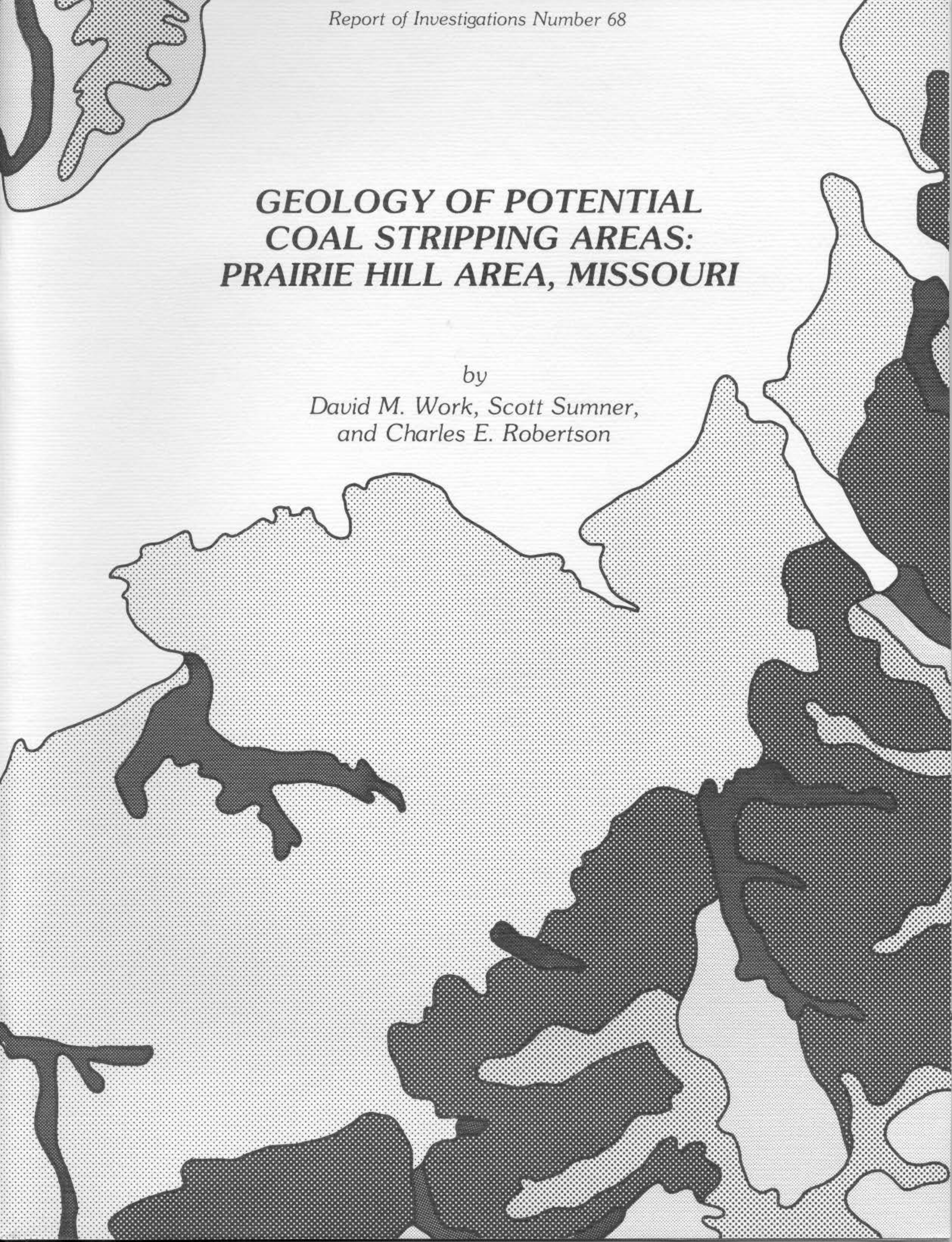


Report of Investigations Number 68

GEOLOGY OF POTENTIAL COAL STRIPPING AREAS: PRAIRIE HILL AREA, MISSOURI

by
David M. Work, Scott Sumner,
and Charles E. Robertson

Report of Investigations
Number 68
1982

Geology of Potential Coal Stripping Areas: Prairie Hill Area, Missouri

by

David M. Work, Scott Sumner,
and Charles E. Robertson

MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY

Wallace B. Howe, Director and State Geologist
P.O. Box 250, Rolla, Missouri 65401

PREFACE

Three authors wrote this report: Charles E. Robertson, H. Scott Sumner, and David M. Work, all geologists with the Missouri Department of Natural Resources, Division of Geology and Land Survey. The Introduction was written by Robertson; Physical Setting (Part I), by Work; Geology and Economic Geology (Part I), by Sumner; and Part II, jointly by Robertson and Work.

