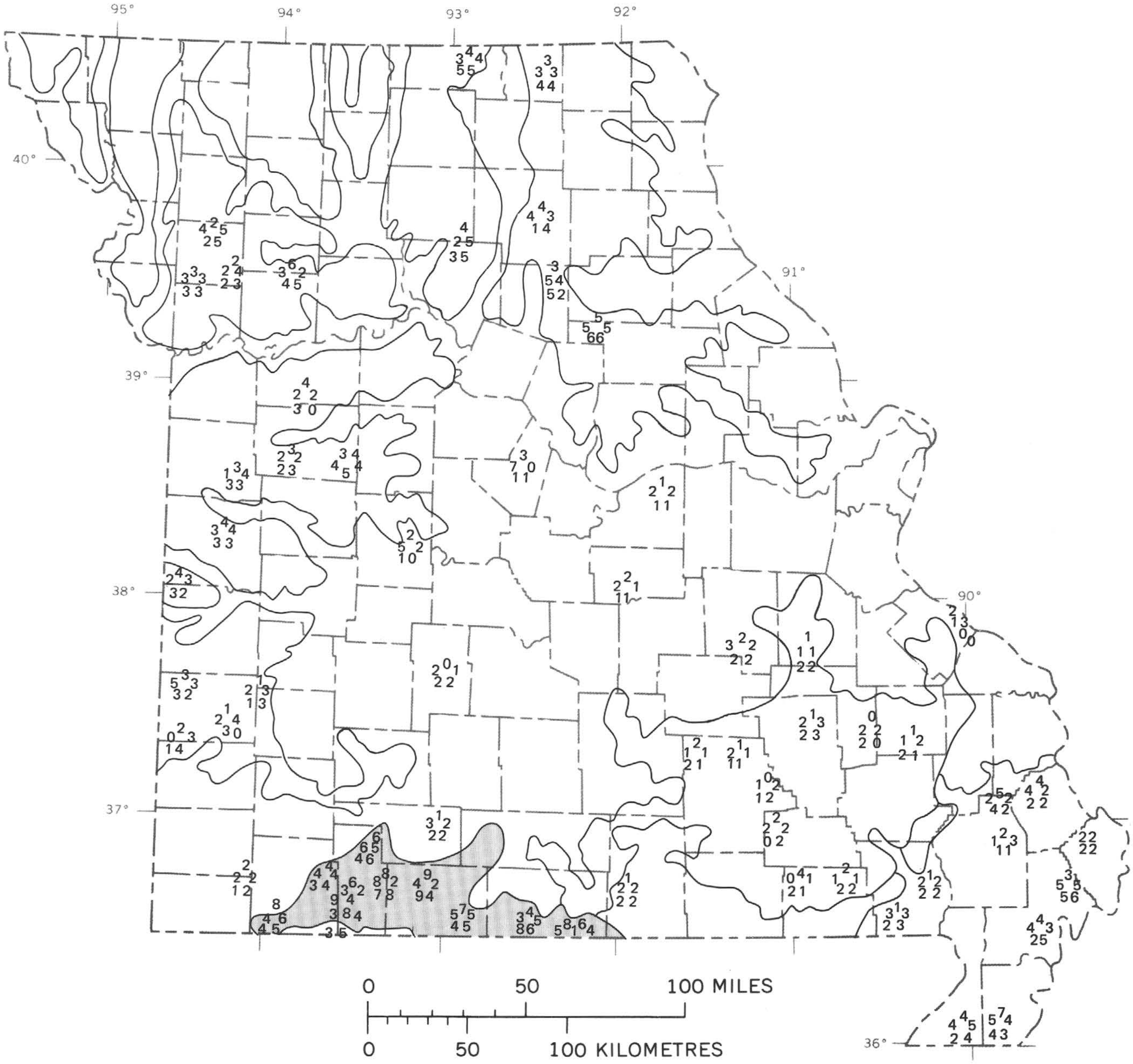


FIGURE 47.—Dominance of carbonate parent material in soils, as indicated by composition loadings based on soil chemistry, in vegetation-type areas of Missouri (modified from Küchler, 1964). Loadings (a_{i3}x10), shown as figures on the map, generally are highest in the Cedar Glade area (shaded).

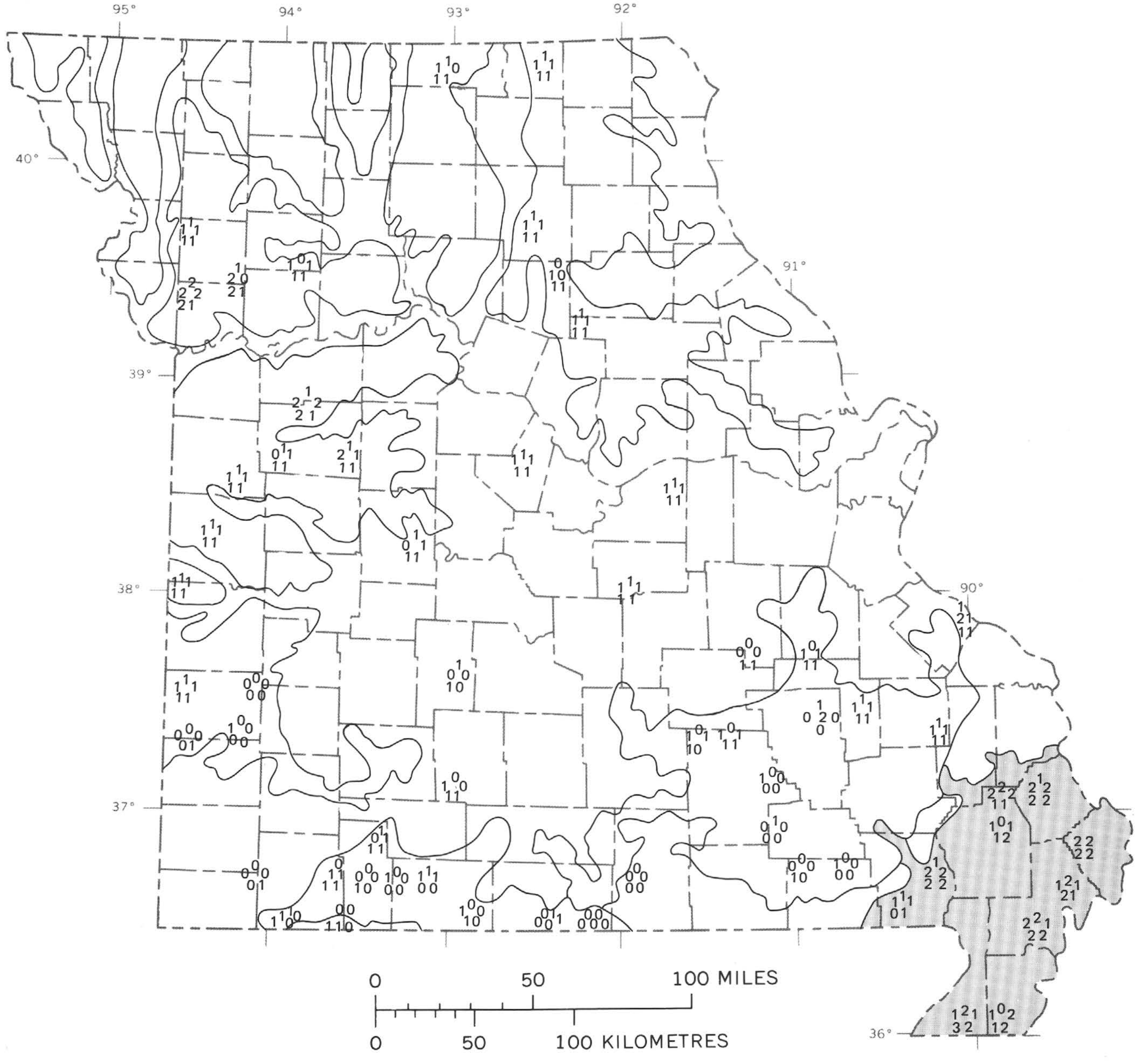


FIGURE 48.—Dominance of feldspathic sand facies in soils, as indicated by composition loadings based on soil chemistry, in vegetation-type areas of Missouri (modified from Küchler, 1964). Loadings (a_{i4}x10), shown as figures on the map, generally are highest in the Floodplain Forest area (shaded).

