Missouri Ozark Forest Soils: Perspectives and Realities

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Abstract.—Ozark forest soils are dynamic in space and time, and most formed in multiple parent materials. Erosion and mass movement have been variable and extensive. Soil attributes including texture, cation exchange capacity, and mineralogy are related to geologic strata and to geomorphic conditions. Soil organic carbon content is influenced by surface shape, position in landscape, and aspect. Phosphorus is universally low, and most P is occluded. Many soil attributes are distributed in patterns related to topographic, geologic, and geomorphic features, but the patterns often are masked by site-specific variability such as tree throw, micro-relief, and slumps. Generalizations about Ozark soil landscapes must be given cautiously and are most meaningful in the context of attribute ranges rather than means.

The Missouri Ozark Forest Ecosystem Project (MOFEP) has provided an opportunity to investigate Ozark forest soils in a context and with a rigor not previously possible. Soils are as essential for most terrestrial life as water and solar energy. However, soils are complex bodies that are difficult to study. They do not exist as discrete individual entities, such as trees, deer, or fish. Soils have many attributes, most of which vary temporarily and are difficult to measure. All soil attributes change at different spatial rates into other attributes. Soils are not as aesthetically appealing to most natural resources students as the biota, particularly trees, fish, and wildlife. Consequently, soils are not so well understood as other ecosystem components and are infrequently included as components of ecosystem studies. When they are included, soils often are trivialized. Misconceptions and untested assumptions often guide sampling schemes, thus ensuring that the sampling will not test the hypothesis. These circumstances have created an unfortunate, often costly situation. One of the most fundamental ecosystem components is poorly understood and frequently mismanaged.

This paper investigates prevailing concepts of Ozark forest soils and compares them with ideas being developed as a consequence of recent studies and projects. The objective is to illustrate important soil-landscape principles, with particular emphasis on their applicabilities in Ozark forests. Rigorous, systematic data evaluation will not be employed because it is assumed that most readers are not well versed in soil science concepts and terminology. The presentation will be framed within a systematic evaluation of a previously published document whose primary tenents seem to persist among non-soil scientists. The purpose in comparing new ideas with old is not to discredit or embarrass others. Rather, it is to force readers to confront old belief systems with new ones and to make conscious, informed choices. Old paradigms are replaced slowly and reluctantly, even when individuals are confronted with hard evidence (Peters 1991, Rowe 1984, Simonson 1968).

"Landscape" is a currently popular term in biological sciences, but it has not been well defined and often is presented in the context of "scale." In this paper, a landscape is defined as a population of geomorphically related landforms. Geomorphology is the study of processes that shape the Earth's surface features. Geomorphology and pedology (the study of soil-forming processes) are synergistic because the temporal and spatial distributions of water and energy control both (Daniels and Hammer 1992). A landform is an individual Earth

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surface feature that can be described in the context of: (1) its location with respect to other landforms, (2) its surface shape (concave or convex), (3) soil attributes within the landform, and (4) stratigraphic attributes (Hammer 1997a). Stratigraphy is the layering of geologic materials. Thus, landforms are three-dimensional entities that vary spatially and temporally. A landscape is welded by the fluxes of materials and energy through its composing parts (landforms), and the parts segregate materials and energy in space and time.

PREVAILING CONCEPTS OF OZARK FOREST SOILS

Sources of Ideas Espousing System Homogeneity

Sources of Ideas

Primary sources of information about Ozark forest soils are published soil surveys (Gilbert 1971, Gott 1975) and an overview of Ozark soils and vegetation (Krusekopf 1963). The ruggedness of the Ozark landscape limited access to sites, the stoney, clayey soils were difficult to investigate, and the lack of perceived need for more precise information all combined, until recently, to limit detailed, systematic investigations of Ozark soils. Discussions with foresters, ecologists, botanists, and wildlife biologists during the early phases of MOFEP and continuing to the present, suggest that early concepts about Ozark soils remain widely held and persistent. For example, the review of Ozark region soil attributes in a recently completed M.S. thesis investigating oak decline in the Ozarks (Jenkins 1992) cited only Krusekopf (1963).

Illustrating the Problem

Scientists representing several disciplines met recently to discuss a proposed statewide ecological classification system (ECS). A botanist suggested that "historic" vegetation, which he defined as the plant communities indicated by the early 19th century land survey, should be a key ECS component. He said this knowledge would be a target towards which to manage native vegetation in the future. A forester argued that the survey records were a very coarse, simple, single "point-in-time" representation of a botanical system whose temporal and spatial variability are widely acknowledged. A soil scientist said that most Missouri soils have been eroded since the original land surveys, and that establishing "original" vegetation might be impossible because the eroded soils differ in various and important ways from the soils which supported the "historic" vegetation. The botanist countered that the soils could be restored to their previous condition by re-establishing the native vegetation.

Most of pre-settlement Missouri was mantled by a veneer of Wisconsin-aged, silt-size loess. The loess originated as water-born sediments deposited on the Missouri River floodplain, from which it was subsequently removed and distributed across the landscape by wind. The loess is underlain by older soil materials of various origins and ages. Erosion of the loess mantle is irreversible and adds to the complexity of the soil landscape (Ruhe 1956).

Several lessons emerge. Rowe's (1984) observation that skeptics are not easily converted in a competitive world is reinforced. Second, the idea that vegetation can "restore" removed material of specific and unusual geologic origin illustrates fundamental ignorance of basic Earth science.

Apparently few botanists, foresters, ecologists and others who work with natural systems include soils beyond the introductory course as part of their professional training. Pervasive evidence illustrates the synergisms of soils with the biota and of the complexities of the interactions of soils, waters and biota. Why do simple system models continue to prevail? These situations are not unique to Missouri (Hammer 1997a), are widespread, and limit the success of all natural sciences (Peters 1991).

Krusekopf's Perceptions

Krusekopf's (1963) research bulletin remains a frequently cited source of information about Ozark forest soils. Unfortunately, many of Krusekopf's key ideas about Ozark soils are untrue:

> ". . . except for a few small spots on the Salem and Lebanon plateaus, the entire Ozark region was originally forested" (p. 5).

> "In their main physical features, both the forests and the soils of the Ozark region are characterized by their sameness." (p. 6).

"Soils are consistently light in color—either gray or brown, shallow in thickness of surface soil, of medium (silt loam) texture, and of relatively low fertility. Varying amounts of chert stone characterize nearly all the soils except in the Ozark Border region." (p. 7).

"The lower subsoil tends to have a brown or reddish-brown color and is consistently acid—a pH value of less than 5. The percent of base saturation is low." (p. 7).

"There are no sharp contrasts in either forests or soils, and all changes tend to be gradational." (p. 7).

"Variations in the forest cannot be correlated with depth or thickness of the surface soil because the latter is remarkably uniform throughout the region." (p. 10).