Drafting and Layout by Billy Ross

Library of Congress Card Catalog No. 82-620013
Missouri Classification No. MO/NR.Ge 8:68

Work, David M., Sumner, Scott, and Robertson, Charles E., 1982, **GEOLOGY OF POTENTIAL COAL STRIPPING AREAS: PRAIRIE HILL AREA, MISSOURI:** Missouri Department of Natural Resources, Division of Geology and Land Survey, Rept. Inv. 68, 57 p., 3 pls., 14 figs., 2 tables.

CONTENTS

Page

PLATES

ILLUSTRATIONS

TABLES

INTRODUCTION

Strip mining of coal in Missouri is expected to increase significantly between now and the year 2000 and to continue into the next century. Current and planned contracts indicate that 30,000 acres or more will be stripped by the year 2000, possibly as much as 50,000 acres if coal production is accelerated beyond the most probable estimates. This report presents data from the first year of a proposed five- to seven-year study of the state's most active coal-stripping areas.

With adequate information and proper planning, coal stripping need result in only minimal environmental impact. The purpose of the present study is to aid in achieving this objective by assisting in the orderly and efficient development of energy resources by the coal mining industry and to assist in analysis and solution of environmental problems associated with energy resource extraction and utilization. This is being accomplished through the acquisition, interpretation, and dissemination of geologic, hydrologic, and related information. Considerable emphasis is placed on disseminating technical and scientific information to those responsible for policies and decisions affecting energy resource development. Collecting and presenting geologic data to aid in complying with mined-land reclamation regulations will be emphasized.

The following studies are considered necessary for analysis of environmental problems related to coal mining in Missouri and form the basis of the present work: (1) bedrock mapping, (2) surficial mapping, (3) hydrologic studies, (4) geochemical studies, and (5) identification of geologic hazards related to mining.

This report is concerned with the Prairie Hill region in Randolph, Macon, and Chariton Counties, a nearly rectangular region of more than 400 mi^2, which includes the Associated Electric Cooperative's (AEC) Thomas Hill power generating station and Prairie Hill Mine (plate 1) and contains a large coal resource base with a substantial reserve of strippable coal. Four mines are currently operating, with a combined annual production of 1.85 million tons, about one-third of Missouri's current annual production. However, by 1982 production at the Prairie Hill Mine alone is expected to reach 3.8 million tons annually. Increased production in other mines in the area could eventually boost the area's annual production to more than 5 million tons. With an expected recoverability of 5700 tons per acre, a maximum of approximately 16,000 acres could be stripped between now and the year 2000. However, the favorable geologic, hydrologic, and climatic conditions of the area make it possible to mine coal and reclaim land, with resulting minimum environmental effects. Information from the present study will help assure proper reclamation.

The report concentrates on geologic and environmental geologic maps of the area, with accompanying cross sections. Companion maps show potential coal-stripping areas, existing and planned mining areas, strip-mined land, and mined-out underground areas.

There are two basic parts. The first discusses the physical setting and geology of the area, including location, climate, stratigraphy, and structural and economic geology; the second, environmental geologic units, hydrology, geochemistry, geologic hazards, and potential mining areas.

PART I
PHYSICAL SETTING

Geomorphology - The Prairie Hill project area lies within the Dissected Till Plains physiographic province, the topography of which is developed primarily on a thick blanket of Kansan and pre-Kansan glacial drift filling preglacial valleys and depressions. After retreat of the glaciers, this drift blanket formed a wide, southward-sloping plain, which has since been dissected by southward-draining streams. The resulting topography is characterized by north-south streams separated by flat divides with gently to steeply inclined slopes. The flat prairies which frequently cap drainage divides are remnants of the original glacial-drift plain. The largest of these, the "Grand Divide," 1 to 5 miles wide, along the eastern edge of the report area, separates Missouri and Mississippi River drainages.

West of the Grand Divide the prairies are broken and eroded by tributaries of the East Fork of the Chariton River. Further west, the divide separating the drainage of the East Fork and the Chariton River is characterized by an undulating surface, long narrow ridges, and gentle slopes. The flat ridges on the divides are several hundred yards to a mile wide and frequently 3 to 6 miles long.

The valley of the Chariton River ranges between 1 to 3 miles in width. In general, bluffs on the east side of the valley are gently sloping, and those on the west side are steep.