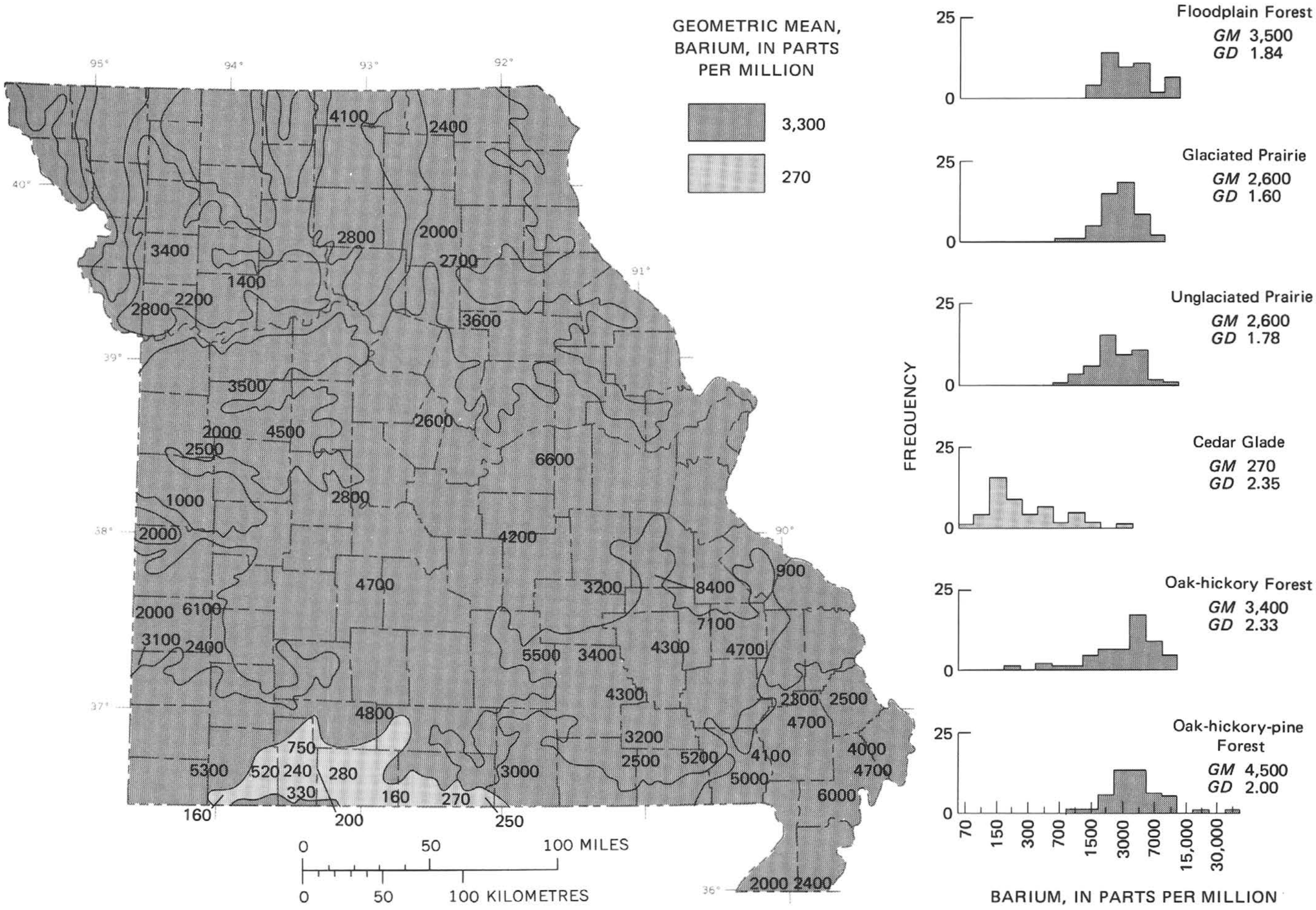


FIGURE 49.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of barium in sumac from Missouri. Each number on the map is the geometric mean concentration of barium in generally five samples from a 7½-minute quadrangle.

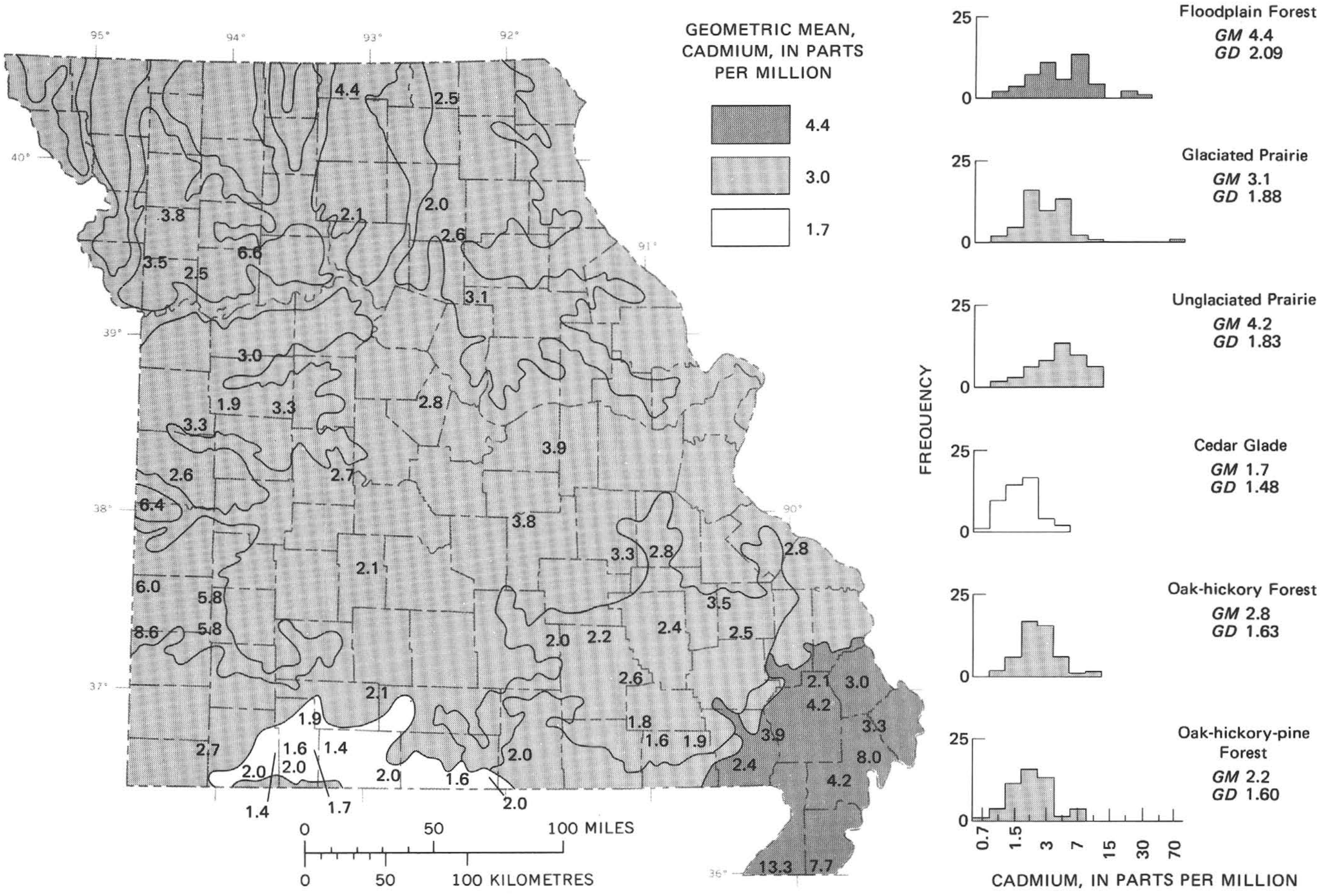


FIGURE 50.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of cadmium in sumac from Missouri. Each number on the map is the geometric mean concentration of cadmium in generally five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

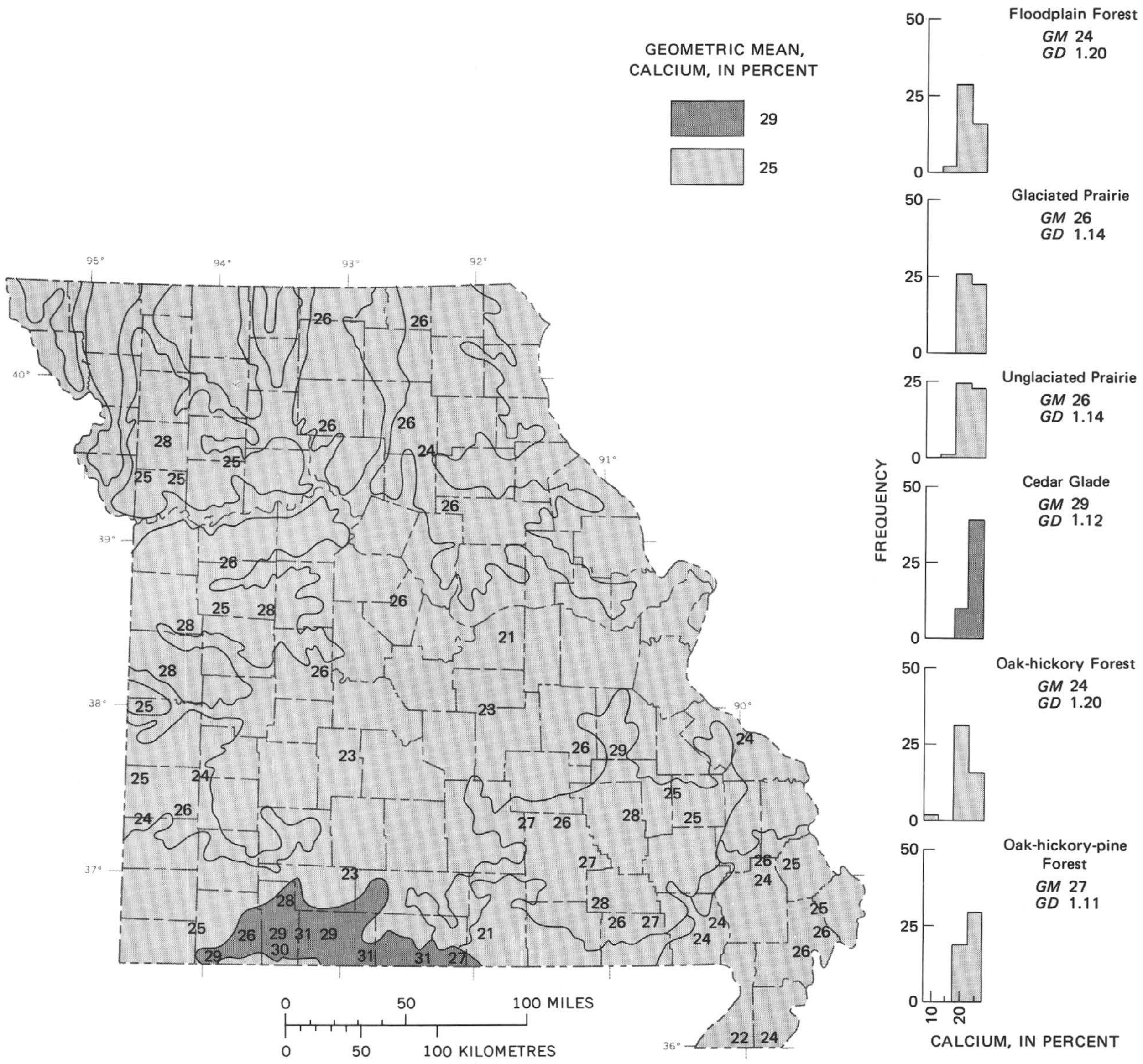


FIGURE 51.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of calcium in sumac from Missouri. Each number on the map is the geometric mean concentration of calcium in generally five samples from a 7½-minute quadrangle.