"On ridges and on slopes of less than 10 percent, most Ozark soils have a fragipan." (p. 14).

"Fragipans do not occur in very stony soils, on steep slopes, or in soils that have a reddish clay subsoil." (p. 14).

". . . geologic boundaries and soil boundaries rarely conform." (p. 16).

"Soil erosion is not a serious problem in most of the Ozark region." (p. 16).

"Soil boundaries are too rigid to serve as forest type boundaries, especially over large areas." (p. 17).

"In general, moisture appears to be the most important soil factor that can be consistently related to forest type distribution and then only as the extreme of soil moisture condition is reached." (p. 17).

The preceding statements will be addressed individually in the context of current knowledge.

Soil Surveys

Soil surveys traditionally have presented foresters with unique and consistent challenges, many of which have been addressed by Grigal (1984) and Hammer (1997b). The two soil surveys published prior to the 1990's and containing areas of Ozark forest soils were Dent County (Gilbert 1971) and the Mark Twain National Forest Area (Gott 1975). The legends of both surveys have relatively few soil series. The Dent County survey contains 14 series, 4 of which are alluvial (table 1). Five of the 12 series mapped in the Mark Twain National Forest are alluvial (table 2). Thus, the complex upland landscape is portrayed as a small group of relatively uniform soils. Is this phenomenon a consequence of Krusekopf's perspective of "sameness" of soils in the Ozark region?

Conversely, site-specific soils investigations conducted by Meinert (Meinert *et al.*, 1977) on the MOFEP sites, an area much smaller then either Dent County or the Mark Twain National Forest, resulted in 47 soil mapping units. Meinert's soil units were conceived to meet MOFEP needs, and were based upon a combination of soil and geomorphic attributes important for forest composition and growth. One would expect scores of mappable soils to be identified in individual Ozark counties, particularly if mappers attempt to identify soil attributes important to the variety of current and potential land uses.

Many of the upland soils in Dent County and the Mark Twain National Forest are mapped across ridges and sideslopes (backslopes). Slope phases within series separate slope soils from ridgetop soils. This conveys a false perspective of soil homogeneity. Many soils are mapped on multiple aspects. Figure 1, an excerpt from the Mark Twain National Forest Area survey, illustrates this model. In the lower center is a ridge with west- and east-facing slopes. Dashed lines on the backslopes indicate ephemeral drainageways. These drainageway incisions indicate that the backslopes contain a mosaic of convex and concave surfaces. A single soil series, with separate "phases" for slope steepness is mapped over the entire ridge. This is a false perception and false portrayal of the soil.

Pedologic studies indicate that different soils occupy different geomorphic surfaces in complex, steeply sloping terrain, and that aspect creates measurable differences in soil attributes which are important for tree growth (Carmean 1975, Hammer *et al.* 1991). Such relationships now are being observed and quantified in Missouri Ozark forest landscapes.

Table 1.—*Soil series mapped in the Dent County, MO soil survey (Gilbert 1971). Series are presented with taxonomic classifications to the subgroup, with parent materials and landscape settings.*

Soil series	Subgroup classification	Parent material	Landscape setting
Ashton	Mollic Hapludalfs	Alluvium	Stream terraces
Captina	Typic Fragiudults	Loess over residuum	Ridges and upper slopes
Claiborne	Typic Paleudults	Colluvium	Toe and footslopes
Clarksville	Typic Paleudults	Cherty dolomite	Ridges and sideslopes
Coustone	Typic Paleudults	Dolomite and sandstone	Ridges and sideslopes
Doniphan	Typic Paleudults	Cherty dolomite or limestone	Ridges and sideslopes
Macedonia	Typic Paleudults	Loess over cherty dolomite	Ridges and sideslopes
Midco	Dystric Eutrochrepts	Cherty alluvium	Narrow stream bottoms
Newark	Aeric Fluvaquents	Alluvium	Lower stream bottoms
Opequon	Lithic Hapludalfs	Dolomitic limestone	Slopes near major rivers
Poynor	Typic Paleudults	Cherty dolomite or limestone	Ridges and sideslopes
Secesh	Ultic Hapludalfs	Alluvium	Low terraces
Viraton	Typic Fragiudalfs	Colluvium	Toe slopes
Wilderness	Typic Fragiudalfs	Loess and residuum	Ridges and upper slopes

Table 2.—*Soil series mapped in the Mark Twain National Forest Area, MO (Gott 1975). Series are presented with taxonomic classifications to the subgroup, with parent materials and landscape settings.*

Soil series	Subgroup classification	Parent material	Landscape setting
Ashton	Mollic Hapludalfs	Alluvium	Terraces and bottoms
Atkins	Fluventic Haplaquepts	Alluvium	Bottoms
Bado	Typic Fragiaqualfs	Loess over cherty dolomite	Broad ridges
Baxter	Tyipic Paleudults	Colluvium	Lower sideslopes/coves
Clarksville	Typic Haplaquepts	Residuum-cherty dolomite	Narrow ridges and sideslopes
Coulstone	Tyupic Paleudults	Resdiuum from sandstone	Ridges and sideslopes
Elkins	Fluventic Humaquepts	Alluvium	Depressions in bottoms
Elsah	Typic Udifluvents	Alluvium	Narrow stream valleys
Gladden	Fluventic Dystrochrepts	Alluvium	Narrow bottoms and valleys
Hobson	Typic Fragiudalfs	Loess over depression fill	Ancient depressions
Lebanon	Typic Fragiudalfs	Loess over cherty residuum	Broad ridges
Moniteau	Typic Ochraqualfs	Loess over cherty residuum	Ridges