Where streams have cut into preglacial uplands and exposed consolidated Pennsylvanian bedrock, they flow through comparatively steep-sided valleys. Where they cross drift-filled preglacial valleys or lowlands, the slopes are gentle, with few exposures of consolidated strata.

Soils - Soil type depends on slope, climate (including rainfall), and parent materials. The soils of the project area are predominantly developed on eolian, glacial, and alluvial deposits.

The entire area was covered by ice during the Kansan Glacial Stage. After the glacier receded, preglacial valleys and depressions were left filled with glacial drift, creating a nearly level plain sloping gently to the south. Preglacial residual soils were deeply buried. The only remains of the original plain are flat, narrow divides between modern stream valleys. During the altithermal following glaciation, a thin mantle of windblown silt (loess) was deposited over the entire area. The upland soils have been developed almost entirely on these two classes of transported, glacially derived material (drift and loess).

Unweathered loess is a fine-grained silt that tends to form vertical banks and steep-walled washes and gullies. Loess-derived soils cover most of the flat drainage divides and their upper slopes. Soils of this type are among the most fertile in the area. Loess-derived soils are mainly utilized for crops and pasture.

Glacial till is composed primarily of unsorted, unstratified, generally unconsolidated drift comprising a heterogenous mixture of clay, sand, gravel, cobbles, and boulders. Till-derived soils cover limited areas of upland divides and slopes where till has been exposed by erosion of thin loess deposits. Till-derived soils vary in quality and are primarily limited to pasturage.

Very rich, heavily farmed alluvial soils in the major stream valleys of the area are developed on flood-deposited sediments from the uplands and commonly produce corn, soybeans, wheat, and oats.

Climate - The climate of the region is temperate. The average annual precipitation is approximately 37 inches; the average annual snowfall, 21 inches. This abundant precipitation makes the reestablishment of vegetation after mining relatively easy. However, occasional prolonged droughts, lasting as long as 2 to 3 years, interfere with revegetation and very heavy rainstorms cause sheetwash and severe gullying.

GEOLOGY

The youngest bedrock formations in the area are of Pennsylvanian age. Rocks assigned to major divisions of the Pennsylvanian System (Atokan?, Desmoinesian, and Missourian Series) crop out along most major streams and attain a combined maximum thickness of more than 280 ft (see Stratigraphic Column, plate 1). Pennsylvanian rocks were deposited unconformably on mature karst topography developed on Mississippian limestone, the outcrop belt of which is isolated and areally insignificant in the area of study. Mississippian and unexposed Devonian, Ordovician, and Cambrian rocks comprise over 2000 ft of strata that rest unconformably on the Precambrian basement.

The oldest Pennsylvanian rocks (Atokan?) comprise conglomerates, sandstones, and clays, the areal distribution and thickness of which are controlled by the topography of the underlying Mississippian rocks. These beds thicken abruptly in paleotopographic lows but thin or disappear completely on the intervening highs.

Desmoinesian rocks of the Cherokee and Marmaton Groups overlie Atokan? rocks and are characteristically expressed as thin, but remarkably persistent, beds of limestone, shale, siltstone, sandstone, clay, and coal. Limestone beds rarely exceed 10 ft in thickness. Shales, siltstones, and conformable sandstone facies thicker than 40 ft are uncommon. Desmoinesian channel sandstone bodies, locally exceeding 40 ft in thickness, sometimes cut, truncate, or replace stratigraphically lower Pennsylvanian units.

Pennsylvanian rocks of the Missourian Series in the study area are Pleasanton in age, consisting of fluvial channel sandstones that often fill channels in stratigraphically lower units. They are genetically and chronologically related to the Moberly channel-sandstone belt south of the study area. Maximum thicknesses of more than 100 ft have been recorded for these deposits in the study area.

Unconsolidated deposits of pre-Kansan and Kansan drift and Wisconsinan loess mantle the Pennsylvanian bedrock and fill topographic depressions in it. The drift is predominantly a heterogenous mixture of silty clay and sand with lesser amounts of gravel and boulders. The loess forms a thin sheet over the drift and bedrock. Only where Pleistocene deposits have been sufficiently eroded by modern streams has the underlying bedrock been exposed. The youngest deposits in the study area are clays, sands, silts, and gravels deposited by modern streams.

The regional dip of the bedrock is about 10 ft per mile to the northwest; it is modified only slightly by several gentle northwest-trending folds. Faulting in Pennsylvanian bedrock is uncommon and of small magnitude; in the underlying, more competent Mississippian bedrock it is more common and of greater magnitude.

