educational series no. 3

an introduction to

MISSOURI'S GEOLOGIC ENVIRONMENT

by Larry N. Stout
and David Hoffman

COVER: Investigation of an outcrop in Montgomery County adds to our knowledge of Missouri's geology. (Photo by L.D. Fellows, Missouri Geological Survey)

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FOREWORD

"An Introduction to Missouri's Geologic Environment" is the first part of a larger three-part study entitled "Missouri: Physical Characteristics and Constraints to Development."

Part I treats Missouri's physical characteristics and constraints for development from a geological perspective and interpretation. The study has two important assets: first, it acts as the initial and introductory phase of the three-part study offering valuable information about Missouri's physical nature, and second, it can be used as an individual source document for anyone seeking geologic information on a statewide scale.

Parts II and III can be found in separate document forms entitled "Standards for Urban Development in Terms of Engineering and Environmental Problems" and "An Investigation and Identification of Areas in Missouri Sensitive to Development," respectively. These documents can be obtained from the Missouri Department of Community Affairs, Jefferson City.

All three parts are intended to be used in a complementary fashion; much of the information discussed in parts II and III rely upon part I as a reference and introductory source.

Eugene L. Horton
Project Coordinator

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INTRODUCTION

This report is a brief, nontechnical description of Missouri's geologic environment. Section 1 deals with bedrock geology, surficial materials, topography and relief, mineral resources, and water resources. Section 2 is concerned with engineering geology and geologic constraints on impoundments, liquid-waste disposal, and solid-waste disposal. Information is portrayed on 18 state maps at scales of 1:1 million and 1:2 million, with short accompanying texts. Some additional readings are suggested, and a glossary of terms is provided. This general introduction to the state's geology is written for nongeologists: for persons in government and industry who must make practical decisions based on Missouri's geology, and for those who are simply curious about their natural surroundings.

Although the geologic environment has always had an influence upon our society, it has only been in recent years that this influence, in its many aspects, has gained appreciation. Because population increase has greatly intensified competition for use of the earth, it is increasingly important that our social schemes take into account the nature of the earth on which we live. Will we henceforth utilize the earth in some optimum fashion, preserving both its beauty and usefulness for future generations? Or will we ignore the fact that there are practical limits to the earth's capacity to accommodate our social "developments"?

The earth provides minerals, water, and space to live, but we can no longer afford to chaotically exploit these finite provisions. We must therefore develop a better understanding of our physical surroundings, and designs for our future must be based on such an understanding. This will require many detailed studies in order to refine the existing general knowledge of Missouri's geology – especially in those areas where human geography is rapidly changing. We hope that this report will provide a context for such detailed studies and generally increase the awareness of Missourians about the land on which they live.

ACKNOWLEDGEMENTS

This report is based on the work of many geologists, past and present, who have spent years in the study of Missouri's geology. We regret that they are too numerous to name, because it is to them that credit is ultimately due.

We acknowledge the invaluable advice given by members of the staff of the Missouri Geological Survey and Water Resources during the compilation of this report; we particularly thank Larry D. Fellows, Dale L. Fuller, James A. Martin, and James H. Williams. We are grateful to Douglas R. Stark, George C. Miller, William G. Ross, and Stephan W. Hardesty for their painstaking preparation of the maps.

Eugene L. Horton of the Missouri Department of Community Affairs coordinated our work with related projects funded through that office; his support and cooperation are greatly appreciated.

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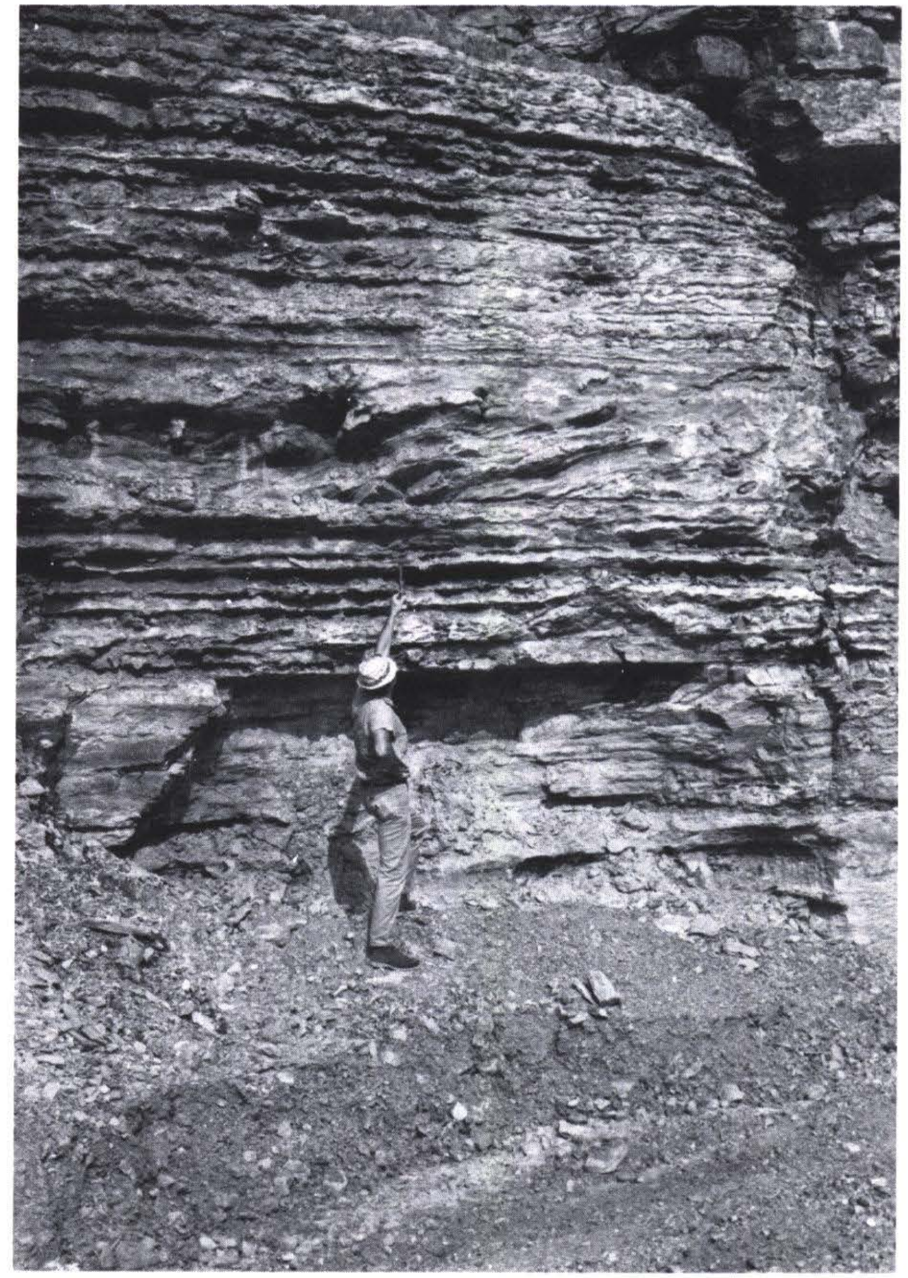
Additional published and unpublished information on Missouri geology is available from the Missouri Geological Survey and Water Resources.

Bedrock geology

SECTION 1

by Larry N. Stout



An exposure of Mississippian limestone along Tanner Branch, McDonald County illustrates the layered structure of sedimentary rocks. (Photo by L.D. Fellows, Missouri Geological Survey)

Source areas of raw materials and minerals which are the basis of industry are prescribed by the distribution of the various kinds of rock. Character of soils and construction conditions are often dramatically different above different kinds of bedrock. Some rocks yield large volumes of high-quality water for industrial, municipal, and domestic use. For these and many other reasons, the fundamental data of geology are of great importance. The accompanying generalized geologic map shows the distribution of different types of bedrock in Missouri. Although more than 200 formally recognized rock units (formations and their various members) are present within the state, these have been synthesized into 18 mostly composite units suitable for portrayal at a small scale. Where thick alluvium covers the bedrock surface, as in the valleys of the Missouri and Mississippi rivers, distribution of bedrock units is not shown. Whereas the geologic map is a two-dimensional representation of a surface, bodies of rock are three-dimensional masses of variable geometry which normally are extensive in the subsurface away from their exposures. To better interpret the geologic map and others which follow it, some understanding of the processes operating through Missouri's long geologic history is important:

Missouri's oldest rocks (of Precambrian age) are exposed over several hundred square miles in the southeastern part of the state and are continuous throughout the remainder of the state beneath a cover of younger, distinctly different rocks. Because these Precambrian rocks are more or less deeply buried in most areas and are the deepest materials penetrated in drill holes, they are collectively referred to as the basement; they are a complex assemblage of mostly igneous rocks (such as granite and felsite), formed during a long interval of highly energetic geologic processes involving widespread melting and recrystallization of even older materials. The Precambrian rocks thus testify to conditions vastly different from those which have since prevailed in Missouri.

Subsequent erosion removed a great thickness of the Precambrian rocks over an interval of half a billion years or more, shaping an ancient land surface preserved today beneath Missouri as the surface of the basement. As indicated by drilling, this surface has considerable relief and includes peaks as high as 2000 feet. These peaks are partially exposed today in the St. Francois Mountains of southeastern Missouri. The long-continued erosion was halted when large areas, including Missouri, slowly foundered and were progressively inundated by an epicontinental extension of the sea. Ocean waters advanced and receded over parts or all of the state many times during the following half billion years. The position of the migrating shoreline during this long interval was primarily controlled by fluctuations of general continental elevation relative to sea level, but in detail was also evidently controlled by tilting and relative vertical movement among large, fault-bounded blocks of the earth's crust. Through these movements, certain areas have persistently stood higher than others and are thus called uplifts, while adjacent, relatively depressed areas constitute basins.

Weathered and disaggregated rock material eroded from land areas was washed into the epicontinental seas and broadly distributed by currents; this terrigenous debris, consisting of clay, silt, sand, and sometimes gravel, slowly accumulated on the sea bottom in successions of comparatively thin, but widespread layers of sediment which today are represented by such bedded rocks as shale and sandstone. Precipitates of substances dissolved in sea water (chiefly calcium and magnesium carbonate) were also intermittently deposited, forming beds of chemical sediment such as limestone and dolomite, which commonly incorporate nodules and layers of chert (flint). Owing to variation in the influx of terrigenous material and changing chemical conditions in the sea, individual beds vary widely in the relative proportions of fragmental and chemical components. Some layers were composed mainly of coarser terrigenous grains, forming sandstones; others consisted mostly of a calcium-carbonate precipitate, forming limestones. Most beds were admixtures of several materials, producing intermediate rock types such as shaley dolomite, calcareous sandstone, and sandy shale. In addition, marine organisms were often incorporated in accumulating sediments, and calcareous or siliceous shells (now fossils) formed a large part of many beds.