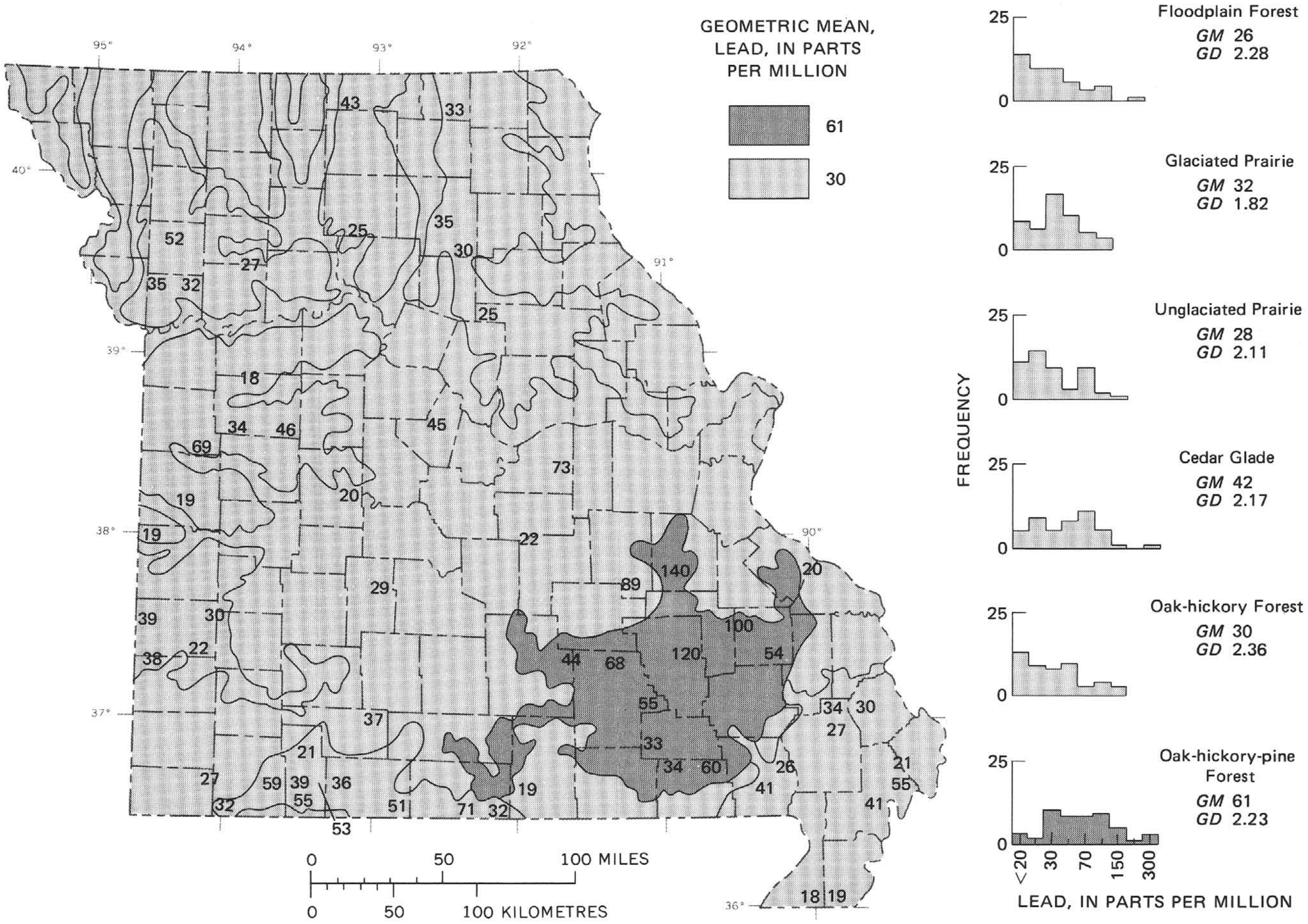


FIGURE 52.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of lead in sumac from Missouri. Each number on the map is the geometric mean concentration of lead in generally five samples from a 7½-minute quadrangle.

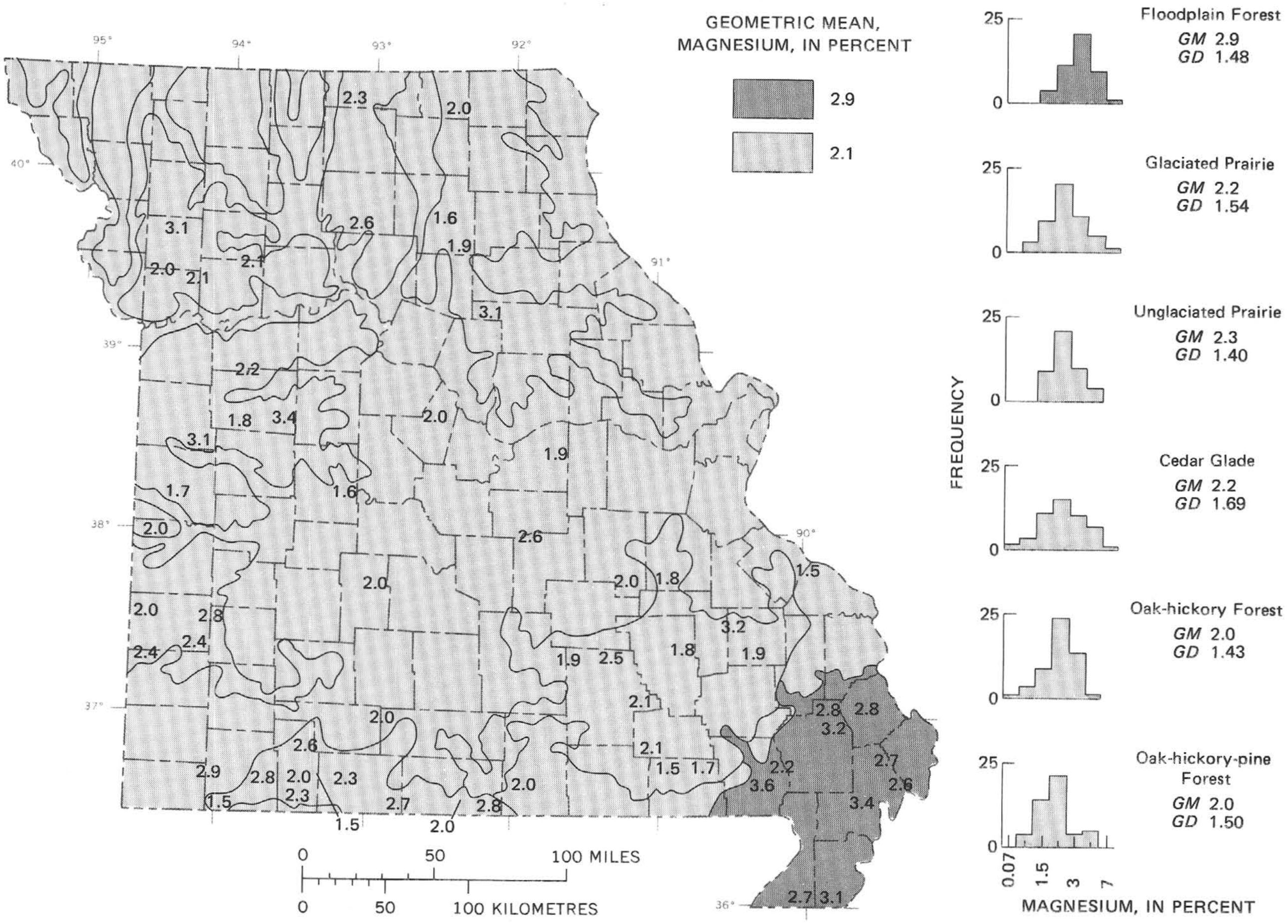


FIGURE 53.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of magnesium in sumac from Missouri. Each number on the map is the geometric mean concentration of magnesium in generally five samples from a 7½-minute quadrangle.