Coal is the most valuable mineral resource in the study area. In the past it was extracted by underground methods; now it is surface mined. In the study area, the Bevier coal bed is of greatest economic importance.

Limestone is the second most valuable mineral resource. Economically important limestone beds in the study area include, in order of importance, the Higginsville, Myrick Station, and Blackjack Creek beds.

Geologic Map

The geologic map (plate 1) depicts the areal distribution of bedrock units and unconsolidated materials in the study area. A generalized section showing the vertical relationships of the units and materials depicted on the map is also shown. Outcropping bedrock units include the Cherokee, Marmaton, and Pleasanton Groups of the Pennsylvanian System. Pennsylvanian bedrock units of the Atokan? Series are included at the base of the Cherokee Group. Mississippian bedrock is also exposed in the study area, but its outcrop belt is areally negligible and is not shown on the map. Unconsolidated materials shown on plate 1 include Pleistocene glacial drift and recent alluvium.

The study area was mapped by standard geologic methods, using 7½-minute topographic quadrangles as base maps. All information compiled on them was generalized and transferred to a 1:100,000-scale base map (plate 1). All nonconfidential stratigraphic sections and subsurface data used in mapping, as well as a more detailed 1:62,500-scale geologic map of the study area, are available for public reference at the Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla.

Unexposed Paleozoic Rocks

Some 2000 ft of unexposed Cambrian, Devonian, and Mississippian sedimentary strata lie unconformably on the Precambrian basement. The only well in the study area to penetrate the entire thickness of these rocks was drilled in search of oil and gas at the R.Y. Powell Farm, near College Mound (NE¼ SE¼ SE¼ sec. 28, T. 56 N., R. 15 W.). It required several years to complete, finally reaching a total depth of about 3000 ft in 1907. The rock units encountered are representative of the pre-Pennsylvanian rocks in the study area. A summary record of the well is as follows:

	Thickness Ft.	Depth Ft.
Quaternary System		
Pleistocene Series		
1. Drift	60	60
Pennsylvanian System		
Desmoinesian Series		
2. Cherokee Group (undifferentiated)	145	205
Mississippian System		
Meramecian Series		
3. Warsaw Formation	27	232
Osagean Series		
4. Burlington-Keokuk	98	330
Kinderhookian Series		
5. Sedalia Formation	100	430
6. Chouteau Group (undifferentiated)	110	540
Devonian System		
7. (undifferentiated)	100	640
Ordovician System		
Champlanian - Cincinnatian Series		
8. (undifferentiated)	130	770
9. St. Peter Sandstone	62	832
10. Everton Formation	12	844
Ordovician System (Canadian Series) - Cambrian System (Upper Series)		
11. (undifferentiated)	1223	2070
Cambrian System		
Upper Series		
12. Davis Formation	75	2145
13. Bonneterre Formation	160	2305
14. Lamotte Sandstone	306	2611
Precambrian Systems		
15. (undifferentiated)	389	3000

Stratigraphy of Exposed Rocks

The following description of the stratigraphy of bedrock units and unconsolidated materials should be accompanied by reference to plate 1.

MISSISSIPPIAN SYSTEM -MERAMECIAN SERIES

Warsaw Formation

The oldest exposed rocks in the study area are Mississippian. They outcrop in a confined locality on the south cutbank of the East Fork of the Chariton River, in SW¼ SW¼ NE¼ sec. 12, T. 54 N., R. 15 W., 3 miles north of Huntsville. The outcrop is poorly exposed but represented by limestone float covering the creek bank. Previous workers (Broadhead, 1873; Hinds, 1912) described a massive limestone bluff as having existed at this location. Broadhead's description of the exposure indicated that it was about 10 ft thick, consisting of dark-gray, finely crystalline, crinoidal limestone containing numerous chert lenses and nodules. A limestone and chert conglomerate 1 to 2 ft thick rested on top of the exposure and probably represented the erosional unconformity at the base of the Pennsylvanian. From field studies in 1966, on the basis of lithologic similarity and stratigraphic position, Gentile (1967) assigned the massive limestone bluff to the Warsaw Formation. A test auger hole drilled by the highway department in 1966, approximately 150 ft southeast of the original outcrop, confirms this correlation, because the hole bottomed in medium-gray, cherty limestone of the Warsaw Formation. The top of the limestone was encountered 15 ft below the bed of the East Fork of Chariton River, thus implying that the outcrop described by Broadhead was probably a small paleotopographic pinnacle of limestone on the surface of the Warsaw (Gentile, 1967). The nearness of Mississippian rocks to the surface in this area is probably the result of a structural high (Gentile, 1967).