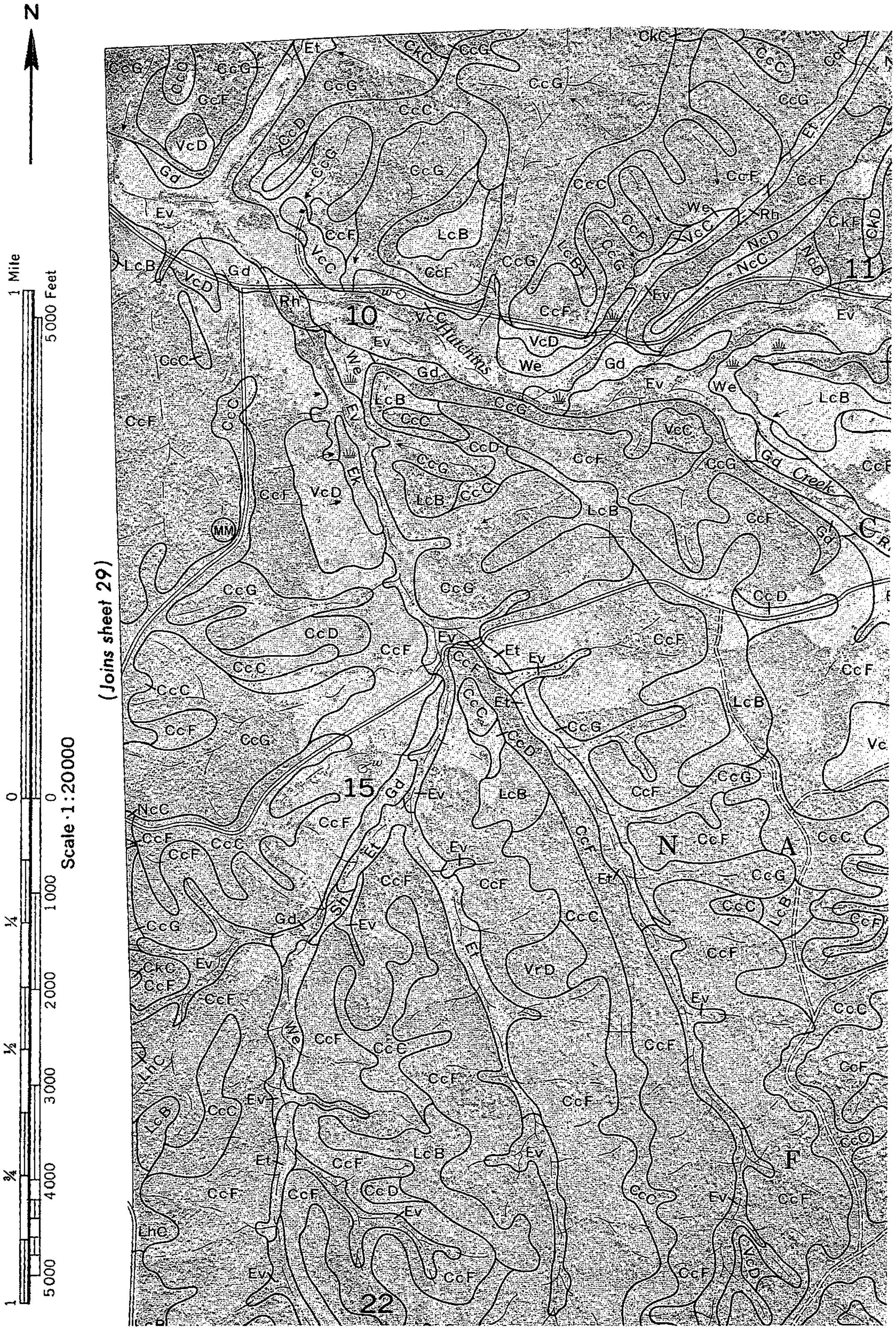

Figure 1.—*A portion of the Mark Twain Area soil survey (Gott 1975) showing a single soil series mapped across all aspects and landforms on a ridge. This figure is from the survey field sheet number 30. Letter and number combinations within delineations are mapping unit symbols. The first two letters of mapping unit symbols represent the soil series and the last letter indicates the slope class.*

Krusekopf's perceptions (1963) seem to have been based upon a two-dimensional concept of soils. He displayed geology as a two-dimensional surface feature (fig. 2), rather than as a three-dimensional feature of a dissected landscape (fig. 3). Krusekopf's geology map conveys to the uninformed user the false perception that only a single stratigraphic layer is locally important. Figure 3 clearly indicates that all exposed stratigraphic components are important in a dissected landscape.

Neither Krusekopf nor the early soil surveys mention geomorphic attributes as determinants of soil conditions and regulators of soil-forming processes. Thus, Ozark region soil surveys which preceded the current mapping effort perpetuated the idea of relatively uniform soils across the spectrum of topographic and geomorphic conditions. Soil series were perceived as widespread, and most soils were thought to have formed primarily in residuum (geologic material which has weathered in place). Most pedologists now would agree that soils formed from a single parent material or single depositional event are rarely found.

THE COMPLEX OZARK SOIL LANDSCAPE

Countering Krusekopf's Perceptions

Original Forest Vegetation

The statement that most of the Ozark region was originally forested is no longer accepted. Much of the Ozark area was a mosaic of forest and savanna (Nelson 1987). Although erosion has removed most original surface horizons, thick buried A-horizons remain in some depressions where hillslope sediments accumulated from higher landscape positions. Hillslope sediment is defined as surficial material which moves slowly downslope under the combined influences of water and gravity (Daniels and