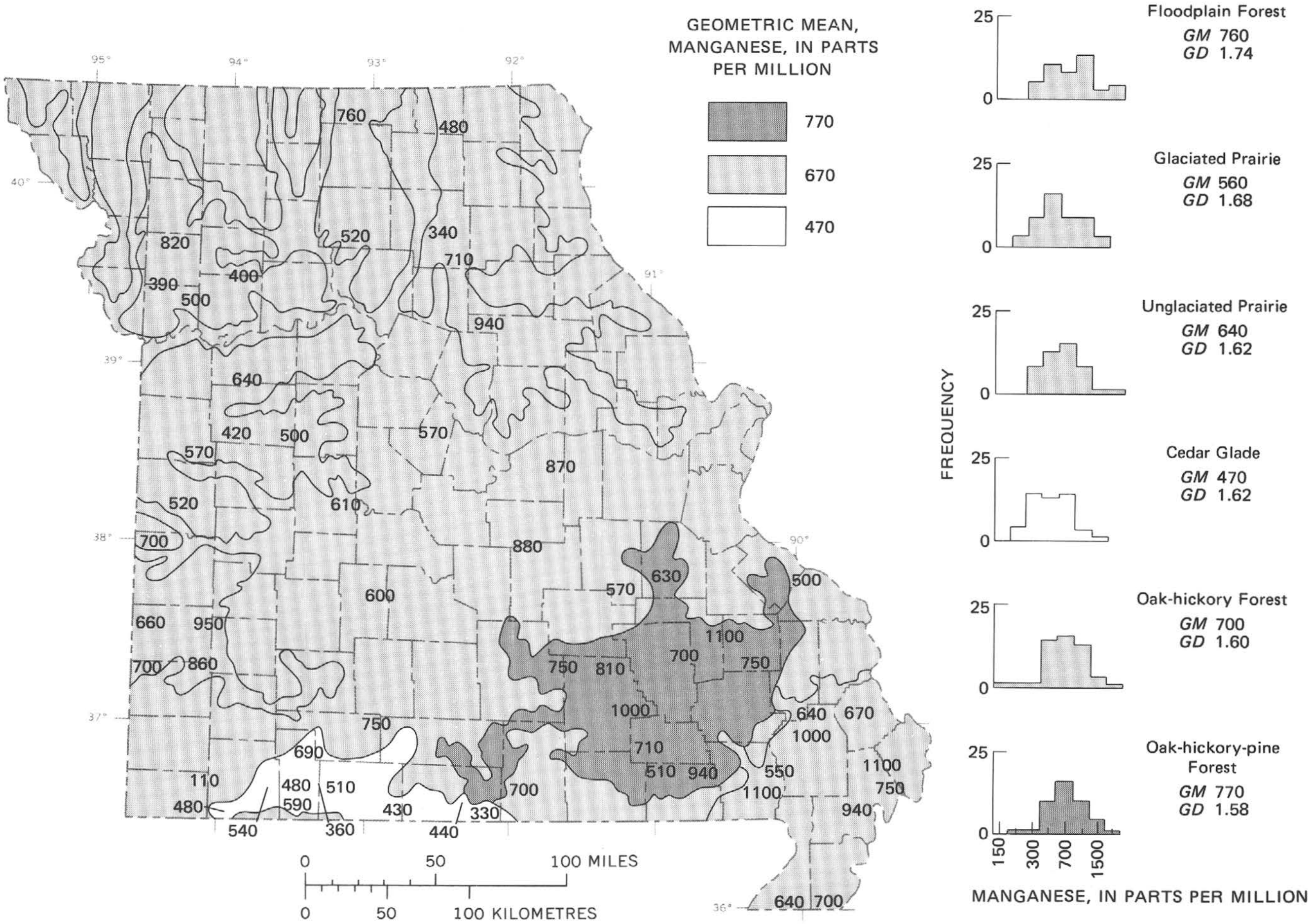


FIGURE 54.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of manganese in sumac from Missouri. Each number on the map is the geometric mean concentration of manganese in generally five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

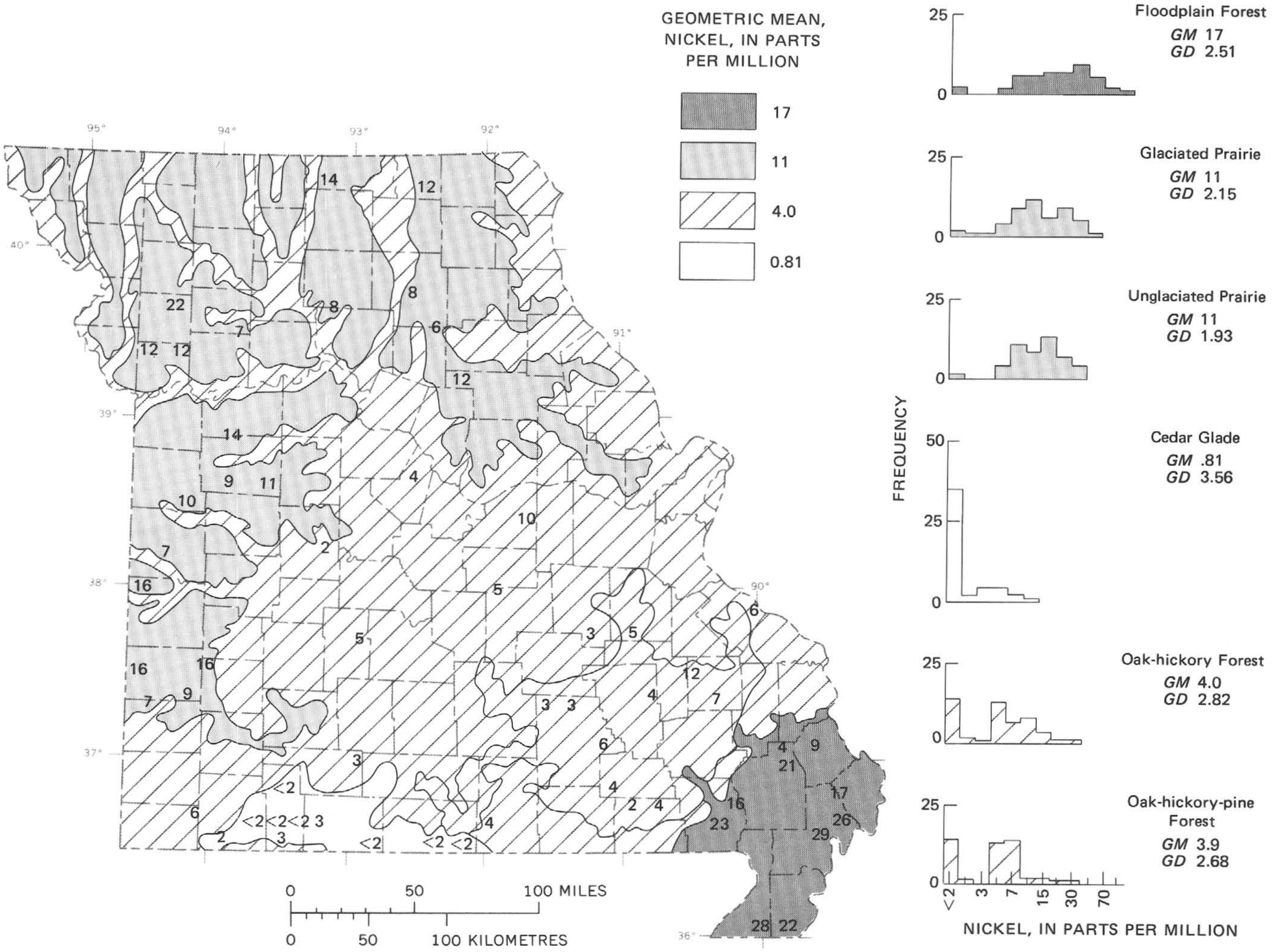


Figure 55.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of nickel in sumac from Missouri. Each number on the map is the geometric mean concentration of nickel in generally five samples from a 7½-minute quadrangle.