PENNSYLVANIAN SYSTEM - ATOKAN? SERIES

Oldest Pennsylvanian Deposits

The oldest Pennsylvanian deposits in the Prairie Hill area are beds and lenses of conglomerate and sandstone, probably of Atokan? age, that in many places are overlain by the high-alumina fireclays of the Cheltenham Formation. The depositional pattern of these deposits is variable and controlled by the paleotopography of the weathered surface of the Mississippian. In paleotopographic lows or depressions, the deposits often dramatically increase in thickness, whereas on the intervening highs they thin to as little as a few inches or disappear. Areal exposure is limited to a few outcrops at the lowest elevations along the East Fork of the Chariton River, near Huntsville, in the southeastern part of the mapping area.

The basal Atokan? deposits vary in lithology from a fine-grained angular to subangular quartz sandstone with ferruginous cement to a matrix of fine-grained ferruginous quartz sandstone enclosing pebble- to cobble-sized clasts of chert and limestone probably eroded and reworked from underlying Mississippian rocks (Searight, 1959). The clasts generally increase in number and size in the deeper pre-Desmoinesian channels.

Cheltenham Formation

Definition - The Cheltenham Formation has been provisionally assigned to the Atokan Series by the Missouri Geological Survey. In the study area it is underlain by Pennsylvanian basal deposits of conglomerate and sandstone and is overlain by beds of Desmoinesian age.

Distribution and Thickness - Deposits of the Cheltenham Formation are exposed in restricted areas at the lowest elevations along the East Fork of the Chariton River, in the southeast corner of the study area. Because the depositional pattern of these deposits was essentially controlled by the paleotopography of the Mississippian surface, their areal distribution and thickness patterns are erratic. The Cheltenham thickens to as much as 10 ft in paleotopographic lows, such as sinks and valleys; it thins or completely disappears on the intervening highs. West and north of the outcrop belt, the Cheltenham is not exposed, and its character and distribution are unknown.

Description - The Cheltenham Formation consists predominantly of clay that is dark brown to gray in its lower part and yellow, plastic, and alkaline above. The upper part, commonly called "poison clay" by the fireclay industry because it is not of refractory quality, probably represents a weathering zone that formed before deposition of overlying Desmoinesian strata.

PENNSYLVANIAN SYSTEM-DESMOINESIAN SERIES

Cherokee Group

In the Prairie Hill area, the Cherokee Group is represented by a maximum of 180 ft of strata, which have been assigned to the Krebs and Cabaniss Subgroups. Sediments of the Cherokee Group are predominantly characterized by successions of shale and sandstone. The overall limestone content is volumetrically insignificant. Cherokee beds lower than the Croweburg Formation are present in the study area but have not been correlated.

Cherokee Group (undifferentiated)

Undifferentiated rocks of Cherokee age, varying between 30 and 100 ft in thickness, lie beneath the Croweburg Formation and rest unconformably upon Atokan? deposits; they characteristically consist mainly of shale and sandstone. Intervening beds of limestone and coal are thin and mostly discontinuous. Where these rocks outcrop along the East Fork of the Chariton River, in the southeast part of the study area, an underlying structural high in Mississippian rocks has caused the sequence to thin to as little as 30 ft. Also, coal and limestone beds present elsewhere in the sequence have either graded laterally into shales and sandstone or disappeared completely; consequently, in the area of outcrop, the entire sequence of undifferentiated Cherokee rocks consists of beds of shale and sandstone that cannot be correlated. North and west of the outcrop belt, the sequence thickens to as much as 100 ft, is more persistent, and presumably contains marker horizons that could be correlated if sufficient stratigraphic information were available.

Over most of the study area, north and west of the outcrop belt, a relatively thick coal bed, locally called the "Eureka coal," lies 40 to 70 ft beneath the Croweburg coal. On the basis of lithologic similarity and stratigraphic position, it has been tentatively correlated with the Weir-Pittsburg coal bed of western Missouri, a correlation made with some hesitation, because adjacent beds above and below cannot be identified, nor can the coal be traced in the subsurface to the type section of the Weir-Pittsburg coal. Lithologic character and distribution are based solely on subsurface data, because the bed is not exposed in the study area. The coal ranges from 6 in. to 4 ft in thickness and may have as many as four partings. In most places it is too thin and too deep to be worked by current strip or underground mining methods.