Countless episodes of sedimentation took place during the shifting transgressions of the sea, interspersed with sporadic uplift above sea level and erosional beveling of previously deposited sediments. The persistently subsiding basins received a greater thickness of sediments than did adjacent uplifts, which did not subside as much or were more often emergent above the sea. The ever-changing ancient geography, with shifting sites of sedimentation and erosion, thus produced complex sequences of beds bounded at various levels by irregular surfaces of erosion, called unconformities. The composite thickness in Missouri of these beds, formed successively during the Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian periods of geologic time (the greater part of the Paleozoic era), is some 10,000 feet; however, due to the geographic and temporal inconstancy of the geologic processes, no single place in the state is underlain by a complete succession. The actual maximum thickness of these strata is about 3,700 feet, in the Forest City basin of northwestern Missouri, where subsidence was most prevalent; in contrast, the broad Ozark uplift, although often entirely submergent, received a generally thinner cover of sediments and has lost all but the older, lower Paleozoic beds through subsequent erosion. Other prominent structural elements which have influenced the sequence and present distribution of sedimentary rocks are the Lincoln fold, an elongate uplift in northeastern Missouri, and the Mississippi embayment, which has had a relatively complex structural history. In addition, there are many lesser structures which have had local or short-term influence on the stratigraphic succession.

Throughout Missouri's geologic history, the earth's crust has adjusted to slow, large-scale movements by buckling and rupturing, so that the sedimentary rocks are characterized by numerous gentle flexures and countless small faults. Along most faults, cumulative vertical displacements amount to only a few feet, but on some exceptional faults the displacement is measured in hundreds of feet. Although movement along near-surface faults has not been observed in Missouri during historic times, many tremors are recorded each year. Several quakes have been strong enough to cause some damage, and the New Madrid earthquake of the early 1800's, centered in the Mississippi embayment, was one of the greatest ever recorded. Thus, the earth beneath Missouri is not static, particularly in the southeastern part of the state.

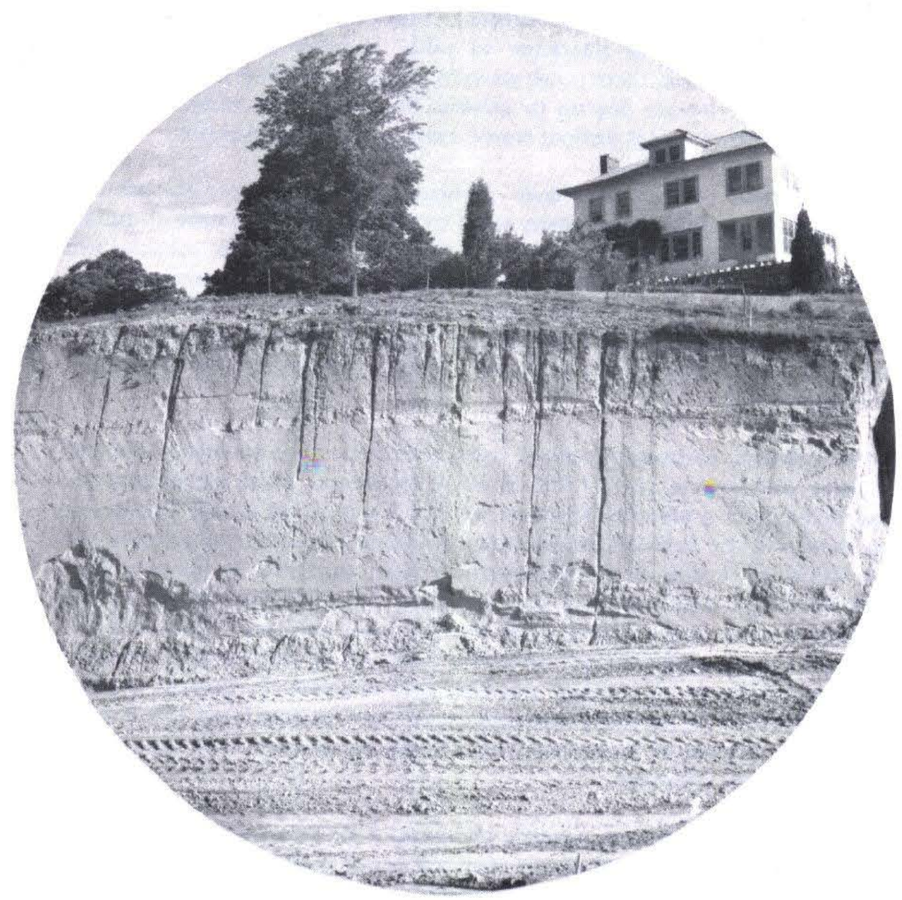
More than 250 million years ago, at the end of the Pennsylvanian period, the sea withdrew from Missouri and subsequently encroached only upon the southeastern corner of the state, where sands and clays were deposited in seas of the Cretaceous and Tertiary periods. Most of Missouri has thus undergone erosion for the last quarter billion years, and vast quantities of the uppermost sedimentary rocks have been stripped away, particularly from the high-standing Ozark uplift. However, during the recent Pleistocene epoch ("ice age"), continental glaciers sequentially covered most of northern Missouri, depositing scoured clays, sands, and gravels. (These and other unconsolidated deposits are shown on the surficial materials map.)

Basically, the geologic map shows the modern geography of the ancient sedimentary strata. Erosion has bared peaks of the Precambrian basement in the St. Francois Mountains, at the crest of the Ozark uplift, and the layered deposits of post-Precambrian seas are in general tilted away from this structural high in all directions. Erosion-truncated beds intersect the surface of the land in a crudely concentric pattern; oldest (stratigraphically lowest) strata are exposed around the St. Francois Mountains, and a traverse away from this center of uplift crosses progressively younger (stratigraphically higher) beds. The synthetic map units, each representing many individual beds, thus form broad, annular belts; the inner edge of each belt encloses an area where only older rocks remain, and the outer boundary of each belt is the line along which the given strata dip into the subsurface beneath younger beds. Because the inclination of beds is generally only a few degrees, at most, from horizontal, outcrop belts are many times wider than the aggregate thickness of constituent strata (measured perpendicular to bedding surfaces).

Departures from this ideal outcrop pattern arise from geographic variation in the sedimentary sequence (for instance, the outcrop belt of Mississippian rocks peripheral to the Ozarks is discontinuous, reflecting a major unconformity), from dislocation of strata by faulting (as across Ste. Genevieve County), and from incision into the layered rocks by ongoing erosion (forming complex extensions of outcrop belts along valleys). Furthermore, differential erosion has left numerous isolated outliers, appearing as islands within the outcrop belts of older, underlying strata (for example, the large outlier of Mississippian rocks in eastern Taney County); numerous such outliers are very small. Conversely, where strata are locally arched, erosion has exposed isolated inliers of older beds within the outcrop belts of younger rocks (such as the inliers of Cambrian rocks in Camden County, far removed from the principal Cambrian outcrops in southeastern Missouri).

Although each of the common varieties of sedimentary materials was deposited during each of the geologic periods from Cambrian through Pennsylvanian, rocks of certain ages have a generally distinct character. Cambrian and lower Ordovician strata are predominantly thick dolomites; Mississippian rocks are mostly thick limestones; and the Pennsylvanian succession is characterized by an alternation of thin shales, limestones, and sandstones. Unique to the Pennsylvanian deposits are a number of coal beds, formed by accumulations of organic matter in ancient coastal swamps.

Surficial materials



An excavation in the Kansas City area reveals thick loess typical of areas along the Missouri River. (Photo by J.D. Vineyard, Missouri Geological Survey)

Surficial materials comprise all the fragmental, unconsolidated or semiconsolidated materials which overlie bedrock. Thickness of such materials varies greatly, being nil in some areas where erosion has kept pace with rock weathering, but reaching as much as several hundred feet where there has been extensive redeposition or in situ accumulation of rock debris. The nature of in situ accumulations of weathered rock is largely a function of bedrock composition, whereas materials redeposited by water, glacial ice, or wind often bear no relation to the bedrock upon which they rest. Weathering of rocks is induced primarily by the chemical reactions of water with mineral grains. Such reactions are facilitated where rock is fractured, increasing the surface area exposed to water. Extensive vertical fractures are common to practically all consolidated rocks, and many smaller fractures are produced near the surface by frost action and wedging by plant roots. Plant debris supplies acid to percolating water, which greatly increases its capacity to corrode rocks.

The carbonate rocks limestone and dolomite, which are particularly susceptible to solution by water, are widespread in the Missouri Ozarks; such rocks are slowly dissolved by groundwater, both at the bedrock surface and at depth in cavern systems. Calcium and magnesium bicarbonate are removed in solution. Such removal is facilitated by the appreciable topographic relief in the Ozarks, which makes for generally higher groundwater flow rates near the surface. Particles of clay, grains of sand, and nodules of chert are far less soluble than the enclosing carbonate rock and thus accumulate at the bedrock surface as a residue (residuum). Large fragments of chert in such residuum serve to stabilize finer particles and increase the permeability of the material, thus retarding erosion by surface runoff.

Residual materials slowly creep downslope on hillsides, under the influence of gravity and slopewash; such material in the process of migration to valley bottoms is called colluvium. Colluvium is thickest at the base of a slope; there it merges with alluvium, which is rock debris that has been transported and sorted to various degrees by streams. By the sorting action of running water, alluvium is segregated into more or less distinct gravel, sand, and silt-clay deposits.

Where solution of carbonate bedrock has been particularly intense, most rainfall may infiltrate, rather than running off in streams, and many small valleys in the Ozarks have no surface flow except immediately after a hard rain. Such vertical infiltration flushes finer particles into bedrock cavities, and alluvium in these dry valleys consists mostly of coarse chert gravel and sand. Enlargement of near-surface solution voids in carbonate bedrock has often caused collapse of overlying surficial materials, forming sinkholes. Sinkholes are scattered throughout the Ozarks, as well as on parts of the carbonate-rock terrain of northeastern Missouri; where they are numerous, the pitted land surface is termed karst.

Owing to differential solution, carbonate bedrock surfaces in some areas are highly irregular, sometimes having pinnacles with several tens of feet of relief. In general, these irregularities are hidden by a smooth mantle of residual material. In places, vertical fractures are greatly enlarged by solution, creating deep chasms in the bedrock surface which are filled and hidden by residuum. In some cases, very large blocks of limestone or dolomite have been separated by solution from bedrock proper and left "floating" within residual clay and chert. Thus, the thickness of surficial materials in carbonate-rock terrains of the Ozarks often changes drastically over short distances. Nevertheless, there are some areas underlain by carbonate rock where the bedrock surface is relatively smooth, and the thickness of surficial materials less irregular. In general, surficial materials are thinner on slopes than on adjacent topographically high and low areas, but absolute thicknesses are controlled by a number of factors and are difficult to correlate with topography, bedrock geology, or any other single influence.

In the St. Francois Mountains, bedrock consists of dense, hard igneous rocks which are relatively resistant to both physical disaggregation and chemical breakdown. Fractures are for the most part widely spaced, so that detached bedrock fragments are often large. Accordingly, residuum and colluvium from the weathering of these rocks consists largely of a thin accumulation of boulders within a matrix of fine-grained material. Thickest accumulations are at the bases of slopes. Streams flowing across this igneous terrain typically have numerous boulders in their beds, and there is relatively little fine-grained alluvium; however, many streams flow alternately on igneous and sedimentary rocks, and their alluvium sometimes has a heterogeneous character.