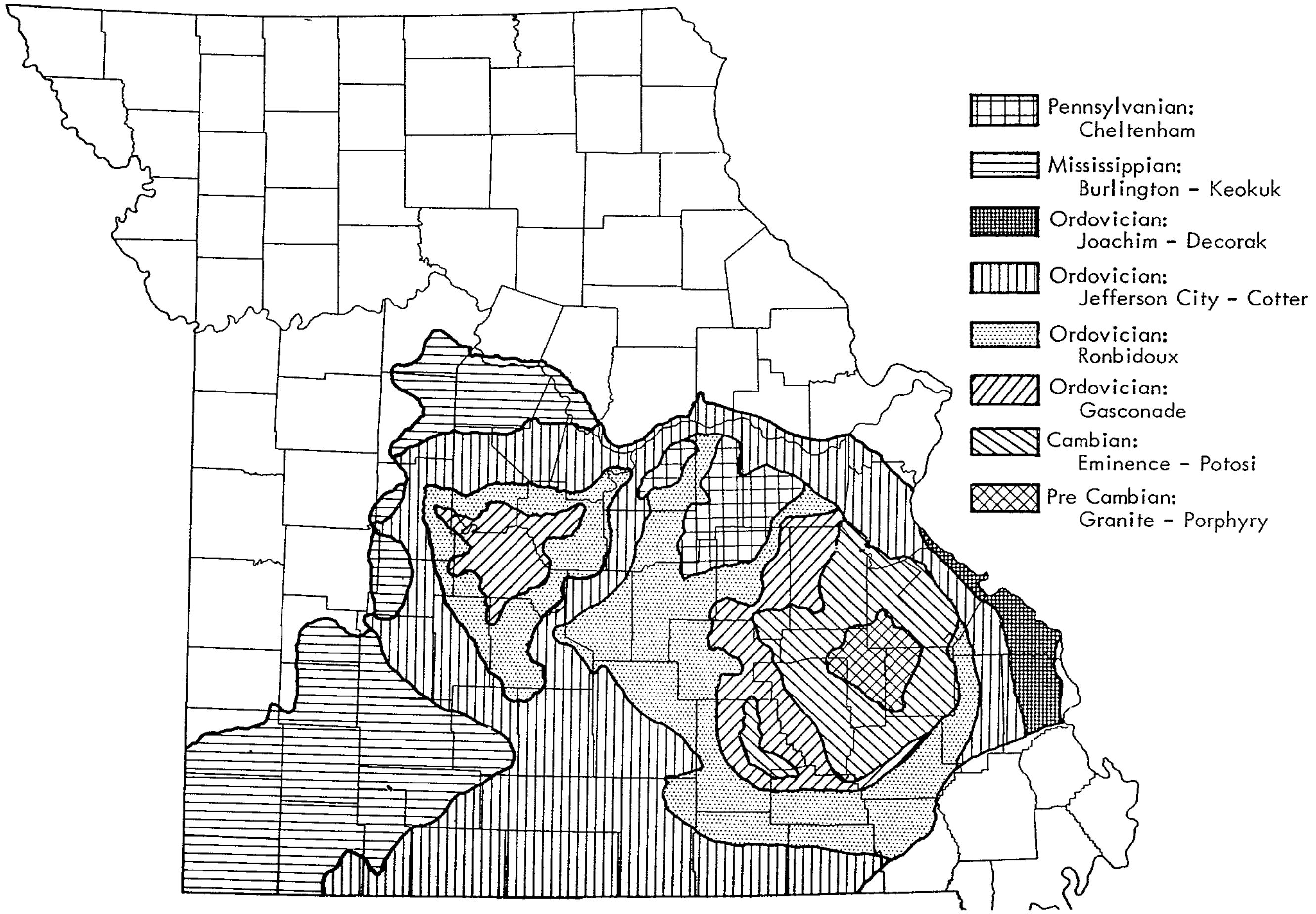

Figure 2.—*A representation of "surficial geology" in the Ozark Highlands by Krusekopf (1963). The lower portion of the figure in the cited text was absent.*

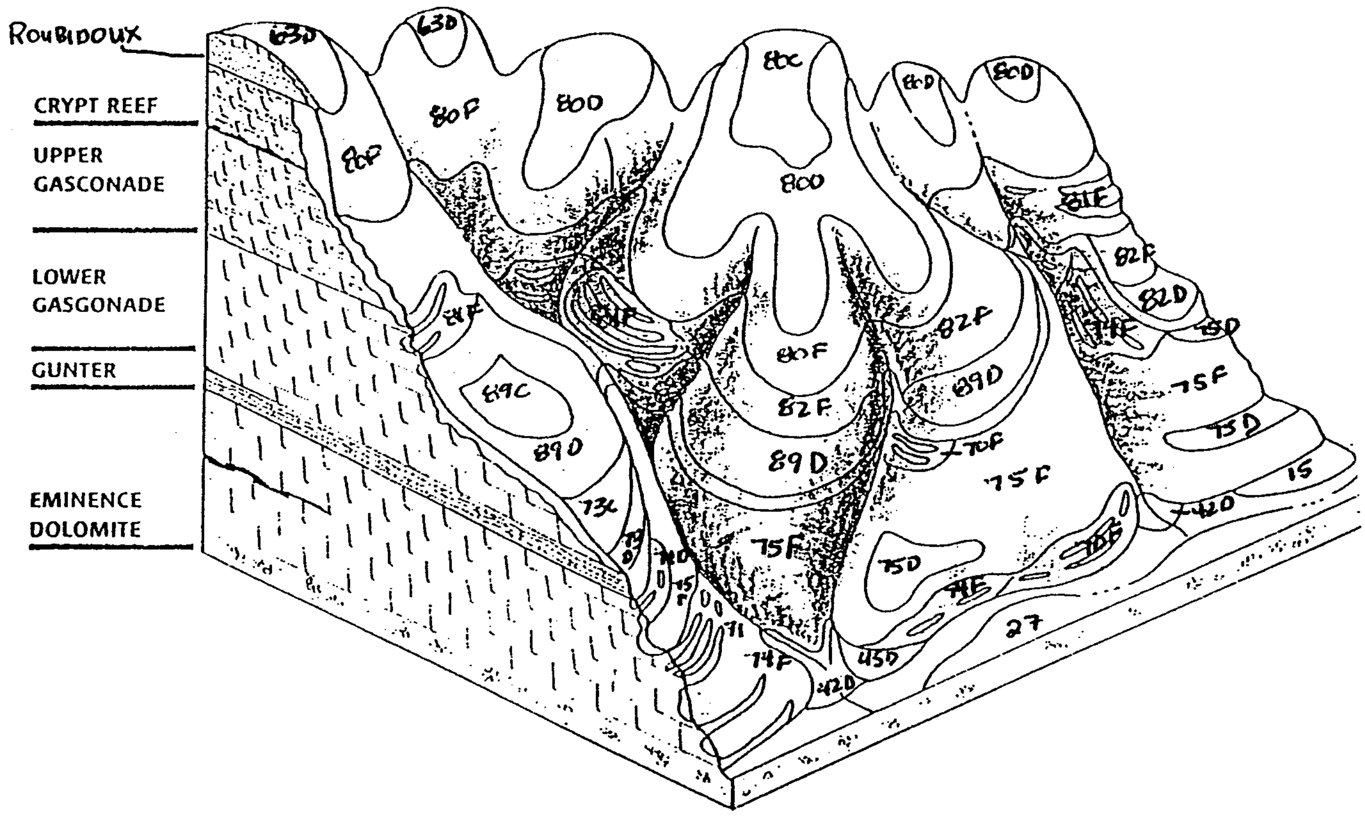

Figure 3.—*A three-dimensional representation of stratrigraphic- and landform-related soils in a dissected portion of the Ozark Highland landscape. Specific soils are delineated by lines and and identified by mapping symbols (63D, 80F, etc.). This figure illustrates the importance of geologic strata on soil distributions in a dissected Ozark landscape. From Meinert* et al. *(1997).*

Hammer 1992). Knowing how to recognize depositional from erosional surfaces is a key to locating buried soils which preserve soil features inherited from past vegetation communities. An excellent buried savanna Mollisol (prairie soil with a thick surface horizon) recently was exhumed at Ha-Ha Tonka State Park just below a ridge summit. A monolith was taken for subsequent display at the park's tourist center. Laboratory analyses are being conducted on samples taken from the profile. A recent visit to upland summits at MOFEP site 8 revealed silty depositional surfaces similar to the one containing a buried Mollisol at Ha-Ha Tonka. Soils at site 8 will be examined carefully to determine if they retain a record of savanna vegetation. Experienced pedologists and geomorphologists would expect to find "relict" soils of past conditions underlying depositional surfaces.

Striking differences in Ozark soil attributes can be found within relatively short distances and often within single soil profiles. The buried Mollisol mentioned in the previous paragraph was underlain by a red paleosol (old soil). Within 100 feet of the Mollisol were an Alfisol (soil with illuvial clay and high base saturation) and an Ultisol (soil with illuvial clay and low base saturation). Thus, three soil orders exist within an area that many people would perceive as a single geomorphic surface, in this case, an upper backslope.