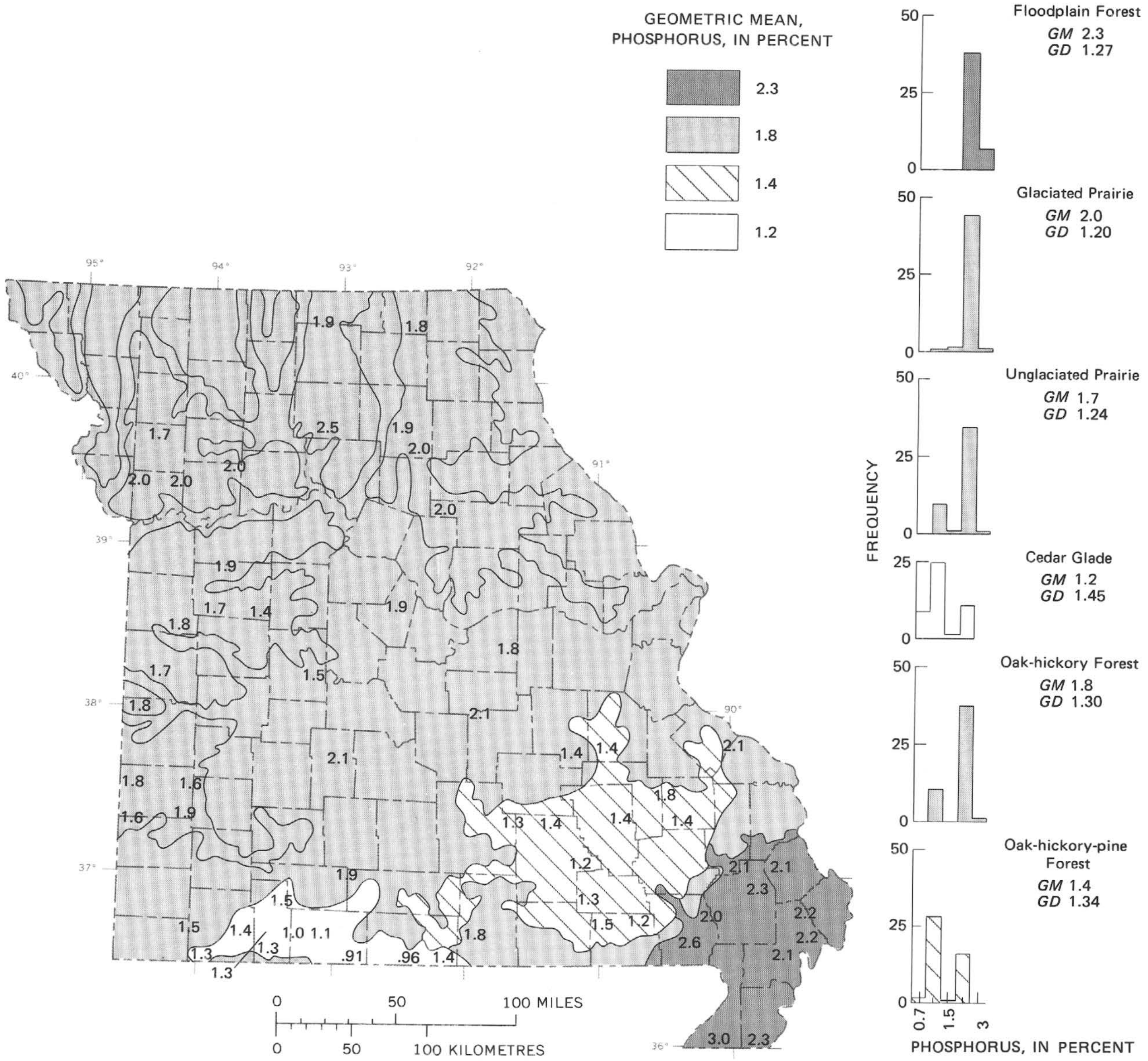


FIGURE 56.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of phosphorus in sumac from Missouri. Each number on the map is the geometric mean concentration of phosphorus in generally five samples from a 7½-minute quadrangle.

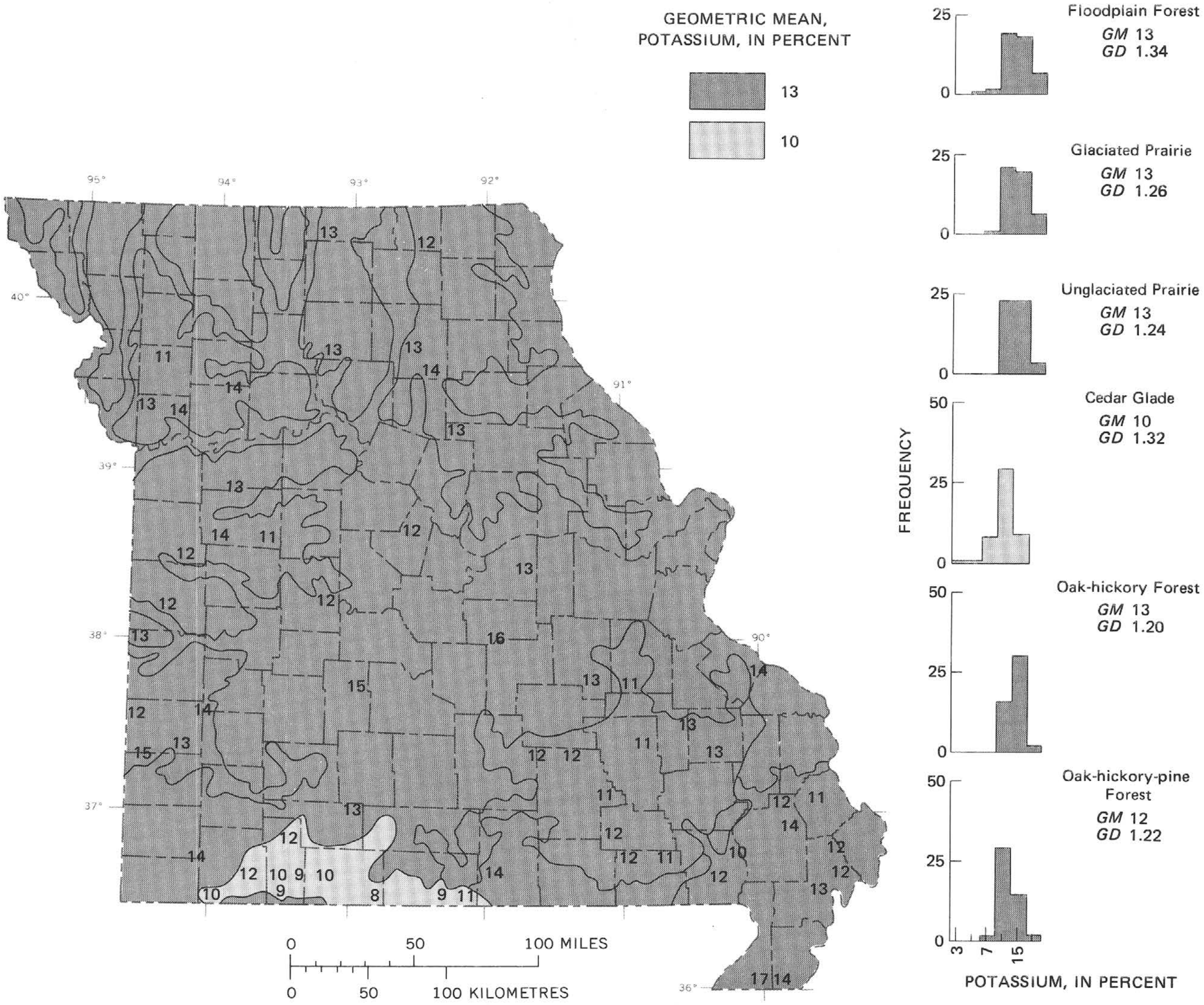


FIGURE 57.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of potassium in sumac from Missouri. Each number on the map is the geometric mean concentration of potassium in generally five samples from a 7½-minute quadrangle.

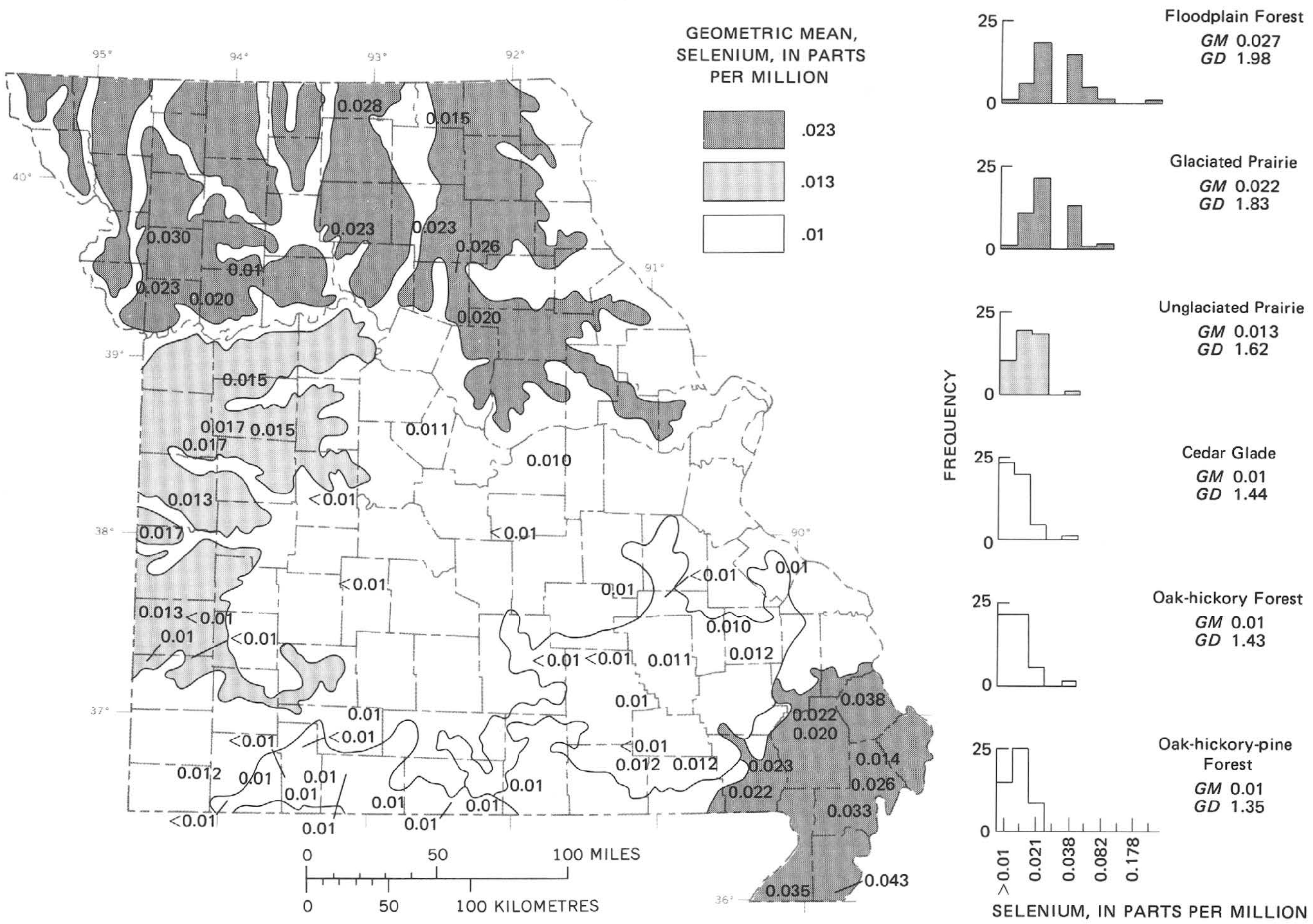


FIGURE 58.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of selenium in sumac from Missouri. Each number on the map is the geometric mean concentration of selenium in generally five samples from a 7½-minute quadrangle.