In areas away from the Ozarks underlain by shales, clays, or sandstones, bedrock is not subject to solution, and the zone of weathered rock is thinner. Due to the general absence of chert-bearing carbonate rocks, there are few large fragments among the residual materials, which are thus more easily eroded by slopewash; also, the amount of surface runoff is relatively high, since bedrock in these areas has relatively low permeability. These factors have kept residual materials thin in areas underlain by non-carbonate bedrock. Bedrock topography in such areas more closely parallels the land surface and lacks the major irregularities found in many parts of carbonate-rock terrains. Alluvium is muddy or sandy, and gravel is generally absent.

Upland gravels on ridges and hilltops are present at numerous localities in eastern and southeastern Missouri; these are transported materials, evidently representing relatively ancient erosional processes. Such gravels are widespread on Crowleys Ridge, where they are as thick as 60 feet in places.

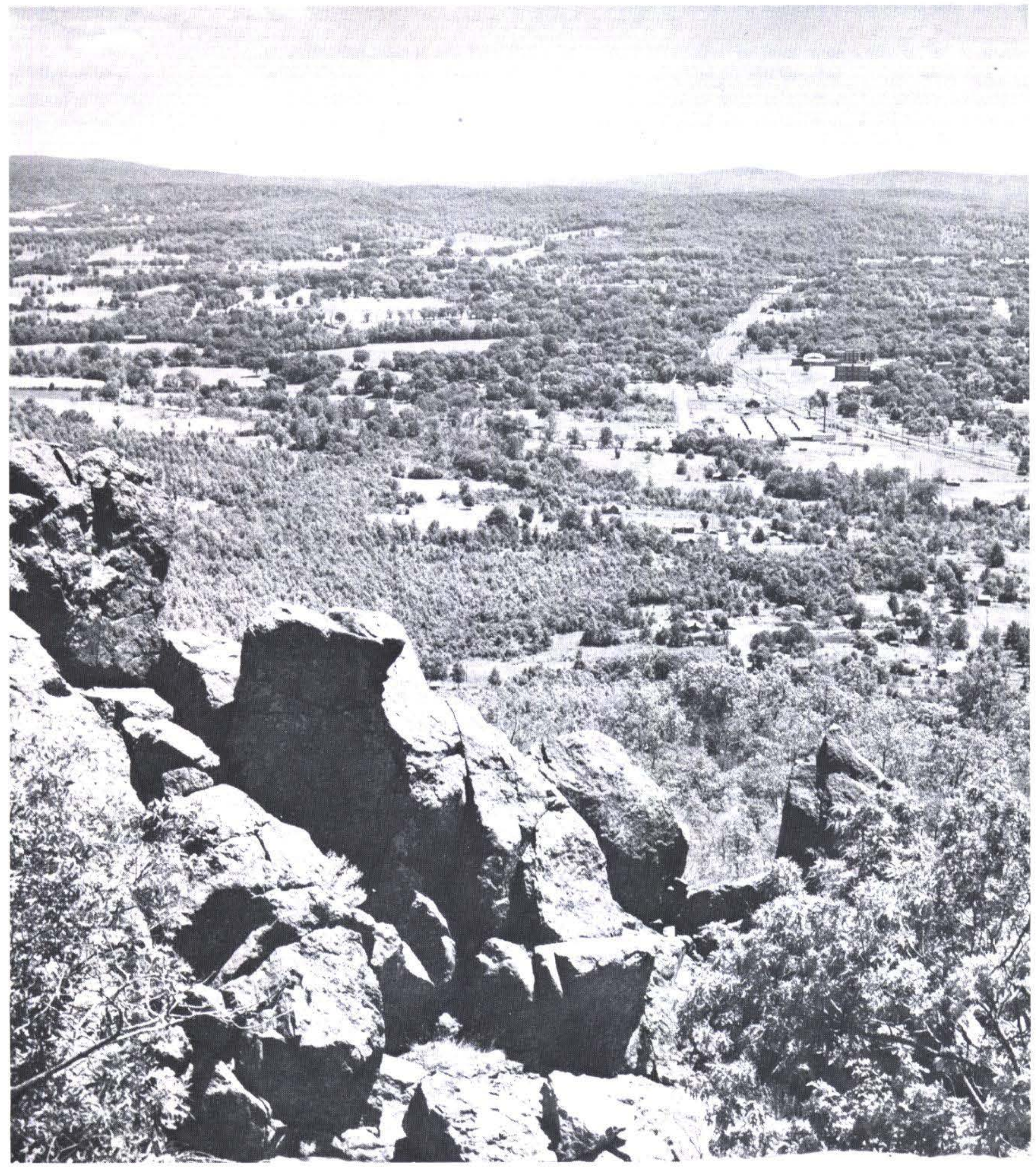
In the valleys of the state's two largest rivers, which drain huge areas underlain by diverse geologic materials, alluvium is largely unrelated to local bedrock geology and has in large part been transported long distances from upstream sources. The floodplains of the Missouri and Mississippi rivers are underlain mostly by sands, with some gravel at the base, near the bedrock surface, and a mantle of silt and clay at the top. In the Mississippi embayment, alluvium is not confined to a valley; rather, in the recent epochs of the geologic past, major river channels have migrated laterally many miles, leaving a broad blanket of alluvium across the lowland. Crowleys Ridge comprises remnants of higher land which escaped destruction by the lateral channel-cutting; a former river channel separates segments of the ridge from the Ozarks. Alluvium in the Mississippi embayment is analogous to that in the valleys of the Mississippi and Missouri rivers, but is somewhat thicker. Although there has been much artificial drainage in this region, the natural drainage of the flatlands is poor, and there are still some swampy areas.

In northern Missouri, there are extensive surficial deposits derived from continental glaciers which invaded the area during the relatively recent Pleistocene epoch of geologic time. Two major ice advances covered a large area of the state, and a third encroached upon a smaller area in and near St. Louis; each major advance was evidently punctuated by several lesser advances and retreats. Huge volumes of sediment were entrained by these glaciers during their southward movement from ice accumulation centers in Canada. Ahead of the advancing ice, meltwater streams carried clay, silt, sand, and gravel into the preglacial valleys of northern Missouri, filling them with more or less poorly sorted debris. Ice subsequently overrode these outwash deposits, leaving an irregular, unsorted deposit of till, consisting mostly of clay, with some sand and scattered pebbles and boulders of both local and exotic rocks. Drainage was sometimes interrupted by ice, forming temporary bogs or shallow lakes in which silt and clay accumulated. Deposition of the various glacier-related sediments was controlled by the complex preglacial topography and by many local irregularities of ice movement; accordingly, the relationships among these sediments are complex, and their thickness is highly variable. The modern drainage of the glaciated area is largely unrelated to the preglacial stream network, but in some cases segments of the older valleys have been reoccupied.

Thickness of the glacial deposits is generally greatest along the courses of the filled preglacial valleys and least over preglacial uplands. The distribution of the major preglacial valleys has been determined by test drilling in northwestern Missouri, but in northeastern Missouri, as well as over much of the southern part of the glaciated area, thickness of glacial sediments and configuration of the underlying bedrock surface is less well known. In general, however, thickness and continuity of these deposits decrease southward toward the Missouri River, whereas bedrock in northernmost Missouri is deeply buried. Alluvium of modern streams in northern Missouri is derived in large part from the blanket of glacial sediments and is thus closely akin to the older outwash deposits in filled valleys. However, in parts of the glaciated area, glacial sediments are now very discontinuous or absent, and surficial materials are more analogous to those of nonglaciated parts of the state.

During late stages of glacier retreat to the north, winds picked up silt and clay from the sediment-choked valleys of the major rivers and redeposited this material as a broad blanket on upland areas over most of the state. Such wind-deposited sediment (loess) is thickest adjacent to the Missouri and Mississippi rivers, particularly along the Missouri River in the northwestern part of the state, where it is more than 100 feet thick in places. Away from the two major rivers, the cover of loess on uplands thins rapidly, and over a large area of southern and southeastern Missouri, there was apparently no loess deposition. Being the most recently formed (topmost) surficial deposit, loess is the parent material of upland soils over most of Missouri; fortuitously, it is in general a more fertile medium than the materials which it covers.

Topography and relief



Terrain of the St. Francois Mountains as viewed from Pilot Knob, a peak of igneous rock. (Photo by G. Massie, Missouri Division of Commerce and Industrial Development)

Topography and Relief

Topography is one of the most significant aspects of the physical environment, since it in large measure determines how and at what cost the land is used. Landforms are evolutionary phenomena produced by the interplay among many geologic processes; there are forces within the earth which act to raise land areas above the sea, whereas running water slowly but relentlessly erodes elevated lands, ultimately carrying weathered rock debris to the oceans. Erosion comprises both transportation of solid particles and chemical solution by water. Winds and glaciers are also important geologic agents which redistribute materials at the earth's surface and thus influence the form of the land, but their roles are greatly overshadowed by the more constant work of rivers and streams. Although water is the immediate agent of erosion, it is powered by gravity, which is thus the ultimate force acting to reduce land areas; there is much slow downslope movement of weathered rock that takes place unaided by running water.

Sea level is called the "base level of erosion," since it is in general the lowest elevation to which any land area can be reduced by running water. On a smaller scale, an individual stream cannot deepen its valley below the elevation of its confluence with a larger stream to which it is tributary; elevations of such confluences are thus local base levels of erosion. Erosion is normally most intense farthest upstream from base level, where stream gradients are greatest; there, erosional landforms such as dissected hills are produced. Stream gradients flatten as base level is approached, and depositional landforms such as alluvial flats are produced. Although erosion goes on constantly, the movement of individual rock particles from higher to lower elevations is intermittent, reflecting the incapacity of running water to keep all available erosional debris in constant transport; there is thus a constant excess of weathered rock material awaiting removal. The distribution of such materials, the slope of the land, and the pattern of drainage are all determined by a number of factors, primarily climate and type of vegetation, physical and chemical properties of bedrock and surficial materials, and broad inequalities of land elevation produced by forces within the earth. The interaction of the several influencing factors can be regarded as an equilibrium, and wherever man alters the landscape, diverts drainage, or changes vegetation, this equilibrium is disturbed. Failure to foresee how nature will act to establish a new equilibrium has sometimes resulted in landslides, collapses, wasting of fertile soils, and a variety of other catastrophes.

Missouri's topography ranges from thoroughly dissected, rugged hill country in the Ozarks to very flat alluvial plains in the Mississippi embayment and the valleys of the major rivers. The state's highest point is the summit of Taum Sauk Mountain in Iron County, at an elevation of 1772 feet above sea level; the lowest elevation is 230 feet above sea level where Little River leaves the state in southern Dunklin County. The state's total relief is thus 1542 feet. Local relief, defined as the difference in elevation between a valley bottom and an adjacent ridge or hilltop, is almost 1000 feet at one place in the St. Francois Mountains. Outside the igneous-rock terrain, maximum local relief does not exceed about 350 feet and is generally in the range 100 to 200 feet. Within a given area, local relief is greatest along the larger streams and becomes steadily less as stream size decreases. Land slopes range from areas which are virtually flat to bluffs which are vertical or even overhung, but outside the alluvial lowlands most slopes are within the approximate range 3-33% (that is, 3 to 33 feet elevation difference per 100 feet horizontal distance). Missouri's highest land is found along a northeast-trending belt from the southwestern to southeastern parts of the state, generally corresponding to the Ozark uplift. A large area along this line is more than 1200 feet above sea level, whereas outside the Ozarks only a small area of northwestern Missouri is higher than 1200 feet.