The Sameness of Soils

This idea was partially addressed in the preceding paragraph. Pronounced differences in soil texture, stoniness, structure, base saturation, pH, and color exist over short distances on MOFEP sites. For example, a 5-acre site near a ridgetop on MOFEP site 1 contained distinct differences in base saturation in three soils within 60 m of each other (fig. 4). Base saturation is the percentage of a soil's exchange capacity which is occupied by nutrient cations.

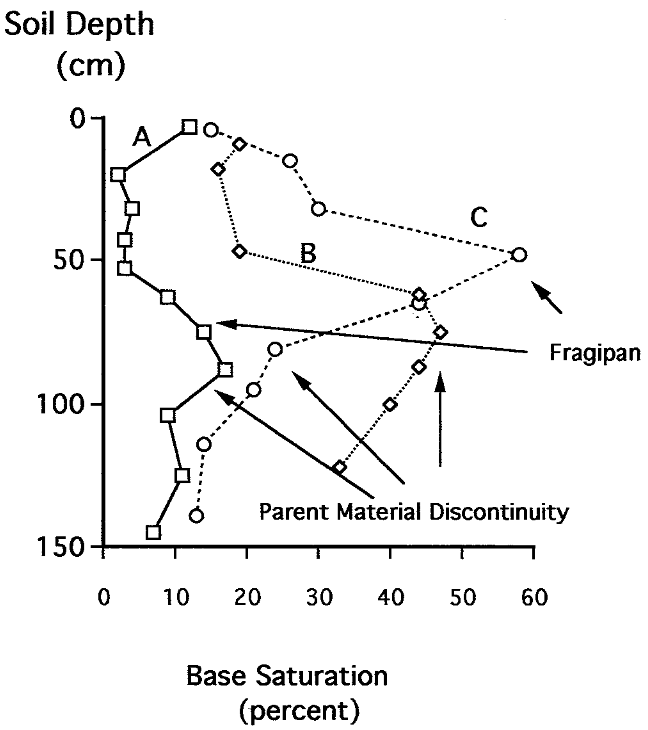

Figure 4.—*Soil depth distributions of base saturation for three soil profiles on MOFEP site 1. All three soil profiles were from the same small watershed and were within 60 m of one another. Fragipan horizons and parent material discontinuities are indicated.*

Aluminum, which is toxic to roots of many plant species, occupies much of the exchange complex in acid soils.

Soil A was on a convex position 60 m below soil C, which was on a shoulder surface with minimal microtopography. Soil B was on a concave position the same distance below soil C and about 10 m from soil B. Soil C had a silt loam surface to a depth of 74 cm, below which the clay content increased abruptly (from 17 to 59 percent). The textural discontinuity was below a fragipan. A fragipan is a layer of high bulk density and massive structure, the combination of which limit both downward percolation of water and infiltration by plant roots. The clay in this profile was primarily kaolinite. Kaolinite has a relatively low cation exchange capacity and is structurally unresponsive through wetting and drying cycles. Soil B appeared to have formed in two deposits of silty material, the upper of which probably was hillslope sediments of relatively recent origin. The sand content increased significantly below the discontinuity, which was at 80 cm. The clay mineralogy was primarily vermiculite, with a trace of montmorillonite. Vermiculite and montmorillonite have higher cation exchange capacities than kaolinite. They also swell when wet and shrink and harden when dry. Montmorilonite expresses these temporal physical attributes more strongly than vermiculite. Soil A contained an exceptionally thick fragipan overlying a leached, stony, red, silty clay loam residuum. The clay in the residuum was kaolinite. The clay mineralogy within a particular soil horizon is partially controlled by pH, which, in turn, is affected by parent material, intensity of leaching, and cation cycling.

Light-Colored Soils, Shallow Surface Horizons, and Low Fertility

Most residual materials in the soils we have observed are red. Laboratory analyses have indicated that the red color is inherited from iron oxides, which concentrate in well-drained soils as more mobile constituents are slowly leached. The reddening of soils requires geologic time periods and a warm, humid environment.

Surface horizons, particularly in concavities in lower slope positions, can be tens of cm thick. Soil B in the preceding section contained a relatively high organic carbon concentration (0.3 percent) to a depth of over 100 cm. This kind of carbon depth distribution can indicate a continuous input of organic material and sediments from higher landscape positions. More than 30 percent of the approximately 130 soil profiles on MOFEP sites for which laboratory data have been collected have base saturations exceeding 40 percent in some portion of the B-horizon. Alfisols and Ultisols co-exist within short distances.

Brown, Acid Lower Subsoil

This statement has been refuted in both preceding sections. About 40 percent of the examined soil profiles had B-horizons in which some portion contained a pH exceeding 5.0. Base saturations tend to increase in lower backslope positions and in soils on depositional surfaces. Clay content in B-horizons is correlated with mineralogy. Soils with 2:1 clay minerals (vermiculite and montmorillonite) have higher base saturations than B-horizons enriched with kaolinitic clay. Generally, but with some exceptions, soils on convex surfaces and soils higher in the landscape tend to be more intensely leached and to have kaolinitic clay mineralogy. Red subsoils are common, but often underly several layers of hillslope sediment and/or mass movement materials.

No Sharp Contrasts in Soils, Gradational Changes

Sharp color, textural, and structural contrasts exist within and among soil profiles. Abrupt changes are associated with different parent materials within profiles, with different geomorphic surfaces within small and large watersheds, and with different geologic strata on backslopes. Alluvial soils have numerous abrupt changes over short distances, both horizontally and vertically. Abrupt differences in stone content are found on surfaces and within soil profiles. Buried stone lines, which indicate past erosional episodes (Ruhe 1956), are common. Abrupt textural discontinuities often occur across buried stone lines, because the stone lines often overly eroded argillic (enriched by illuvial clay) horizons.

Stone line genesis is illustrated in figure 5. Erosion selectively removes sand, silt, and clay, concentrating coarse fragments on the erosional surface. Subsequent deposits can bury the stone line. New surface (A and E) horizons form in the truncated profile, but have different textural and chemical attributes than surface horizons in nearby, uneroded soils.

Mass movements and hillslope sediments are the most common burial processes. Many existing soil surfaces have high concentrations of stones (sometimes called "armor plating" by soil mappers), which indicate that erosion has occurred relatively recently. High surface stone concentrations impede subsequent surface erosion. These attributes combine to support the idea of geologically recent accelerated soil erosion, probably caused by past land use practices in the Ozarks.