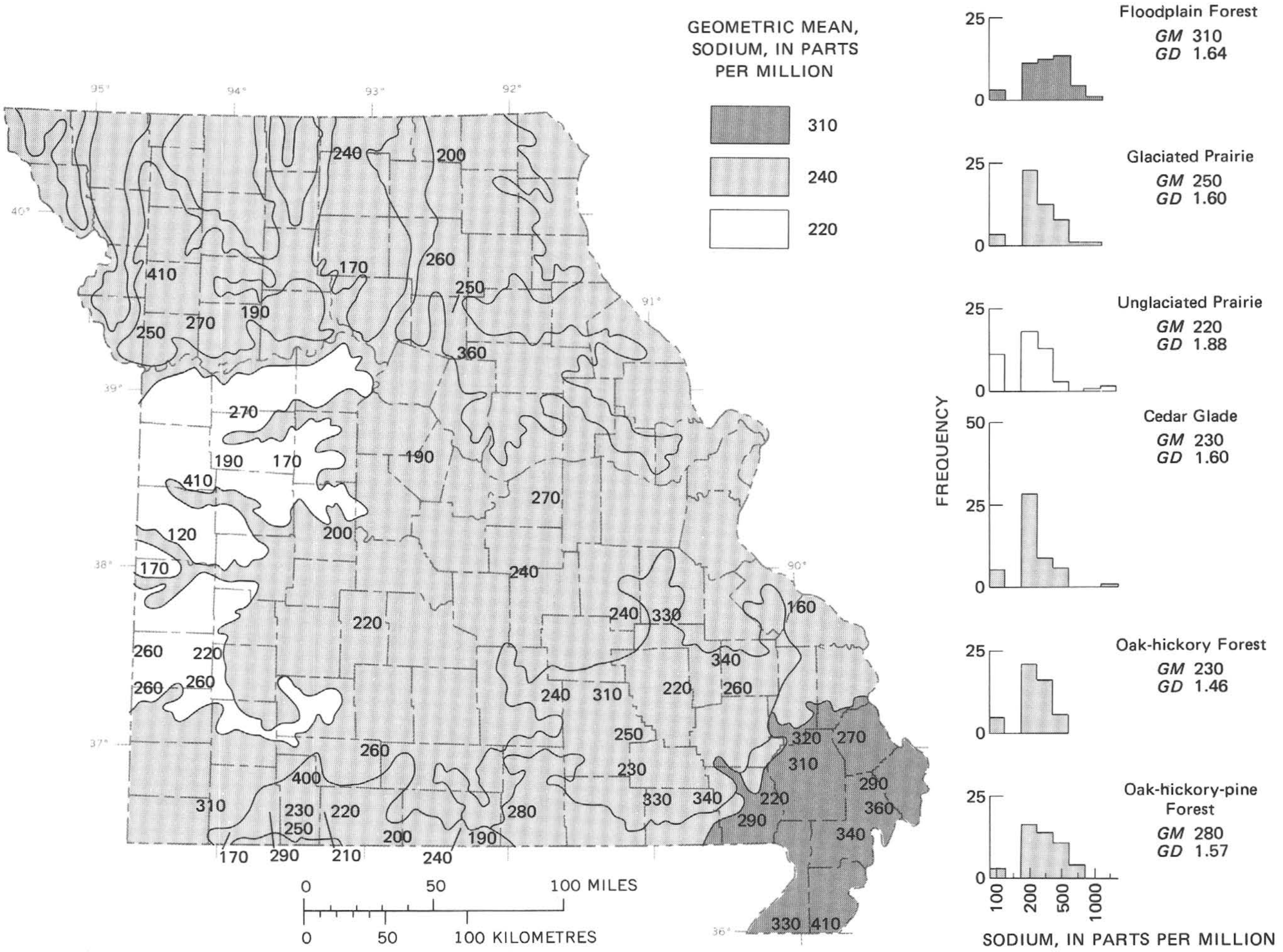


FIGURE 59.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of sodium in sumac from Missouri. Each number on the map is the geometric mean concentration of sodium in generally five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

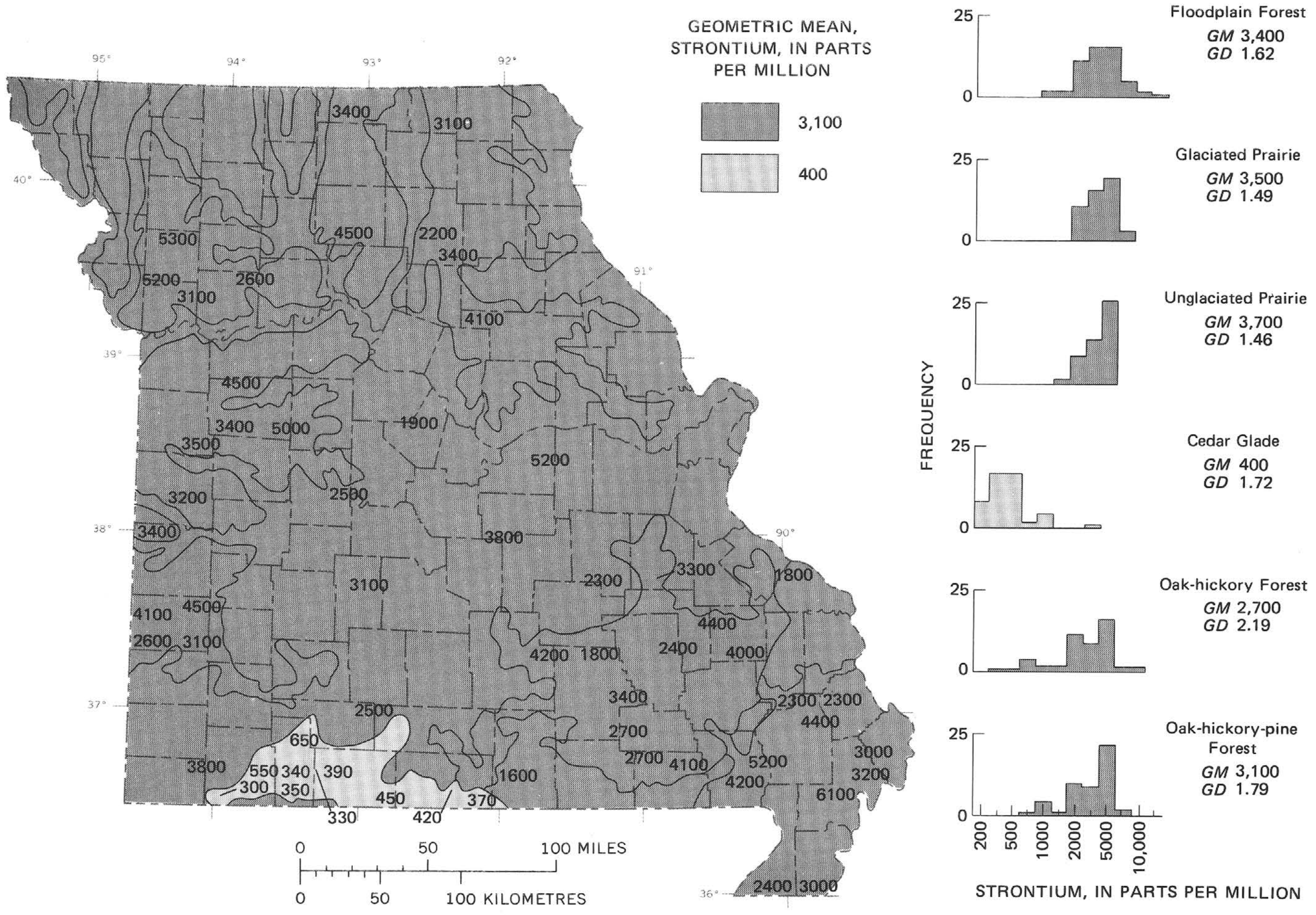


FIGURE 60.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of strontium in sumac from Missouri. Each number on the map is the geometric mean concentration of strontium in generally five samples from a 7½-minute quadrangle.