In the St. Francois Mountains, topography is conditioned by an unusual geologic situation; peaks of igneous rock which are part of the ancient Precambrian land surface have been partially exhumed from a cover of sedimentary rocks. It is thought that these landforms, developed on erosion-resistant rocks, have been little-altered by the process of exhumation. This resistance to erosion has led to relatively high relief in the area, with maximum local relief in the general range 500-750 feet in the vicinity of igneous peaks. Slopes in the St. Francois Mountains area are 10% or less in intermontane valleys, while slopes as great as 35% are common on mountain sides, and in places slopes reach 50%. Although the absolute relief is high, and much of the land is in steep slopes, drainage is not as intricate as in some other areas of Missouri, since the hard igneous rocks inhibit the incision of tributary valleys. Peaks of the St. Francois Mountains are thus smooth, rounded forms, lacking the numerous hollows or gulches which characterize other areas of the Ozarks. Topographic features unique to this area are the so-called "shut-ins," which are abrupt constrictions of stream courses where they pass through narrow defiles between igneous peaks. A "shut-in" thus connects more expansive intermontane valleys underlain mostly by sedimentary rocks.

Outside the St. Francois Mountains, the Ozarks region is underlain mostly by cherty dolomite or limestone. The solubility of these rocks has permitted extensive chemical erosion, with a concomitant suite of physical features peculiar to carbonate-rock terrains. Such features include numerous sinkholes, caves, springs, and other phenomena of karst topography. In general, the Ozarks is a highly dissected terrain; that is, the drainage is intricate, with valleys and ravines closely spaced and often steep-sided. Maximum local relief is in the general range 200-350 feet, and high bluffs are common along the incised valleys of large streams. Although there are some large smoother landscapes isolated within the Ozarks, most of the region is typically in slopes of 10-35%, and slopes as steep as 50% are not uncommon. Both valleys and upland divides are usually narrow. From geologic evidence, it appears that the Ozarks region has been slowly uplifted relative to bordering areas during the recent geologic past; this uplift initiated the dissection by streams which has, over a long period of time, produced the present, generally rugged topography.

Irregular areas of lesser relief and smoother topography are found throughout the Ozarks, surrounded by the more typical rugged terrain. Most such areas are small, but a number of them encompass many square miles. For the most part, they represent relatively undissected divides between major drainage systems, but some areas have a less straightforward relation to drainage. Maximum local relief within these areas is typically 100-150 feet. Surfaces are gently rolling, with slopes mostly less than 10%; some slopes reach 25%, but few are steeper.

In southwestern and west-central Missouri there is a low-relief plain which has undergone relatively little stream dissection. This terrain is developed on thick limestones in its southern part, where there is prominent karst topography in many places. To the north, it is developed on thin shales, sandstones, and limestones, and in part on glacial sediments near the Missouri River, but differences of topography caused by the varying resistance of these materials are minor. Maximum local relief on this plain is about 75-200 feet, with the higher relief found generally in the southern part, nearer the Ozark uplift. There the valleys tend to be narrower and steeper-sided, whereas to the north the terrain is rolling, with broader valleys. For the region as a whole, most slopes are less than 10%; maximum slopes are in the neighborhood of 35% in the south, decreasing to about 25% in the north.

In northeastern Missouri, there is a large area of exceptionally smooth topography and low relief, developed largely on glacial deposits. Within this virtually undissected plain, there is maximum local relief of 75-100 feet, and most of the land slopes at less than 5%. Uplands between streams are thus nearly flat. Maximum slopes of about 25% are found, but slopes exceeding 10% are not common.

The remainder of northern Missouri is mostly a terrain of low, rolling hills. This topography is likewise developed mostly on glacial deposits, but in some areas nearer the Missouri and Mississippi rivers these deposits are thin or absent, and the topography is carved largely on bedrock. From the vicinity of the Lincoln fold south to St. Louis, limestone bedrock is at or near the surface in many areas, and there is significant development of karst topography in places. Maximum local relief on these hilly plains is about 100-200 feet; most slopes do not exceed 10%, and maximum slopes are usually about 25%. Although slopes are uniformly gentle, there is little land with less than 5% inclination. Across the region, intricacy of drainage, or degree of dissection, shows considerable variation, probably reflecting the heterogeneity of glacial materials underlying the surface; for the most part however, the terrain can be described as moderately dissected.

Over the broad Mississippi embayment, and in the valleys of the Missouri and Mississippi rivers, there are alluvial lowlands with nil relief and slopes of only a few feet per mile. These featureless areas constitute the state's flattest land. High bluffs separate the lowlands from bordering terrains in many places, but the change in topographic character in some areas is not abrupt.

Within the Mississippi embayment, the several segments of Crowleys Ridge comprise dissected lands underlain mostly by semiconsolidated sandstones and clays; along the northwestern parts of the ridge, a somewhat more rugged topography is developed on dolomites and limestones. Maximum local relief on Crowleys Ridge is generally 150-200 feet; most slopes are in the range 10-25%, but some are as steep as 50%.

Mineral resources

Crystals of galena, the chief mineral of Missouri's lead-ore deposits and official State mineral. (Photo by G. Massie, Missouri Division of Commerce and Industrial Development)

Missouri's mineral resources are diverse; they include sedimentary rocks such as limestone, concealed metal deposits, coal, and a number of other commodities. The various rocks and minerals are not evenly distributed over the state, and some are found only in relatively restricted areas. Some abundant commodities are practically inexhaustible, while others will eventually be depleted.

LIMESTONE & DOLOMITE. Limestone is basically a hard, calcium-carbonate rock, but physical properties and chemical composition vary considerably. Chert nodules are an undesirable component of many Missouri limestones. Dolomite is a calcium-magnesium carbonate rock of similarly variable properties, also often cherty. These stones are fundamental to industry. Limestone serves as aggregate in concrete and paving materials, as the major raw material for manufacture of cement and high-calcium lime, as agstone, and in other capacities. Dolomite may be useful as aggregate, as raw material for dolomitic lime, as agstone, and as a refractory material. In general, the chemically purer varieties of these rocks are most sought-after, but certain physical properties may be critical for specified applications.

Northern and western Missouri are underlain by numerous thin limestones interbedded with shales and other rocks; these beds are commonly only a few feet thick, but a few are as thick as 35 feet or so. Although they are generally not cherty, shaley partings may be abundant. These stones have been used principally as aggregate and agstone, but also in part in the manufacture of cement. Glacial deposits limit accessibility of the limestones in parts of northern Missouri, and thinness of most beds further hinders exploitation. In southwestern, central, and northeastern Missouri are large areas underlain by thick limestones. These are the most extensively quarried limestones in the state, being used as aggregate and agstone, and for manufacture of cement and lime. They are generally of high quality, but chert content is often high, and some rocks are shaley or dolomitic.

High-quality, chert-free stone is of relatively restricted occurrence, although the absolute available amount is still large. Peripheral to the Ozarks and along the Lincoln fold, various limestones and dolomites with somewhat irregular outcrop patterns are present with other rocks. These stones are of variable quality and thickness, but included are some high-quality rocks extensively exploited for aggregate, agstone, and use in cement manufacture. Except for isolated outliers, most of the Ozarks lacks limestone, but is underlain by thick, mostly cherty or somewhat shaley dolomite; chert-free dolomite is largely confined to the counties surrounding the St. Francois Mountains. In the Mississippi embayment, carbonate rocks crop out only along the northern part of Crowleys Ridge.

CLAY & SHALE. Clays and shales are relatively soft rocks made up of very fine particles of a variety of minerals. Clays have the finest particle size and consist mostly of hydrous aluminum silicates with varying chemical and physical properties. Clays with high alumina content are refractory ("fire clays") and are a raw material for heat-resistant ceramics. Some clays are used in the manufacture of brick, tile, and related structural products, and there are numerous other applications. Shales may consist mostly of clay minerals, but usually have an admixture of coarser, non-clay particles. Certain shales serve as a major raw material of cement, others are used alone or in combination with clays in the manufacture of structural products, and some are amenable to bloating in the manufacture of lightweight aggregate for concrete and other products.

Shales and clays interbedded with other rocks constitute most of the bedrock in western and northern Missouri, and in the St. Louis area. Certain of these materials have been exploited for use in structural products and lightweight aggregate, and the lowermost part of this sequence of strata is the refractory clay of east-central Missouri. Several shales crop out irregularly along the Lincoln fold in northeastern Missouri, where they are in part exploited as cement raw materials. In southeastern Missouri, a variety of clays are widely exposed along Crowleys Ridge; these have been mined only on a limited scale, but they may have considerable potential value. In the Ozarks, there are miscellaneous, isolated clay deposits, some of which have been mined for use in structural products. In addition, loess has served as a raw material for structural products and cement, and alluvium has been used in cement manufacture. Although Missouri's total clay and shale resource is inexhaustible, materials meeting particular specifications may be subject to eventual depletion.

SANDSTONE, SAND & GRAVEL, IGNEOUS ROCKS. Along a narrow belt from southeastern to east-central Missouri, a quartz sandstone of unusual purity crops out. Both the composition (greater than 99% silica) and the uniform grain size of this silica sand make it eminently suitable for manufacture of glass; it is also used in abrasives. Although this sandstone has been extensively exploited, the remaining resource is virtually inexhaustible. Sandstones other than silica sand are found in most parts of the state, but have only limited use as building stone. Unconsolidated sand and gravel deposits are mined in many areas of Missouri and used as aggregate in concrete and other construction materials. Sand is obtained by dredging from the Missouri and Mississippi rivers, gravel and a lesser amount of sand are taken from stream channels in the Ozarks, and some gravel is mined from glacial deposits in northern Missouri and from upland deposits on Crowleys Ridge. In the St. Francois Mountains, granite has been quarried for decorative stone, and some felsite is used to manufacture roofing granules.

LEAD-ZINC ORES, BARITE. Southeastern Missouri's lead-ore deposits are possibly the world's largest, and the known remaining ore can sustain mining for many decades to come. Besides lead, the ores yield significant quantities of zinc, copper, and silver. Cobalt and nickel are present in minor amounts, but are not presently recoverable. The ore minerals contain sulfur, and some byproduct sulfuric acid is produced at smelters; crushed dolomite (tailings) is separated from the ore minerals and in part used as agstone. The ores are of uncertain origin and are concealed in dolomite host rock hundreds of feet below surface; estimation of the total resource is thus not feasible, but it is distinctly possible that some major deposits are still undiscovered. The ores appear to be related to certain favorable sedimentary environments influenced by relief of the Precambrian surface in the environs of the St. Francois Mountains.

Over much of Washington County there are accumulations of barite (barium sulfate) within residuum, above largely barren bedrock. Origin of these accumulations is problematic; their presence at the surface facilitates exploitation, but leaves little prospect of significant future discoveries of similar ore. The identified resource is nevertheless considerable and can maintain Missouri's position as a leading producer for some time. Barite is used mostly as a component of oil-well drilling fluids; a lesser, but important amount is used by the chemical industry in a variety of products.