Remarkably Uniform Surface Soil, Lack of Correlation with Forest Variation

As previously mentioned, A-horizon thicknesses vary considerably across the Ozarks. Some of this variation is the natural consequence of soil-forming processes across the mosaic of aspects, slope steepnesses, slope lengths, slope surface

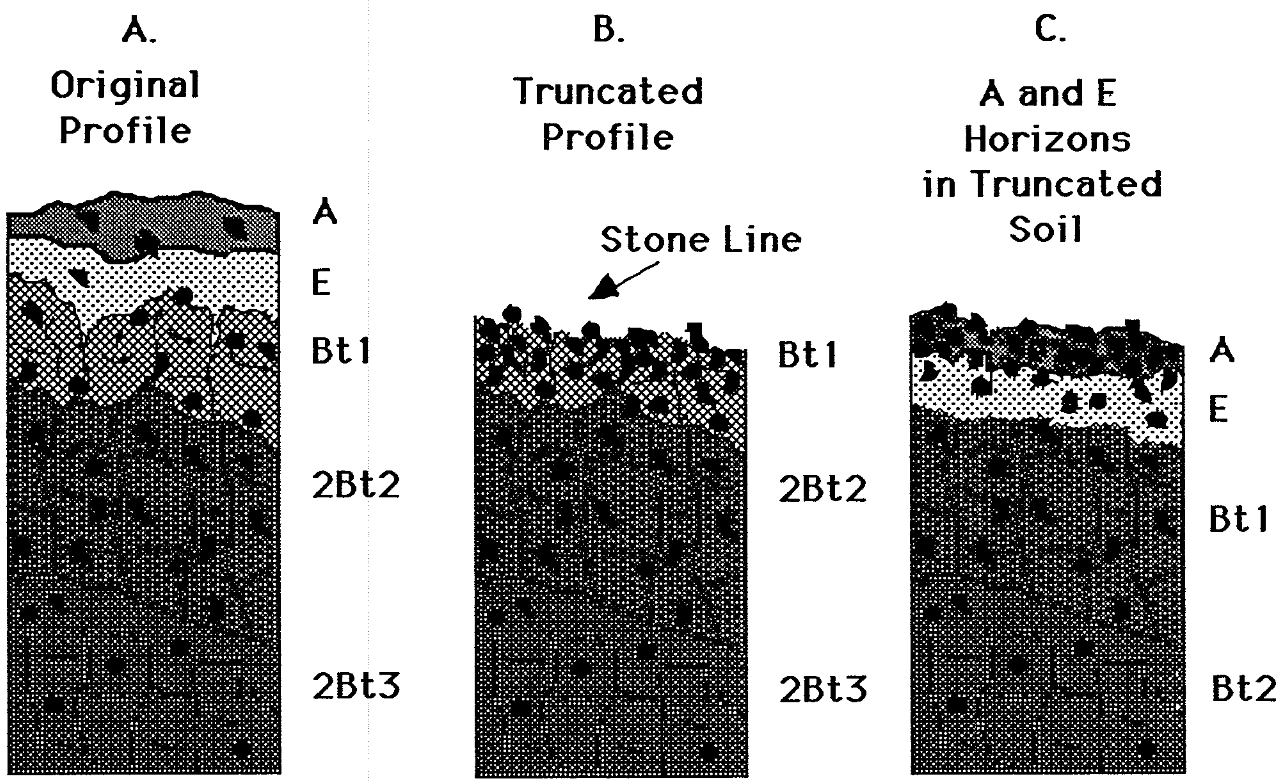

Figure 5.—*Representation of stone line development in an eroded soil. Part A is the uneroded soil. Part B illustrates the concentration of rock fragments on the eroded soil surface after finer particles have been removed. Part C illustrates the new soil surface (A and E) horizons developing after the new surface has stabilized.*

shapes, soil textures, and botanical communities within the Ozark uplands. The natural variation has been exacerbated by differential erosion and deposition resulting from human activities, including timber harvest, farming, home-building, and recreation. Table 3 presents A-horizon and combined A- and E-horizon thicknesses from 48 soil pits on the MOFEP sites. These profiles are from six small watersheds near interfluve ridge summits. They represent a small portion of the total area between interfluve summits and perennial streams. These data clearly illustrate variable horizon thicknesses both within and among watersheds.

Forest site index research has demonstrated the relationships of soil attributes with tree growth. Graney and Ferguson (1972) showed that shortleaf pine (*Pinus echinata* Mill.) site index in the Ozark uplands is correlated with aspect, slope shape, soil organic carbon in the A-horizons and depth to fragipan. McQuilkin (1972) observed increasing black oak (*Quercus velutina* Lam.) site index with increasing A-horizon thickness and with decreasing A-horizon sand content. Carmean's (1975) review of forest site productivity cites numerous instances in which site index has been correlated with surface horizon attributes.

On Ridges and on Slopes of Less Than 10 Percent, Most Ozark Soils Have a Fragipan

Fragipans are volumes of material within a soil profile which have higher bulk density and coarser structure than overlying and underlying materials. Fragipans generally restrict, but do not necessarily prohibit, the infiltration of water and penetration of plant roots (Witty and Knox

Table 3.—*Statistical information for soil surface horizon thickness in six Missouri Ozark Forest Ecosystem Project study plots. The plots represent three forest management treatments, a control, an uneven-aged cut, and an even-aged cut. All forest management treatments were observed on east- and west-facing aspects.*

Plot	Number of samples	Minimum	Maximum	Mean	Variance	Standard deviation
A-Horizon						
		Horizon thickness				
		cm				
Control east	10	2	7	5.1	3.2	1.8
Control west	6	2	4	2.5	0.7	0.8
Even-aged east	8	2	6	3.5	2.6	1.6
Even-aged west	9	3	8	4.7	3.0	1.7
Uneven-aged east	7	3	7	5.4	2.3	1.5
Uneven-aged west	7	2	7	4.1	3.5	1.9
All sites	48	2	8	4.3	3.3	1.8
A- and E-Horizons						
Control east	10	4	18	9.9	19.0	4.4
Control west	6	5	27	12.5	63.5	8.0
Even-aged east	8	5	10	7.8	3.9	1.9
Even-aged west	9	4	21	10.6	23.0	4.8
Uneven-aged east	7	7	15	10.6	6.3	2.5
Uneven-aged west	7	6	14	9.7	9.6	3.1
All sites	48	4	27	10.6	19.1	4.4

1989). Fragipans occur where relatively unweathered parent material overlies an older soil surface (Franzmeier *et al.* 1989). Fragipans seldom are in alluvial deposits, regardless of slope. Fragipans are not always on summits. They occur most often on broad interfluve divides on which loess was deposited during the Wisconsin glacial epoch. Fragipans may extend off the summit onto upper backslopes.

Fragipans Do Not Occur in Very Stony Soils or in Soils with a Reddish Clay Subsoil

Fragipans in the Ozark Highlands occur in stony soils, in red clay subsoils, and in soils with both stones and clay. Many fragipans in the Missouri Ozarks have physical morphology unlike fragipans in other parts of North America. The Natural Resources Conservation Service, as part of the accelerated soil survey in Missouri, has conducted special characterization investigations to quantify attributes of fragipans in Ozark soils. Less is known about these fragipans than others because, until recently, the Ozark soils had not been studied or mapped in detail.