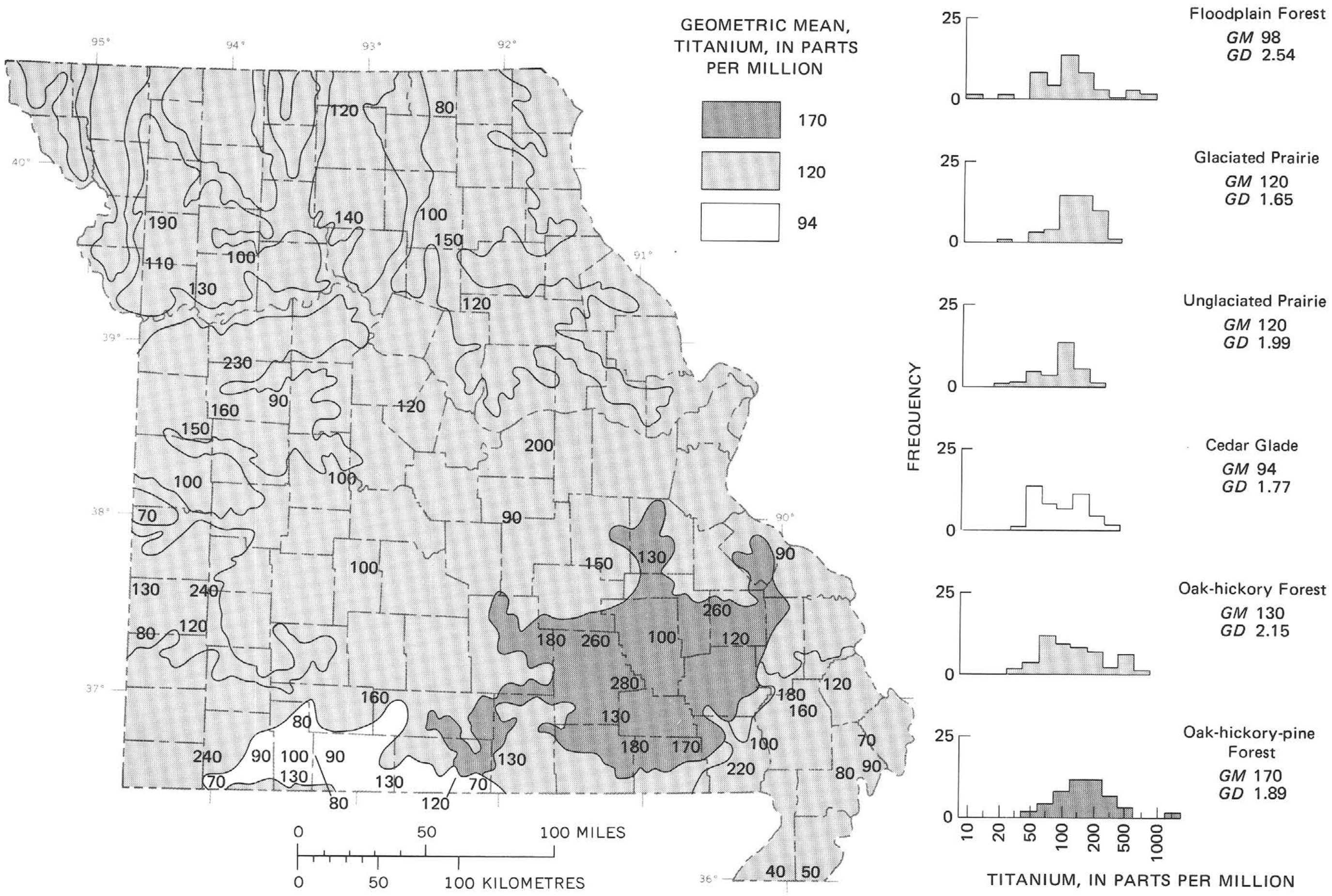


FIGURE 61.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of titanium in sumac from Missouri. Each number on the map is the geometric mean concentration of titanium in generally five samples from a 7½-minute quadrangle. Only areas of high and low mean concentration are significantly different.

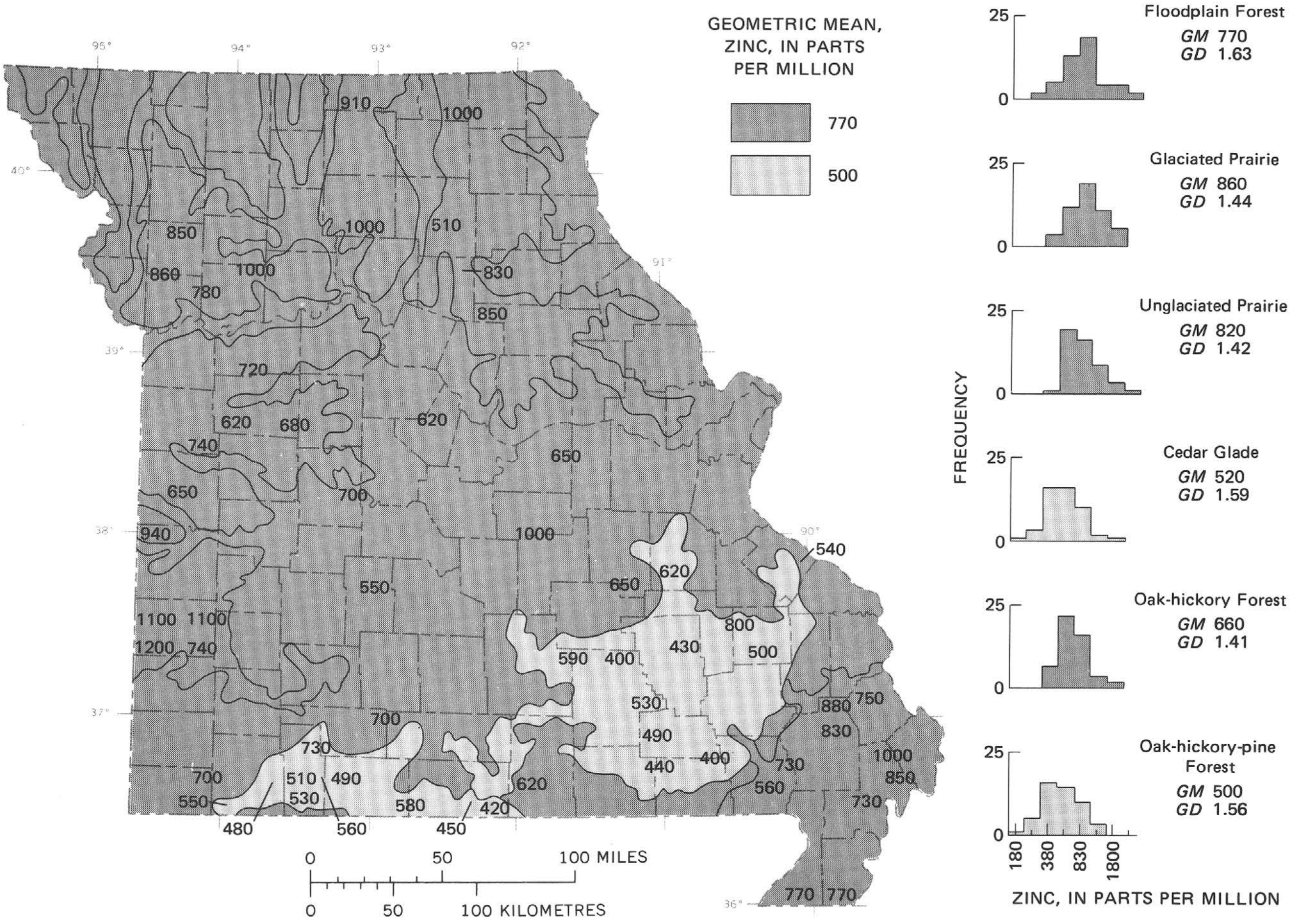


FIGURE 62.—Vegetation-type areas (modified from Küchler, 1964) classified according to average concentration of zinc in sumac from Missouri. Each number on the map is the geometric mean concentration of zinc in generally five samples from a 7½-minute quadrangle.

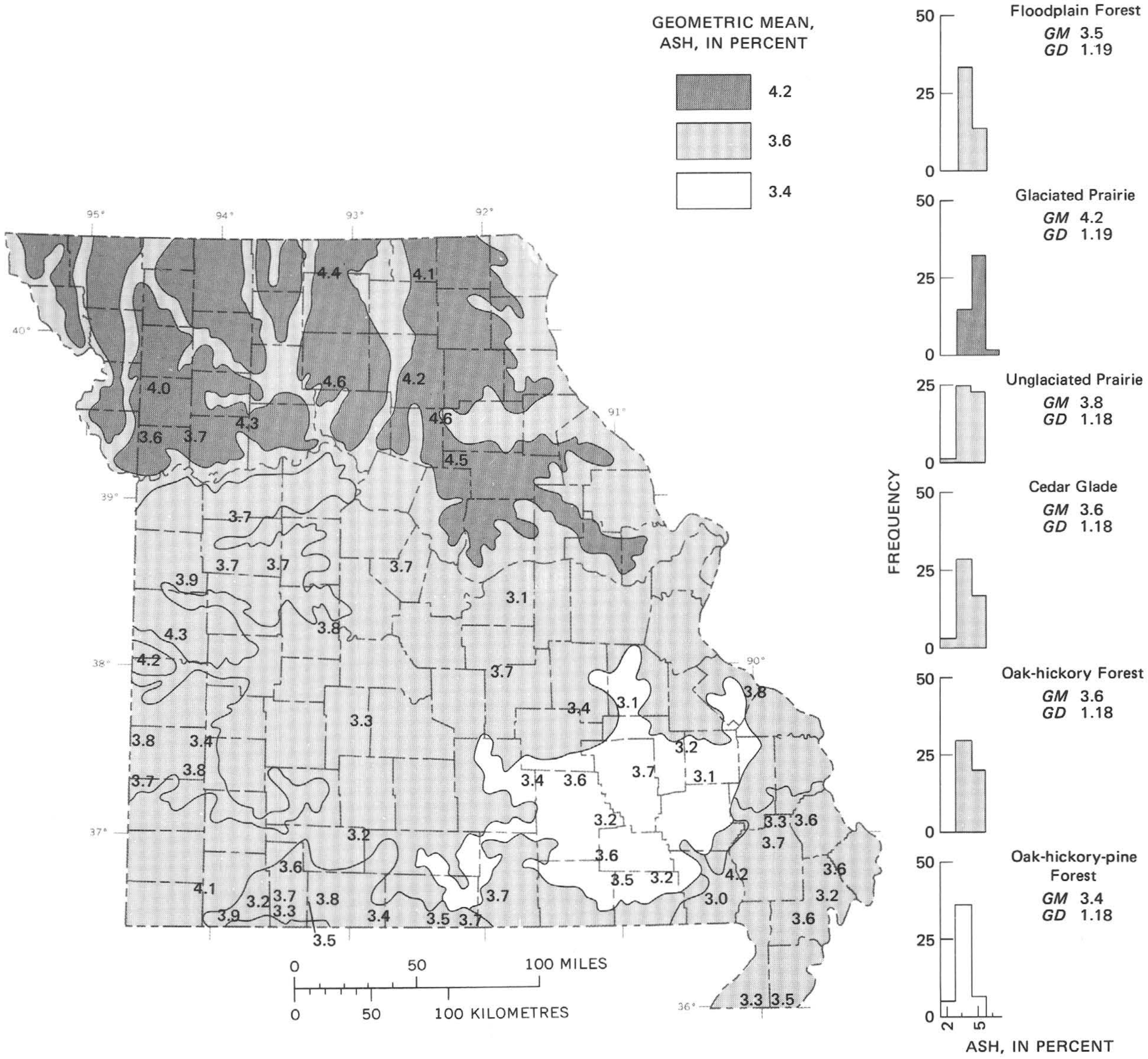


FIGURE 63.—Vegetation-type areas (modified from Küchler, 1964) classified according to average ash content of dry sumac stems from Missouri. Each number on the map is the geometric mean ash content in generally five samples from a 7½-minute quadrangle. Only areas of high and low concentration are significantly different.