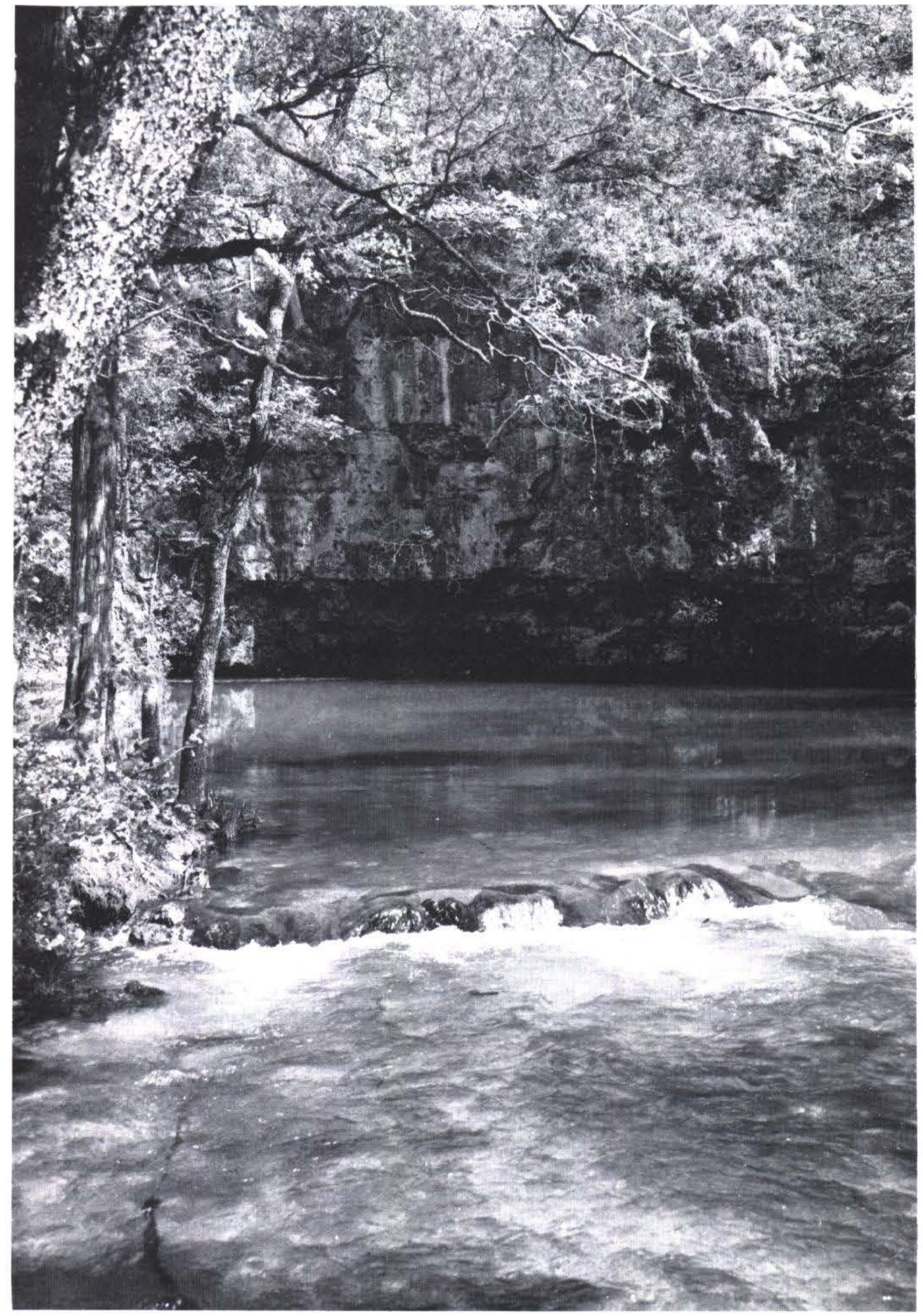
Southwestern Missouri's tri-state area produced zinc-lead ores from cherty limestones for many decades, but known mineable deposits there have been depleted. There are numerous small, scattered barite deposits in central Missouri which have been mined sporadically for many years; this barite is exceptionally pure (chemical-grade), but large-scale mining is prohibited by the small size of the deposits. Minor mineral occurrences are widespread in the Ozarks, and in spite of extensive exploration in the region over many decades, the possibility of significant new discoveries of concealed deposits remains.

IRON ORE. Several large iron-ore deposits are known within the Precambrian rocks of southeastern Missouri; most are covered by some hundreds of feet of sedimentary rocks, but the ore is magnetic, which permits remote detection and also facilitates beneficiation. The two deposits now being mined, together with the larger amount of unexploited ore, constitute a large resource. Significant amounts of copper are associated with some of the unexploited ores, and there is often considerable phosphate (separable from the ore), of which some is used in fertilizer manufacture. Small amounts of other valuable minerals have been found at various places within Missouri's Precambrian rocks, and it is probable that significant deposits of ore other than iron exist in concealed parts of the basement complex; however, exploration and exploitation of these deeply buried rocks will be relatively difficult and uncertain.

COAL. Missouri has a coal resource of 49 billion tons or more, of which about one-third is currently considered mineable. The coal is classed as high-volatile bituminous and has a high sulfur content. More than 40 individual beds have been distinguished, but only 13 or so have sufficient thickness and areal extent to be of importance. The coals are interbedded with clays, shales, sandstones, and limestones and crop out along a broad, irregular belt from southwestern to northeastern Missouri; north and west of the outcrop belt, the coals are present at various depths beneath largely barren rocks, and the overburden of glacial deposits is thick in many areas. Coal is fundamentally important as an energy source, but can also be used to manufacture a variety of chemical products.

OIL & GAS. Missouri produces some oil and gas, but the amount is insignificant by comparison with the major petroleum states. Most production has been from western Missouri, within the Forest City basin, but there has also been some production in the St. Louis area. Certain sandstones present at shallow depth in west-central Missouri are impregnated by a highly viscous oil or asphalt which cannot be recovered by existing means; this material may represent some 30 million barrels of petroleum. Some of the asphaltic sandstone has been mined for use in paving materials. It is possible that significant oil or gas pools may yet be discovered in other parts of the Forest City basin, in the environs of the Lincoln fold, or in the Mississippi embayment. The petroleum potential of the Ozark uplift is nil.

Water resources



Blue Spring on Current River, near Owls Bend: the beautiful large springs of the Ozarks are striking evidence of the region's great water resource. (Photo by J.D. Vineyard, Missouri Geological Survey)

Because of the obvious importance of water to man, knowledge of its behavior, distribution, and qualities is of great utility. The movement of water is termed the hydrologic cycle; this movement is complex in detail, but the overall scheme involves evaporation from oceans, precipitation, and return of water from the continents to the sea via rivers. There are numerous, intricate subcycles. Precipitation which does not run off in streams and which is not evaporated or taken up by plants enters the groundwater system by infiltration through pores and cracks in earth materials. Recycling (discharge) of shallow groundwater may be relatively rapid, but deeper groundwater may reside in rocks for many years, or even centuries.

Water is distilled by evaporation, but precipitation contains small amounts of dissolved atmospheric gases and solids. In movement through soils and rocks, water acquires varying quantities of additional solutes, so the chemical quality of surface and subsurface waters depends in large part on its history of migration. The solubility of different substances in water varies tremendously; the more soluble substances may be present in relatively high concentration, whereas less soluble materials will be present only as traces even if they are abundant in the materials traversed by water.

Surface streams and groundwater are interconnected and can be regarded as parts of a single system, differing mainly in flow rate. Near-surface groundwater may move several feet per day, while some deep groundwater has an immeasureably low velocity. In the special case of water-filled caverns, velocities may be very high. Stream flow consists both of direct runoff from precipitation and a contribution from groundwater discharge. Runoff is subject to wide fluctuations, while the steadier influx of groundwater to a stream reflects the water storage and transmission capacity of the surrounding earth materials.

Water-bearing earth materials are fundamentally divisible into two groups: unconsolidated surficial materials (notably alluvial sands), and bedrock. Alluvial sands beneath the floodplain of a river have high porosity and permeability; accordingly, large quantities of water can be pumped from such materials at a high rate. Sediments deposited by meltwater from former glaciers likewise include considerable sand, but water yields are normally lower due to angularity (and closer packing) of the grains, and due to silt and clay in pores and in irregular beds within the sands.

Storage and transmission of water by bedrock varies with the type of rock. Sandstones are somewhat analogous to alluvial sands, but the grains are packed more closely, and pores may be partially occluded by mineral cement. Open spaces in fine-grained rocks such as shale and clay are so minute that transmission of water can proceed only at an extremely low rate. In the carbonate rocks limestone and dolomite, individual grains usually interlock tightly, and porosity, with some exceptions, is low. However, there are normally sufficient spaces between beds and along fractures to permit appreciable water flow. Also, groundwater slowly dissolves carbonate rocks along cracks and bedding planes, sometimes creating complex cavern systems of large volume. Such caverns greatly increase the capacity for storage and transmission of water, and large springs are found where stream valleys intersect these systems. In igneous rocks such as granite, there is virtually no porosity, and fractures are not susceptible to enlargement; well yields from such rocks are thus low.

In Missouri, the most copious groundwater supplies are present in the alluvial sands of the Mississippi embayment and the Missouri and Mississippi river valleys. In these areas, there is a near-surface water table, porosity and permeability of the sands are high, and large volumes of water can be pumped rapidly from shallow wells. Also, recharge is rapid. Water from the alluvium is hard and contains sufficient iron to cause stains, but otherwise the quality is generally good.

In northern Missouri, groundwater is contained in glacial outwash sediments, but can be obtained in large quantities only from areas where thick sands are present. These areas generally correspond to sediment-filled preglacial valleys, where unconsolidated materials overlying bedrock are as much as several hundred feet thick. Continuity of sands in such deposits is variable and in general not comparable to that of modern alluvium, and the irregular presence of silt and clay within the glacial sediments retards movement of groundwater in many places. The yields of wells are accordingly variable. Maximum yields are similar to those from wells in modern alluvium, but location of favorable well sites is difficult, and moderate to low yields are the rule. The general distribution of filled valleys has been determined by test drilling in northwestern Missouri, but elsewhere in the glaciated region the distribution and character of unconsolidated sediments are not well known. Away from filled valleys, small yields are locally obtainable from thinner, irregular sands and gravels. Water from glacial sediments is hard and sometimes contains considerable iron. The concentration of dissolved substances is extremely variable, probably reflecting upward movement of saline water from bedrock in places, and some of the water has not been usable. Recharge characteristics are commonly poor.

In the Ozarks, groundwater is obtained from bedrock, which there consists mostly of carbonates and interbedded sandstones. There is extensive vertical leakage among beds along fractures, and flow systems are very complex. Under such conditions, individual beds are not readily distinguished as aquifers, since water communicates through the entire stratigraphic sequence. Nevertheless, certain beds such as the Potosi dolomite and the several sandstones are more uniformly permeable over the entire region and are reliable water producers. Wells which fortuitously penetrate water-filled caverns may be capable of relatively high yields.