Geologic Boundaries and Soil Boundaries Rarely Conform

The coincidence of soils with geologic materials is well documented throughout the world. Much work confirming the synergisms of geology, soils, and biota was conducted before Krusekopf's (1963) treatise. Coile's research, summarized in his 1952 treatise, is a noteworthy example. Fletcher and McDermott (1957) established that shortleaf pine growth in Missouri was restricted to four distinct geologic strata, and that the soils developed from those strata were unique. Fletcher and McDermott observed that distinguishing criterea were confusing and unclear for several of the commonly identified Ozark soils, including the Clarksville and Eminence.

Hack and Goodlett's (1960) investigation of soils, geomorphology, and forest ecology in the central Appalachians remains a classic template of how to conduct a systematic evaluation of forest site attributes. Their work revealed the importance of contemporary geomorphic processes as an important determinant of forest hydrology at scales important to forest tree growth within and among watersheds.

Meinert *et al.* (1997) in this symposium have clearly illustrated the importance of geologic strata as structural controls in the landscape and as determinants of soil and landform attributes in the Ozark Highlands. Meinert's work on MOFEP sites has revealed some important general soil-geologic relationships, some of which are portrayed in figure 6.

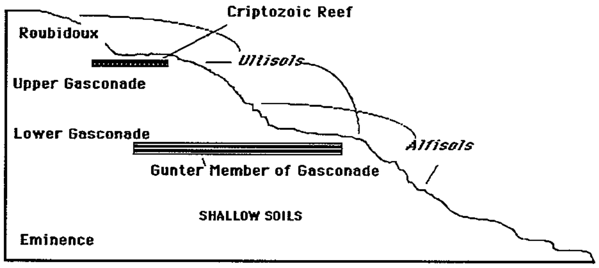

Figure 6.—*A hypothetical cross-section of the lower Ozark Highland landscape indicating soil and geomorphic attributes related to the geologic strata.*

Structural benches are caused by resistant geologic strata such as the Gunter sandstone and the cryptozoic reef. Backslopes in the Roubidoux and Upper Gasconade formations tend to be convex. The Lower Gasconade and Eminence formations produce concave backslopes, often with a "stair-stepping" pattern on backslope surfaces. Soils higher in the landscape tend to be more strongly leached and have lower base saturations with kaolinitic mineralogy. Lower landscape positions, particularly those with soils shallow to dolomite (carbonate rock which contains magnesium in addition to calcium), tend to have higher base saturations and clay mineralogy containing more montmorillonite.

Soil Erosion is not a Serious Problem in Most of the Ozark Region

Soil erosion is a serious problem over much of the Ozark region. Erosion has been widespread and can be locally severe. Disentangling the effects of erosion on species distribution and site productivity will be difficult. The evidence of past erosion is everywhere present in the geomorphic record. The most widespread and obvious is the presence of chert stone lines on much of the contemporary soil surface. Stone lines were described previously in this manuscript. Other evidence of erosion is accumulation of silty materials in depressions, concavities, and hollows; presence of alluvial fans where upland drainages transition abruptly to nearly level bottoms; and multiple textural and material discontinuities in soil profiles.

Erosion probably has created important plant nutritional and hillslope hydrologic consequences over much of the landscape. In sloping forest landscapes, tree throw mass movement, soil creep and other processes combine to mix the upper portion of the soil profile. The differential effects of these processes are most readily observed in the spatial distributions of surface soil organic matter. Concave surfaces and lower landforms tend to collect forest litter from higher, surrounding areas, and have higher concentrations of organic matter. Wetter locations tend to have higher concentrations of organic matter than drier locations. Thus, one would expect higher concentrations of soil organic matter on north- and east-facing slopes than on drier and cooler south- and west-facing slopes. One also would expect higher soil organic matter concentrations in concave and lower landscape positions. This was confirmed in the Ozarks by 24 soil transects conducted by Udawatta and Hammer (1995). Results are partially summarized in figure 7.

Figure 7 reveals increasing soil organic matter concentrations downslope in concavities, but decreasing concentrations downslope on convexities. This distinction has never previously been reported in the literature. However, no single transect represented the trends indicated by the means of all the data. The system is so heterogeneous that trends are revealed only by means of many transects. Thus the concept of "representative" transects or "representative" soil profiles is suspect in this terrain.

Soil Boundaries are Too Rigid to Serve as Forest Type Boundaries

This is a very puzzling statement by Krusekopf. Considerable research has shown that soil series generally are poor indicators of forest site productivity because the soil series concept and mapping scales create soil inventory units which are too large and too variable to discriminate site productivity attributes (Carmean 1975, Grigal 1984, Hammer *et al.* 1991, Hammer *et al.* 1995, Hammer 1997b). Many land managers and resource scientists not familiar

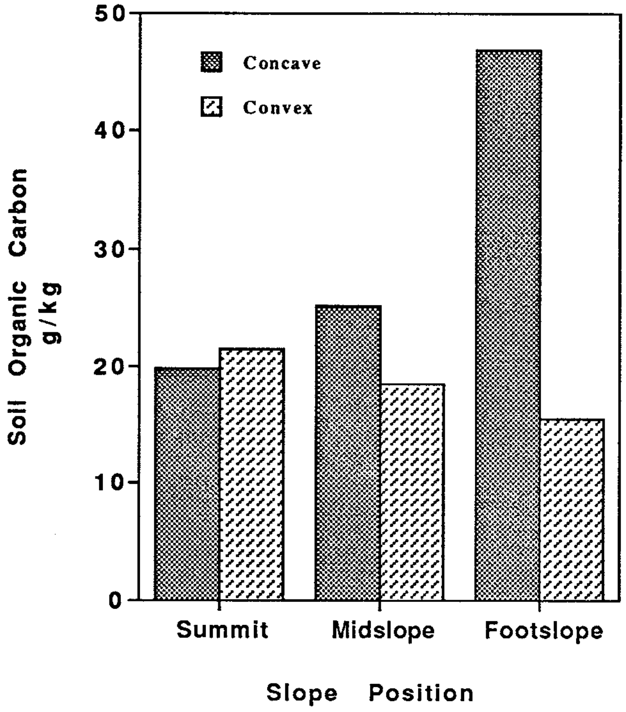

Figure 7.—*A-horizon soil organic carbon distributions along downslope transects on concave and convex surfaces in the Missouri Ozark Forest Ozark Project research area. Transects were primarily on sites 1 and 2.*

with soil survey techniques assume that map units delineate relatively homogeneous soil bodies. All soil mapping units, as astutely observed by an experienced forest biometrician, are hypotheses.