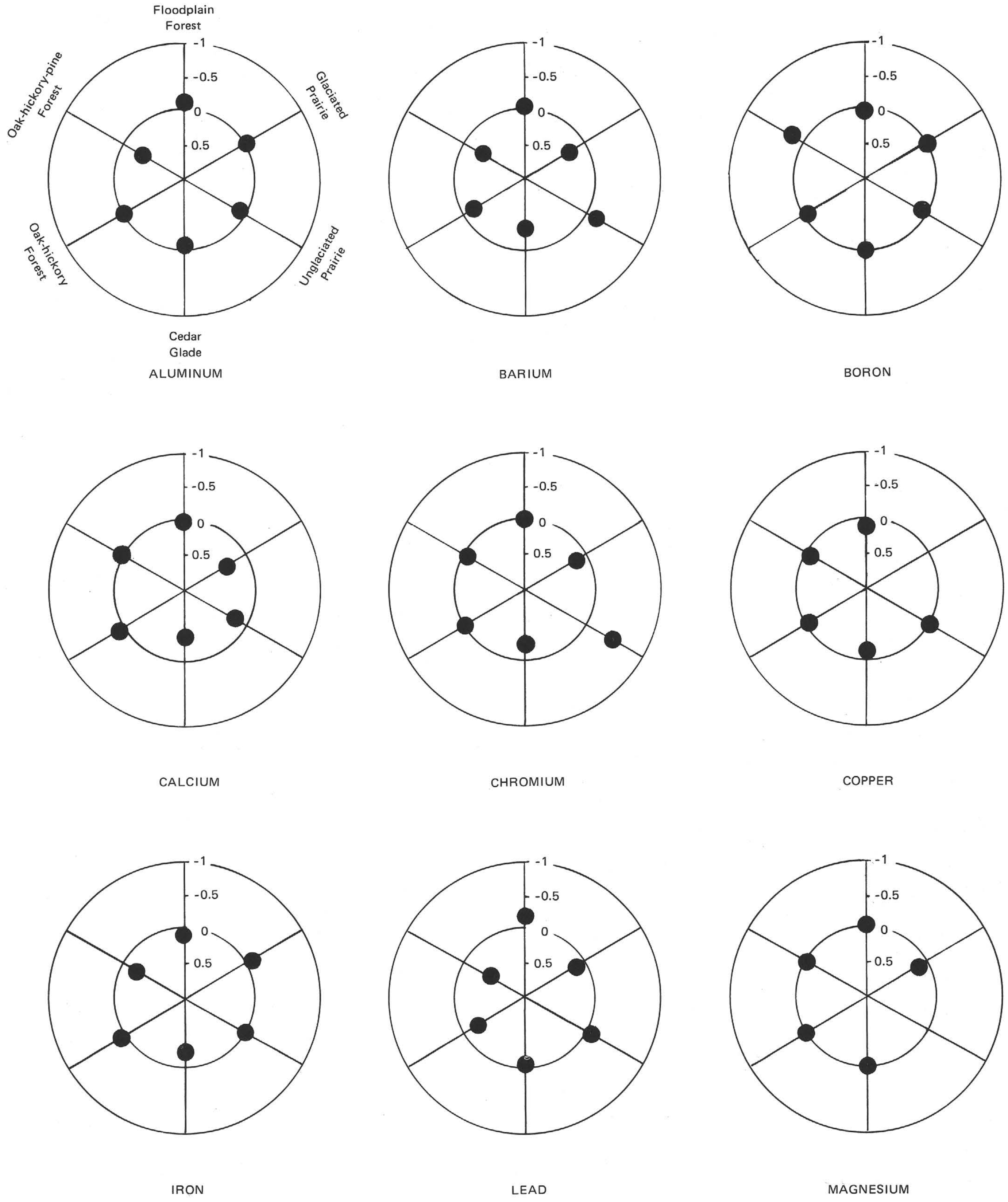
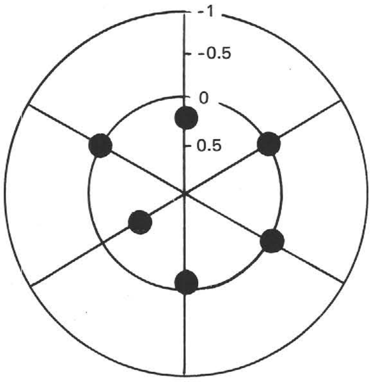
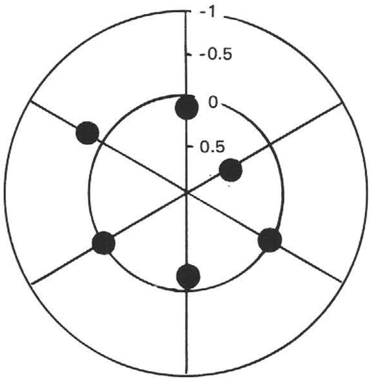


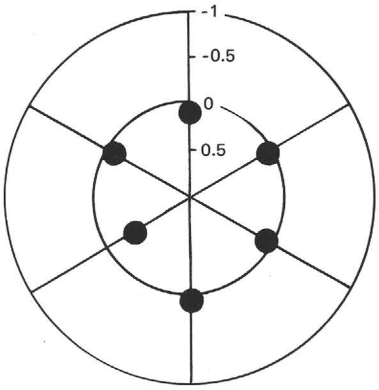
FIGURE 64.—Correlations between the concentrations of selected elements in sumac stems and those of associated soils from six



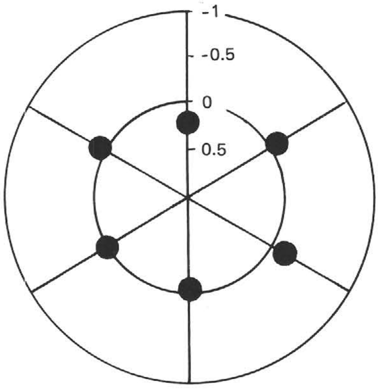
MANGANESE



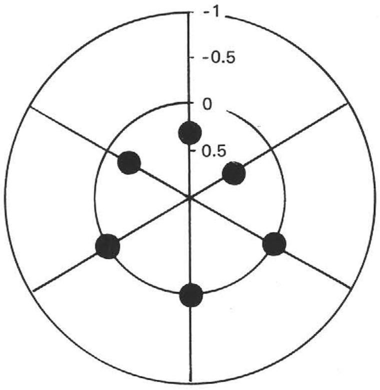
NICKEL



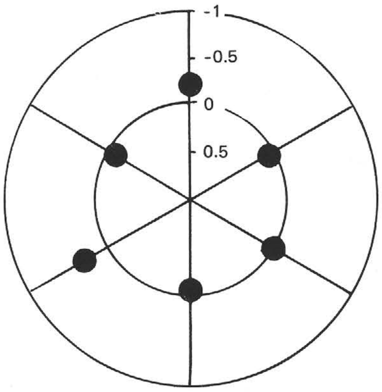
PHOSPHORUS



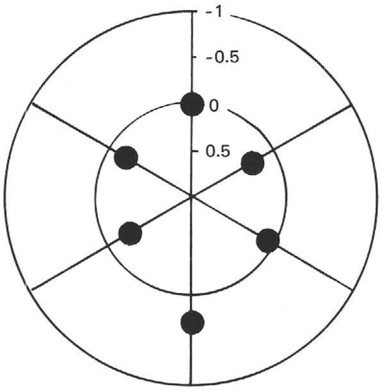
POTASSIUM



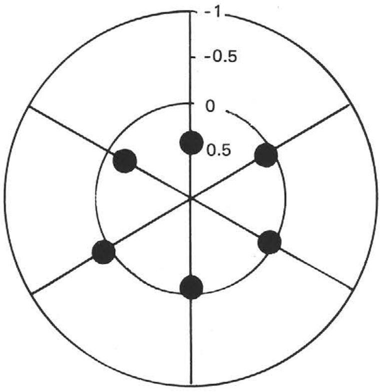
SELENIUM



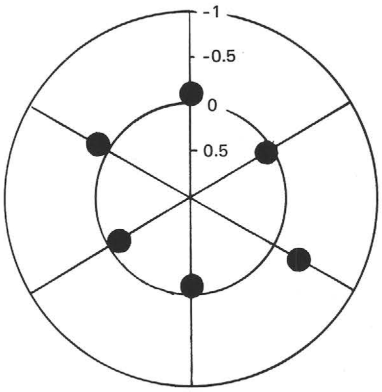
SODIUM



STRONTIUM



TITANIUM



ZINC

vegetation-type areas in Missouri. The points on the radii indicate the correlations by their distance from the center of the circle.

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