Much groundwater in the Ozarks discharges as large springs. A large number of springs have flows averaging a million gallons per day or more, and some average more than 100 million gallons per day. Increase of spring discharge corresponds closely to precipitation, demonstrating the general facility of groundwater recharge (and ease of pollution) in the Ozarks as a whole. Although the large springs are spectacular evidence of the great water storage capacity of bedrock in the Ozarks, a far greater total discharge into streams is accomplished by innumerable smaller springs and seeps. In dry periods, this steady discharge maintains the flow of rivers at an appreciable level. In detail, the interrelationship between stream flow and groundwater is often complex; many streams not only are fed by springs, but also lose water through their beds along some stretches. Groundwater in the Ozarks is hard, but otherwise the quality is very good except where pollutants have been introduced. In general, large supplies of good water can be developed anywhere in the Ozarks, except in and near the igneous bedrock of the St. Francois Mountains.

Along the northern and western fringes of the Ozarks, content of dissolved substances in bedrock water increases rapidly. Throughout northern and western Missouri, water in bedrock is excessively saline, except for small amounts of relatively fresh water present locally at very shallow depth. In addition to calcium and magnesium bicarbonate, which produce ordinary hardness, these waters contain variable concentrations of sodium, sulfate, and chloride. This high salinity can probably be ascribed to the long residence time of groundwater in rocks within and around the Forest City basin. The low permeability of shales, particularly in the thick sequence of Pennsylvanian rocks, allows only an extremely slow transmission of water to discharge areas, and chemical reactions with rocks are protracted. The shales may also act as filters, slowly passing water molecules, but retaining dissolved salts. Along the transition zone bordering the fresh water of the Ozarks, excessive pumping can cause local outward migration of this saline basin water into wells. Because of the low groundwater discharge rate, stream flow is very poorly sustained during dry periods, and in parts of northern and western Missouri artificial storage of surface water is required.

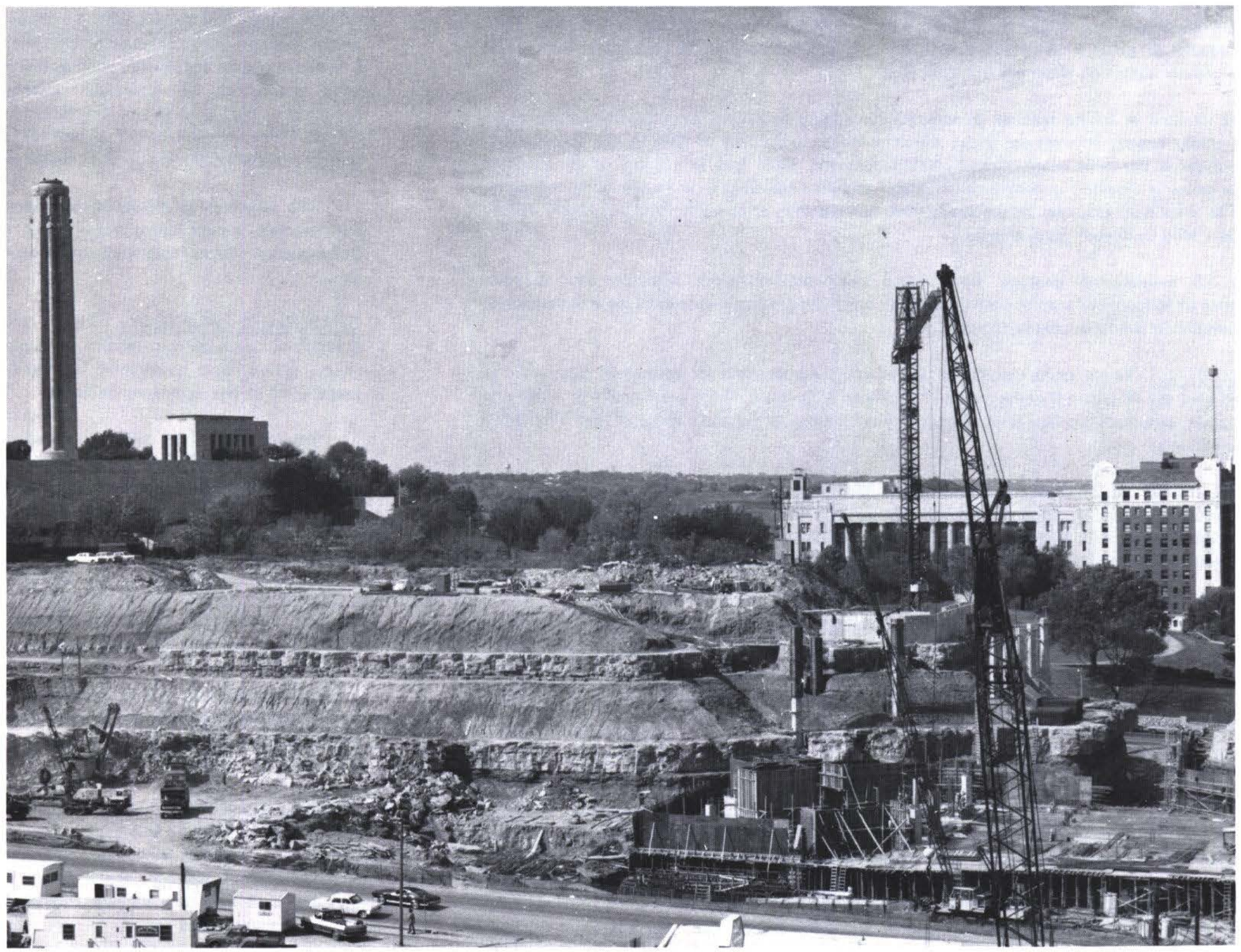
In the Mississippi embayment, a thick, poorly consolidated sandstone (Wilcox sand) directly underlies the alluvial cover south and east of Crowleys Ridge. This formation is somewhat less permeable than the alluvial sands, but the yields from wells are still high. Water from the Wilcox is hard, but commonly has less iron than water from alluvium, and the general quality is good. Direct connection with the overlying alluvium over most of the area permits rapid recharge. Deeper in the subsurface of the embayment, dipping southeast from exposures along Crowleys Ridge, is the McNairy or "Ripley" sand, which is separated from the Wilcox by thick, impermeable clays. Unlike other Missouri waters, that from the McNairy is soft; it is also low in iron. Water yields are not high, however, and locally may be very low due to high silt and clay content. Recharge is confined to areas in and near the exposures. Southeastward, the McNairy sand increases in depth to as much as 2500 feet below surface, but artesian flow from wells is common.

In summary, groundwater supplies are abundant in alluvium along the large rivers and in the Mississippi embayment. In the embayment, additional large supplies are available from poorly consolidated sandstone in the subsurface. Throughout the Ozarks, groundwater from dolomite, sandstone, and limestone is abundant, but supplies in igneous rocks of the St. Francois Mountains are small. In northern and western Missouri, groundwater in bedrock is excessively saline, except for minor amounts of near-surface water. Erratic supplies of usable water are obtainable from glacial deposits in northern Missouri, but quality may be marginal and recharge poor. In contrast to the Ozarks, streams in northern and western Missouri are not well-sustained by groundwater discharge, and artificial storage of surface water has often been necessary. Virtually unlimited water supplies are available from the Missouri and Mississippi rivers, but extensive treatment is required.

Engineering geology, impoundments, liquid and solid waste disposal

SECTION 2

by David Hoffman



Construction on interbedded Pennsylvanian shales and limestones in Jackson County. (Photo by J.D. Vineyard, Missouri Geological Survey)

ENGINEERING GEOLOGY MAP

INTRODUCTION. The engineering geology map portrays general characteristics of near-surface materials that affect the location, engineering design, construction, and behavior of all structures and facilities except those with very deep foundations. The physical properties of the aggregate of near-surface materials (soil and/or bedrock) have been the criteria for designation of map units. Similar-behaving soils and rock formations have been grouped together without regard to their age, texture, profile, mineralogy, lithology, stratigraphy, structure or location.

Drawing of the intricate boundaries between units had to be greatly generalized to fit the scale of the printed map. Transition zones and local variations could not be shown. Because of these limitations, the mapped boundaries are based on the characteristics of materials on uplands and ridges. Because of the map scale, many details have been omitted. Typically, the boundaries between units are not as distinct as the line shown on the map. Transition zones with intermediate properties usually exist on both sides of a map-unit boundary. Also, isolated areas of material mapped as one unit may exist within the boundaries of another map unit.

Where karst topography is present, it takes precedence over all other factors and classifications. All known large areas of concentrated karst have been shown. Where the area of concentrated karst was too small to encircle with a line, the letter "K" appears on the map. Isolated sinkholes or small areas of karst exist at many other places where carbonate rocks are at or near the surface, although these are not indicated.

Losing streams or losing reaches of streams have been indicated by superimposition upon other map units. Losing streams are those which decrease in volume of flow in the downstream direction, which is the reverse of normal stream behavior. Such loss in volume of flow occurs because the water is diverted underground through solution openings in the underlying carbonate bedrock. The flow may reappear in springs further downstream or as springflow in another valley, or it may be added to deeper groundwater.

Some 23 engineering geology units have been delineated to describe the soil-rock characteristics of Missouri related to land use. These units are grouped into seven general categories and are described in the following paragraphs.

ALLUVIAL SOIL. These units consist of unconsolidated deposits of water-laid sediments in river valleys and the Mississippi embayment ("Bootheel"). Because of the narrow valley width and small map scale, alluvium has not been shown in river valleys other than those of the Mississippi and Missouri Rivers.

Alluvial soils in the Missouri and Mississippi River floodplains are 100 to 150 feet thick, except for isolated thinner deposits. In the "Bootheel," the thickness of alluvial soils increases, and alluvium merges with the underlying, poorly consolidated sandstone bedrock. Typically, the upper 20 feet of alluvial soil is a silt, silty clay, or clay. Below this level there is an increase in sand and gravel.

Many alluvial deposits in valleys of northern Missouri range from 40 to 60 feet in thickness. These deposits are silt loam to silty clay, with low percentages of sand and gravel. In the Ozarks, alluvial deposits typically range from 20 to 30 feet in thickness and are usually very gravelly. The Osage, Gasconade, and Meramec River valleys have alluvial soil thicknesses of 40 feet or more and contain significant groundwater supplies.

Developments on alluvial soils must tolerate flooding.

GLACIAL DRIFT. Glacial drift consists in general of silty clay mixed with stones. Pockets, lenses, and buried channels of water-bearing sand and gravel also exist. The modern surface soil has a thickness of 5 to 8 feet. This surface soil, in part deposited by wind (loess) has developed a relatively impermeable clay layer (claypan) at depths of 2 to 3 feet on the flatter portions of the upland terrain in the central and eastern parts of northern Missouri. This is underlain by increasingly silt-rich subsoil to a depth of 6 to 8 feet, where a clay-rich zone is again present. Typical glacial deposits of brown silty clay mixed with some stone fragments (of gravel to boulder size) underlie this lower clay-rich zone. The hillslope surface soils are clay textured, but an actual claypan development may be faint or absent. In northwestern Missouri, the thick glacial soil has a clay texture, but does not have the prominent claypan development characteristic of the flatter upland portions of east-central and eastern Missouri.