Soil taxonomy has a strong bias towards attributes of agricultural soils and is less suited for mapping forest soils (Grigal 1984, Hammer *et al.* 1995, Hammer 1997b). Mapping scale restricts the sizes of map units which can be delineated. The commonly used soil survey mapping scale of 1:24,000 allows a 5-acre delineation as the smallest mappable unit. Many soil mappers are not familiar with soil-landscape attributes which segregate forest species and contribute to their variable growth patterns.

Further compounding the problem is the multivariate nature of soils. Only a few combinations of soil attributes can be identified and mapped. If managers could afford use-specific maps (a map for roads, a map for species distribution, etc.), many would be surprised to learn that different delineations would be made for different uses of the same area.

The previously discussed synergism of soils and landforms has led many who study forest ecosystems to conclude that a mapping system which more closely identifies related soils and landforms is the most meaningful and useful mapping approach (Rowe 1984, Grigal 1984, Hammer *et al.* 1991, Hammer 1997b). This philosophy has formed the conceptual framework of the MOFEP soil inventory.

In general, moisture appears to be the most important soil factor that can be consistently related to forest type distribution, and then only as the extreme of soil moisture condition is reached.

This statement is generally true, but Krusekopf carried it to extremes. "The extreme of soil moisture condition" could be intrepreted to mean that extremely dry and wet sites are the ends of the continuum he perceived in soils and vegetation, and that only the ends of the continuum were observably different. The forest hydrology, soil, and vegetation mosaic is more subtle and complex, as has previously been discussed.

Nutrient Relationships

General Knowledge

Increasing evidence suggests that nutrient distributions influence forest species distributions, competitive interactions, and growth, yet little is known about Ozark forest nutrient dynamics. Remley's (1992) research in Ozark forest soils revealed tree root response to increased soil pH and to calcium inputs. Remely was unable to determine if the observed responses were to reduced aluminum activity or were positive responses to calcium. Unpublished subsequent work (G.S. Henderson, personal communication) strongly suggests a positive root response to calcium.

Donaldson and Henderson (1990) investigated nitrification dynamics in Ozark forest soils. Their work suggests that low soil pH and the presence of polyphenolic compounds combine to inhibit nitrification. Vegetational repression of nitrification could be a mechanism to conserve a limited biological nitrogen pool. Much remains to be learned about the nitrogen cycle and its effects on other nutrients in Ozark forests.

Phosphorus Dynamics

Phosphorus dynamics may be an important determinant of botanical interactions in the Ozarks. Phosphorus is known to be an important constituent of proteins and amino acids, and is a necessary nutrient for plant metabolism. Primary minerals, primarily apatite, are the sources of soil phosphorus, and the forms of phosphorus in soils are controlled by pH (Walker and Syers 1976). Thus, as soils weather, phosphorus tends to become limiting. As soil acidity increases, phosphorus becomes occluded by iron and aluminum, and the biologically available P pool is reduced. This well-established relationship is illustrated in figure 8.

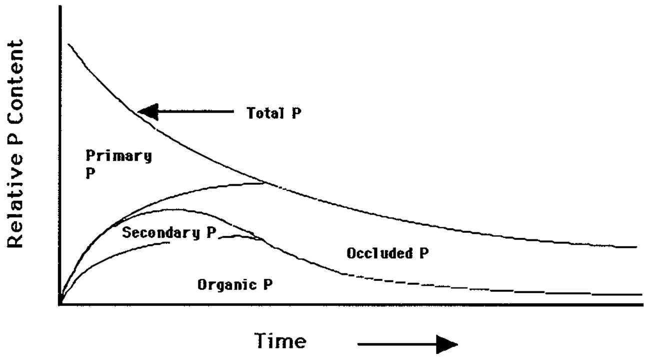

Figure 8.—*Changes in phosphorus form and abundance with weathering and time in a hypothetical soil (from Walker and Syers 1976).*

The primary source of phosphorus in pre-European settlement Ozark soils would have been the veneer of Pleistocene loess, much of which has since eroded. One soil component of the MOFEP soil research is a quantification of phosphorus forms and distributions. Preliminary results indicate that phosphorus concentrations are low in Ozark soils and that most of the total phosphorus is occluded by iron and aluminum. This finding conforms to established knowledge of phosphorus distributions in highly weathered soils.

However, phosphorus distributions are correlated to geologic parent materials as well as to hillslope sediments and silt materials which probably are of loessal origin. Figure 9 shows

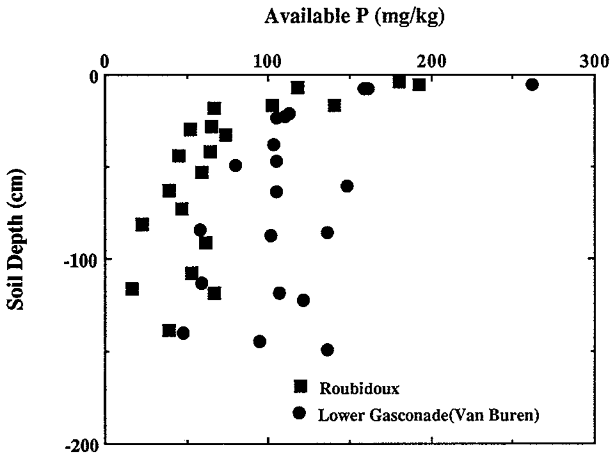

Figure 9.—*Available (organically complexed) soil phosphorus distributions with depth in soil profiles developed in residuum from Gasconade and Roubidous geologic strata on the Missouri Ozark Forest Ecosystem Project research area.*

that available phosphorus concentrations are higher at the surface and with depth in a soil associated with the Lower Gasconade formation than in a soil developed from Roubidoux residuum.

CONCLUSIONS

The Ozark soil landscape is a complex mosaic of parent materials and soil attributes whose relationships with the associated biota are poorly quantified. Early assumptions of ecosystem and soil homogeneity were inaccurate and were based upon supposition rather than systematically acquired data.

Most soils formed in multiple parent materials. Erosion has been widespread and locally severe. Important synergisms exist among soils, geologic materials, and geomorphic landforms. Trends occur in the landscape, but large sample numbers are necessary to identify patterns and relationships. Site-specific variability creates a "noisy" ecosystem in which single transects are unlikely to represent patterns. Data must be interpreted cautiously and in the context of local site attributes.

Much remains to be learned about the role of nutrients in vegetative behavior in the Missouri Ozarks. Preliminary examinations indicate more complex nutrient patterns and processes than are indicated in the literature. The interactions of nitrogen, and phosphorus are unknown, and the potential responses of native vegetation to calcium, nitrogen and phosphorus inputs are unmeasured.

The complex Ozark landscape presents a formidable challenge to scientists wishing to understand ecosystem pattern and process.

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