Where glacial drift is thin, character of the underlying bedrock is of importance. Under part of this area bedrock is a sequence of thin limestones and some coal beds interbedded with thicker shales and sandstones. In some places the limestones may be as much as 20 to 30 feet thick, but usual thicknesses are only a few feet. Under the remainder of the area, bedrock is massive limestone.

MIXED BEDROCK TYPES WITH THIN SOIL COVER. The bedrock of these units is composed of interbedded layers of two or more of the following rock types: carbonates, sandstone, shale, and coal. Typical thickness of bedrock units ranges from 5 feet to 30 or more feet. The soil cover is thin (less than 40 feet), and the soil type and its properties vary with the underlying bedrock type.

Where limestone is present, solution activity may have formed caves, crevices, sinkholes, and springs. The limestones usually have a high permeability because of their many solution openings. The sandstones usually have a high permeability due to vertical and horizontal fissures and porosity of the rock. The shales are very impermeable except where fractured.

SANDSTONE BEDROCK-SOIL. These units, although differing in thickness of soil, exhibit similar engineering properties and relationships with the underlying parent bedrock. The bedrock is predominantly sandstone, although some beds of dolomite are present or have existed prior to deep weathering. Groundwater recharge is significant, since bedrock permeability is high, particularly along numerous fractures. The unweathered bedrock is competent. However, in the central Ozarks most bedrock exposures have been deeply weathered, and these units in general are poorly consolidated rock and soil materials.

The soils vary in thickness, but do not exhibit significant variation in physical characteristics. Soil texture ranges from very stony, with little silt and clay, to very clay-rich materials. Permeability ranges from high in the stony areas to low where clay becomes predominant in the soil.

CARBONATE BEDROCK. These units consist of thick carbonate rocks (dolomite and limestone), representing several geologic formations. The soil overburden has an admixture of chert, gravel, and sandstone boulders. The soil has developed as residuum from chemical weathering of the carbonate bedrock.

Weathering of the thick carbonate formations is attested by the prominence of pinnacles, caves, springs, and isolated, massive bedrock bluffs projecting through a mantle of soil. Dry stream valleys and streams with low flow also characterize the area. Loss of all or part of the flow of many surface streams to underground channels represents a serious threat to groundwater where surface streams become polluted.

Weathering processes have formed a variety of soil types ranging from very stony soils to soils with a predominant clay texture. An unusual, red, nearly pure clay soil abundant in this area has high permeability, as do the more stony soil types. A less abundant, but more typical-behaving clay soil, usually having a lower clay content, has low permeability.

Karst terrains are a very important special case of carbonate bedrock areas. These are areas of land having numerous sinkholes and little or no surface drainage in streams. The sinkholes are the surface expression of subsurface collapse, resulting from chemical removal of sizeable amounts of bedrock by groundwater solution.

Karst topography normally occupies upland areas of low relief, generally lacking well-defined surface streams. The sinkholes act as natural funnels for surface drainage. A well-developed karst topography indicates integrated underground drainage. Surface water from rainfall, sewage treatment plants, lagoons, septic tanks, and landfill drainage would be funneled underground in the karst area and then resurge in springs at a lower level or become part of the groundwater supply. Sinkholes and regions of high internal drainage are widespread across southern and central Missouri. However, only the regions of moderate to dense sinkhole concentration are shown.

RESIDUAL SOIL. This unit represents the thickest soil cover in Missouri. Residual soil consists of insoluble remnants of bedrock that has been subjected to extensive weathering and solution. The original bedrock was predominantly carbonate (limestone and dolomite), with some sandstone. The limestone and dolomite have been dissolved, leaving an insoluble soil residue of clayey material mixed with chert fragments up to boulder in size. There may be large masses of sandstone in the residual soil profile that have been little affected by the weathering processes. As a result, various amounts of sandstone may be encircled by the residual stony clay. The residual soils of this unit are more than 100 feet thick; locally they are more than 300 feet thick.

IGNEOUS BEDROCK. Igneous bedrock underlies the central portion of the St. Francois Mountains. The exposed igneous bedrock includes rhyolite, granite, and indurated volcanic ash. A different variety of soil is associated with each major type of bedrock. This complexity is heightened by the sporadic presence of carbonate bedrock. The granite weathers to form moderately permeable soil, particularly where joints (rock fractures) are well developed. Rhyolite, however, usually forms barren rock knolls covered only by a veneer of soil.

The most serious problem in the igneous bedrock area is insufficient quantity of soil, rather than unfavorable quality. Generally, soil developed on igneous bedrock is a well-mixed deposit of sand, silt, and clay that has good water-holding capabilities. There are local situations where permeable soil, usually associated with weathered granite, may cause seepage losses from sewage lagoons or lakes.

IMPOUNDMENT, LIQUID-WASTE DISPOSAL, AND SOLID-WASTE DISPOSAL LIMITATIONS MAPS

These maps have been prepared using qualitative information based on regional assessments rather than on detailed studies. Thus, the maps are to serve as initial guidelines and not as final site-selection and operational procedures.

The rating system considers the number and complexity of engineering-geology problems and the associated cost of delineating and solving these problems. The economic-feasibility portion of the rating is based on an assumption of limited financial resources of the many average- and small-size non-metropolitan communities of the state. Assuming unlimited funds, almost any project is possible, and there would be little need to utilize these maps.

The rating is based solely on engineering-geology considerations. The suitability of an area for development based on other factors, such as accessibility, resources, manpower, aesthetics, etc., has not been considered in any way.

Within an area having a given rating there exist small areas of higher and lower ratings. Larger-scale maps, together with on-site field studies, would be necessary to delineate these smaller areas. Facilities that require a small area of land for their construction can sometimes take advantage of locally favorable land situated within an area mapped regionally as having a low rating.

These maps can be used more effectively if they are used in conjunction with the engineering geology map. From a limitations map, nearby areas of higher ratings may be located, and then from the engineering geology map an idea of the nature and properties of the particular area may be found.

In the rating of an area, consideration was given to the type and number of problems that exist. Impoundments, liquid-waste disposal facilities, and solid-waste disposal facilities must all have water-retention capability to perform satisfactorily. Any condition that would affect either short- or long-term water-holding ability is of major importance. Therefore, highly permeable soil or insufficient soil over permeable bedrock constitutes a severe limitation to the operation of these types of facilities. Groundwater pollution would also occur in the case of liquid- and solid-waste disposal facilities. In some cases it is economically feasible to perform remedial work and use such a site if no other problems exist. If the leakage problem is due to karst, or if there is potential for surface collapse in thick residuum, then remedial work is almost always too costly. Some of the lesser problems that limit the usability of a site are: poor slope stability, high erosion rates, swelling soils, and the weakening effect of freezing and thawing on some soils.

ENGINEERING GEOLOGY MAP – LEGEND

Al–Tc THICK CLAYEY ALLUVIAL SOIL: a clay-textured surface soil that becomes coarser at depth; greater than 40 feet thick; low permeability; high strength when dry, but low strength when wet

Al–Tm THICK SILTY ALLUVIAL SOIL: a silt-textured surface soil that becomes coarser at depth; greater then 40 feet thick; moderate to high permeability; moderate strength when dry, but low strength when wet

Al–Ts THICK SANDY ALLUVIAL SOIL: a sand-textured surface soil that becomes coarser at depth; greater than 40 feet thick; high permeability; high strength

Al–Tu UNDIFFERENTIATED THICK ALLUVIAL SOIL: a soil that varies in texture over short lateral distances and becomes coarser at depth; greater than 40 feet thick, but locally thin; permeability and strength vary with texture

Gl THICK GLACIAL SOIL: a silty clay mixed with stones; greater than 40 feet thick; low permeability, with a slight increase in northwestern Missouri; poor internal drainage; swelling of clay subsoil; slope failures on hillslopes; freez-thaw breakup of roads

Gl–Cy THIN GLACIAL SOIL OVER CYCLIC BEDROCK: a silty-clay soil mixed with stones, covering several types of bedrock; less than 40 feet thick; low permeability; where massive limestone is present, stone content and permeability increase; slope-failure problems; freeze-thaw breakup of roads; drainage impedence by impermeable bedrock

Gl–Ca THIN GLACIAL SOIL OVER CARBONATE BEDROCK: a silty-clay soil mixed with stones, covering massive limestone bedrock; less than 40 feet thick; low permeability, with swelling clays and poor internal drainage; solution features, including pinnacles, small caves, and springs, in the limestone; leakage and excavation problems where limestone is near the surface

C–S POORLY CONSOLIDATED CLAYS, SHALES, SANDS AND GRAVELS: thickness variable; permeability high in sands and gravels, but low in clays and shales; easily excavated, except for cemented sandstone and shale layers; stability and bearing capacity poor to fair; more permeable portions serve as groundwater recharge areas

Cy CYCLIC SEDIMENTARY BEDROCK: silty-clay soil over bedrock of shale, sandstone, limestone, and coal; soil and rock have low permeability; soil thin, increasing to 25 – 35 feet in the north; water ponds on the surface; lack of soil in some areas; slope-failure problems

Ca–Cy CARBONATE AND CYCLIC BEDROCK: Western Missouri - silty-clay to silty-loam soil over alternating limestone and shale; limestones 20 – 40 feet thick; shales 5 – 15 feet thick; limestone permeable; limestone is a valuable resource and is mined; soil less than 40 feet thick has low permeability and slope-failure problems. Eastern Missouri - silty, gravelly, clay soil over sandstone and shale and some limestone; many ancient sinkholes filled with fire-clay deposits; soils have low permeability except the lower horizons that are over sandstone; soil 10 – 30 feet thick; bedrock ledges frequently protrude

Ca–Sh CARBONATE BEDROCK WITH SOME SHALE: clayey-silt soil over massive limestone and some shale; soluble limestone; slope-stability problem where thick shale is present; soil thickness less than 30 feet; soil moderately permeable

Ca–SS CARBONATE BEDROCK WITH SOME SANDSTONE: stony, silty-clay soil over massive limestone with sandstone beds; bedrock has moderate to high permeability; soil less than 30 feet thick, with moderate to low permeability; water leakage through soil and rock.

SS SANDSTONE BEDROCK: little soil cover over massive sandstone bedrock; high permeability; in southeastern Missouri this is a groundwater recharge area for an important aquifer; soil averages 10 feet or less in thickness and frequently may be 2 or 3 feet; silty to sandy clay soil

SS–T THICK RESIDUAL SOIL OVER SANDSTONE BEDROCK: stony, silty-clay soil over sandstone bedrock; sandstone highly permeable; soil 40 – 100 feet thick; soil permeability high to low; catastrophic sinkhole collapses; hillslope erosion can be severe; slope stability fair to good

SS–I INTERMEDIATE-THICKNESS RESIDUAL SOIL OVER SANDSTONE BEDROCK: stony, silty-clay soil over sandstone bedrock; sandstone highly permeable; soil 20 – 40 feet thick; soil permeability high to low; catastrophic sinkhole collapse may occur; hillslope erosion can be severe; slope stability fair to good.

SS–S SHALLOW RESIDUAL SOIL OVER SANDSTONE BEDROCK: stony, silty-clay soil over sandstone bedrock; sandstone highly permeable; soil less than 20 feet thick; soil permeability high to low; occasional sinkhole collapse; hillslope erosion can be severe; slope stability fair to good; thin soil cover

Ca–T THICK RESIDUAL SOIL OVER CARBONATE BEDROCK: stony, red clay soil over carbonate bedrock; soluble, highly permeable bedrock; soil 40 – 100 feet thick; soil permeability low to high; moderate to high strength unless wetted; danger of pollution and failure of water impoundments because of high permeability

Ca–I INTERMEDIATE-THICKNESS RESIDUAL SOIL OVER CARBONATE BEDROCK: stony, red clay soil over carbonate bedrock; soluble, highly permeable bedrock; soil thickness 20 – 40 feet thick; soil permeability low to high; moderate to high strength unless wetted; danger of pollution and failure of water impoundments because of high permeability

Ca–S SHALLOW RESIDUAL SOIL OVER CARBONATE BEDROCK: stony, red clay soil over carbonate bedrock; soluble, highly permeable bedrock; soil less than 20 feet thick; soil permeability low to high; moderate to high strength unless wetted; lack of soil cover a major problem

Ca–V VARIABLE-THICKNESS SOIL OVER CARBONATE BEDROCK: stony, red clay soil over carbonate bedrock; soluble, highly permeable bedrock; soil 0 – 40 feet thick, averaging 20 – 30 feet; bedrock surface and soil thickness extremely uneven over very short lateral distances; soil permeability moderate to high; moderate strength; clay soil behaves much like a silt; "floating" bedrock blocks common

Ca–K KARST: stony, red clay soil over carbonate bedrock; extremely soluble and highly permeable bedrock; soil 0 – 100 + feet thick; bedrock surface, soil thickness, and land surface highly undulating; soil permeability high to low; soil strength moderate to high unless wetted; numerous sinkholes; little or no surface drainage in streams; highly integrated internal drainage; many foundation and water problems

Re VERY THICK RESIDUAL SOIL: stony, red clay soil; greater than 100 feet thick; moderate to high permeability; moderate to high bearing capacity and stability; contains "floating" bedrock blocks; leakage from reservoirs, lagoons, and landfills

Ig IGNEOUS BEDROCK: variable soil types with generally low permeability except near weathered granite; generally sandy-silty-clayey soil; soil mostly thin to very thin; lack of soil is a major problem

GLOSSARY OF TERMS

AGGREGATE Materials such as crushed limestone, crushed dolomite, gravel, and sand, used as bulk in concrete and similar products.

AGSTONE Finely crushed limestone or dolomite applied to agricultural lands to "sweeten" the soil.

ALLUVIAL Pertaining to alluvium.

ALLUVIUM Fragmental sediment (clay, silt, sand, gravel) which has been transported and sorted by a stream.

AQUIFER A rock or unconsolidated sediment from which water can be obtained; particularly, a distinct layer of rock in which wells can successfully be drilled.

BARITE A heavy mineral composed of barium sulfate; also called "heavy spar" or "tiff".

BASEMENT In Missouri, the Precambrian (mostly igneous) rocks, which everywhere underlie the lowermost sedimentary rocks.

BASIN A segment of the earth's crust which has been depressed relative to adjacent segments in the geologic past; consequently, an area where the total thickness of sedimentary rocks is relatively great.

BEARING CAPACITY The ability to support loads, such as buildings.

BITUMINOUS Descriptive of coal of intermediate to high energy value.

CALCAREOUS Consisting largely of calcium carbonate; limestone is a calcareous rock.

CAMBRIAN The period of geologic time following the Precambrian and preceding the Ordovician period; the oldest period of the Paleozoic era.

CHERT A siliceous rock found as nodules and beds within limestone or dolomite; also called "flint".

CLAY A very fine-grained, relatively soft sedimentary rock, consisting of various hydrous aluminum silicates (clay minerals)

CLAYPAN A relatively impermeable layer of clay developed in a soil profile.

COLLUVIUM Surficial materials which creep down slopes; particularly, accumulations of such materials at the bases of slopes.

CONTOUR INTERVAL The difference in elevation represented by successive contour lines on a topographic map.

CRETACEOUS The period of geologic time preceding the Tertiary period.

CYCLIC ROCKS Strata characterized by repetitive alternation of different rock types, such as shale, limestone, and sandstone.

DEVONIAN The period of geologic time following the Silurian period and preceding the Mississippian period.

DOLOMITE A sedimentary rock composed largely of calcium-magnesium carbonate, commonly containing considerable chert.

EPICONTINENTAL Disposed upon a continent, as an epicontinental sea.

FAULT A fracture in rocks along which there has been relative movement between the rocks on either side.

FELSITE A hard, fine-grained, light-colored igneous rock.

GLACIAL DRIFT All sediments derived directly or indirectly from glaciers, including outwash deposits and till.

GRANITE A hard, coarse-grained, light-colored igneous rock.

GROUNDWATER Water within the earth, both in unconsolidated surficial materials and in bedrock.

GROUNDWATER DISCHARGE The emergence of water from the earth to its surface, for the most part as unnoticeable seepage, but also as springs.

GROUNDWATER RECHARGE The infiltration of surface water into the earth.

IGNEOUS Descriptive of rocks which solidified from a molten state.

INLIER An isolated area of exposure of older rocks, surrounded by exposures of younger rocks.

KARST A suite of phenomena related to solution of bedrock, including sinkholes, caves, springs, pinnacled bedrock, and losing streams.

LIGHTWEIGHT AGGREGATE An artificially bloated rock such as shale, used as bulk in concrete and similar products.

LIMESTONE A sedimentary rock composed largely of calcium carbonate, commonly containing considerable chert.

LOAM A soil consisting of sand, silt, and clay in the approximate ratios 2:2:1.

LOESS Silt and clay deposited by winds on uplands during the latter part of the Pleistocene epoch.

LOSING STREAM A stream that does not increase, or even decreases in volume of flow downstream, due to loss of water into cavernous bedrock.

MINERAL A substance of more or less distinct chemical and physical properties, constituting part or all of a rock; also, any earth material of commercial value.

MISSISSIPPIAN The period of geologic time following the Devonian period and preceding the Pennsylvanian period.

ORDOVICIAN The period of geologic time following the Cambrian period and preceding the Silurian period.

OUTCROP A place where bedrock crops out and is not covered by surficial materials.

OUTCROP BELT A continuous area immediately underlain by a particular bedrock unit, including outcrops proper and intervening areas where bedrock is covered by surficial materials.

OUTLIER An isolated area of exposure of younger rocks, resting on and surrounded by older rocks.

OUTWASH DEPOSITS Crudely stratified sediments deposited by meltwater streams emanating from glaciers.

PALEOZOIC An era of geologic time, comprising several periods; all of the sedimentary rocks in Missouri were formed during this era (during the Cambrian through Pennsylvanian periods), except for the much younger Cretaceous and Tertiary deposits of the Mississippi embayment.

PENNSYLVANIAN The period of geologic time following the Mississippian period.

PERMEABILITY The relative ease with which fluids (such as water) can pass through a rock or unconsolidated earth materials.

PINNACLES High, irregular projections on a bedrock surface, produced by solution.

PLEISTOCENE The epoch of geologic time preceding the Recent; also called the "ice age" because of the glaciation of that time.

POROSITY The amount of open space among grains in a rock or unconsolidated earth material.

PRECAMBRIAN All of geologic time prior to the Cambrian period.

QUATERNARY The youngest period of geologic time, comprising the Pleistocene and Recent epochs.

REFRACTORY CLAY Clay with high alumina content, used in the manufacture of heat-resistant ceramics; also called "fire clay".

RESIDUUM Fragmental residue of rock weathering left more or less in place as other material is removed; particularly, such residue above soluble carbonate rocks.

ROCK A consolidated or semiconsolidated material of the earth's crust, composed of one or more minerals.

SANDSTONE A sedimentary rock composed of sand grains.

SEDIMENTATION The process of sediment accumulation, particularly at the bottom of a body of water, including accumulation of transported particles and chemical precipitates.

SHALE A fine-grained, slabby, relatively soft sedimentary rock, consisting of a variety of minerals; sometimes mistakenly called "slate".

SILICA SAND A sand or sandstone composed almost exclusively of quartz (silica) grains, thus usable in the manufacture of glass.

SILICEOUS Consisting largely of silica; chert is a siliceous rock.

SILURIAN The period of geologic time following the Ordovician period and preceding the Devonian period.

SINKHOLE A depression in the surface of the land produced by collapse of cavernous bedrock.

SOIL PROFILE The sequence of different soil layers caused by weathering.

SOIL STABILITY The resistance of a soil mass to movement such as landslide.

STRATA Beds or layers of sedimentary materials.

STRATIGRAPHIC Pertaining to strata, or layered rocks.

STRUCTURE The relative arrangement of more or less distinct segments of the earth's crust on either a large or small scale; also, any segment separately, such as an uplift or basin.

SWELLING SOILS Soils which significantly expand and exert high pressures when wetted and contract when dried.

TAILINGS Crushed rock rejected in the processing of ores.

TERRIGENOUS Derived from the land; descriptive of eroded particles which are redeposited on a sea floor.

TERTIARY The period of geologic time following the Cretaceous and preceding the Quaternary.

TILL Unstratified, unsorted sediment deposited directly from glacial ice; typically a clay with scattered pebbles and boulders.

TOPOGRAPHY The configuration of the surface of the land.

UNCONFORMITY A discontinuity in a sequence of strata representing a period of erosion which intervened between periods of sedimentation; there are thus no rocks in the sequence which represent the time of erosion, and part of the pre-existing rocks will have been removed.

UPLIFT A segment of the earth's crust which has been elevated relative to adjacent segments in the geologic past; consequently, an area where the total thickness of sedimentary rocks is relatively thin.

WATER TABLE The level in unconsolidated materials below which all open spaces are filled with water; the term is generally not applicable to water in consolidated rocks, which is subject to confining pressures.

WEATHERING Near-surface physical and chemical alteration of earth materials.

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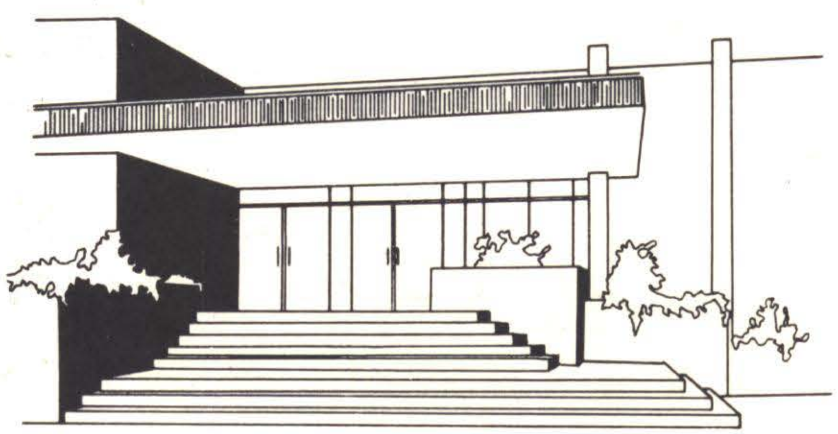

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an introduction to

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