A typical sequence of undifferentiated lower Cherokee beds was penetrated in the shaft of the Northwestern No. 8 mine, about 1 mile south of Bevier and was logged as follows (shown with modern stratigraphic nomenclature):

Drilling at Northwestern No. 8 (SE¼ sec. 22, T. 57 N., R. 15 W.) (Modified after Hinds, 1912).

	Thickness Ft.	Thickness In.	Depth Ft.
Quaternary System			
Pleistocene Series			
1. Drift	55		55
Pennsylvanian System			
Desmoinesian Series			
Marmaton and Cherokee Groups (undifferentiated)			
2. Shale, gray, "slaty" (laminated)	51		106
Cherokee Group			
3. Sandstone	26		132
4. COAL (Bevier)	4		136
5. Clay	1	2	140
6. Sandstone and shale	2	10	140
7. Limestone, blue	4		144
8. Shale	3		147
9. Limestone	2		149
10. Shale	8		157
11. Shale, in part black and "slaty"	2		159
12. COAL (Croweburg)		6	159½
Cherokee Group (undifferentiated)			
13. Shale	26	6	186
14. Limestone	2	6	188½
15. Shale	24	6	213
16. COAL (Eureka)	1	2	214
17. Sandstone, blue	16	10	231
18. Shale, gray and red	9		240
Mississippian System			
Meramecian Series (undifferentiated)			
19. Limestone, gray, hard	16		256

Croweburg Formation

Definition - As defined by Searight and others (1953), the Croweburg Formation in western Missouri includes the beds from the top of the Fleming coal, upward to the top of the Croweburg coal. The lateral persistence of the Croweburg in the study area permits definition of the Croweburg Formation's upper boundary. The lower boundary, however, is very difficult to define, because the Fleming coal bed has not been identified in the study area, and other beds beneath the Croweburg coal are extremely variable and not widely exposed. Gentile (1967) defined the formation's lower boundary in Macon and Randolph Counties as the base of the first prominent limestone bed encountered below the Croweburg coal and that definition is used in this report.

Distribution and Thickness - The outcrop belt of the Croweburg Formation extends from Huntsville, north almost to College Mound, along valley walls of the East Fork of the Chariton River. Along this outcrop belt the Croweburg formation ranges irregularly from 5 to 25 ft in thickness. To the west and north the formation is essentially unexposed, but limited subsurface data indicate that the thickness is less, ranging from 15 to 25 ft.

Description - From the base upward, the Croweburg Formation has been subdivided into three distinct members: (1) a basal limestone member, (2) a shale member, and (3) the Croweburg coal and its underclay.

Basal Limestone Member - The basal limestone member is a discontinuous bed that varies, when present, from a few inches to 2 ft in thickness. It is sparsely fossiliferous; highly fragmented, unidentifiable brachiopod remains are the dominant fossils. The weathered surface of this bed is tan and often iron stained. When the basal limestone is not present, definition of the Croweburg Formation's lower boundary is arbitrary.

Shale Member - The shale member of the Croweburg Formation, like the underlying basal limestone, is very discontinuous and variable along the outcrop belt in the eastern part of the study area. Where present, it ranges in thickness from a few inches to over 18 ft. West of the outcrop belt, limited subsurface data indicate that the shale member becomes more laterally persistent, ranging from 15 to 18 ft in thickness. In a complete succession, the lower 4 to 6 ft of the shale member consist of soft, black flaky shale, with abundant pyritized wood, that grades upwards into a gray silty shale, 10 to 12 ft thick, that becomes sandy toward the top.

Croweburg Coal and Underclay - The underclay of the Croweburg coal is medium gray, structureless, iron stained, commonly contains carbonized root impressions in its upper few inches, and ranges from 1 to 4 ft in thickness.

The Croweburg coal, the top bed of the formation, is a remarkably persistent unit averaging 14 in. thick, a minimum of 6 in. having been recorded 1 mile south of Bevier, and maxima in excess of 30 in., 3 miles northeast of Huntsville and several miles northwest of Wien. The coal is black, blocky, bright, and occasionally contains nodules and veinlets of pryite. In weathered exposures gypsum occurs in the cleats.

Verdigris Formation

Definition - As defined by Searight and others (1953), the Verdigris Formation includes the beds from the top of the Croweburg coal to the top of the Wheeler coal. Lateral persistence of the two coal beds in the subsurface greatly facilitates recognition of the boundaries of the Verdigris Formation in the study area.

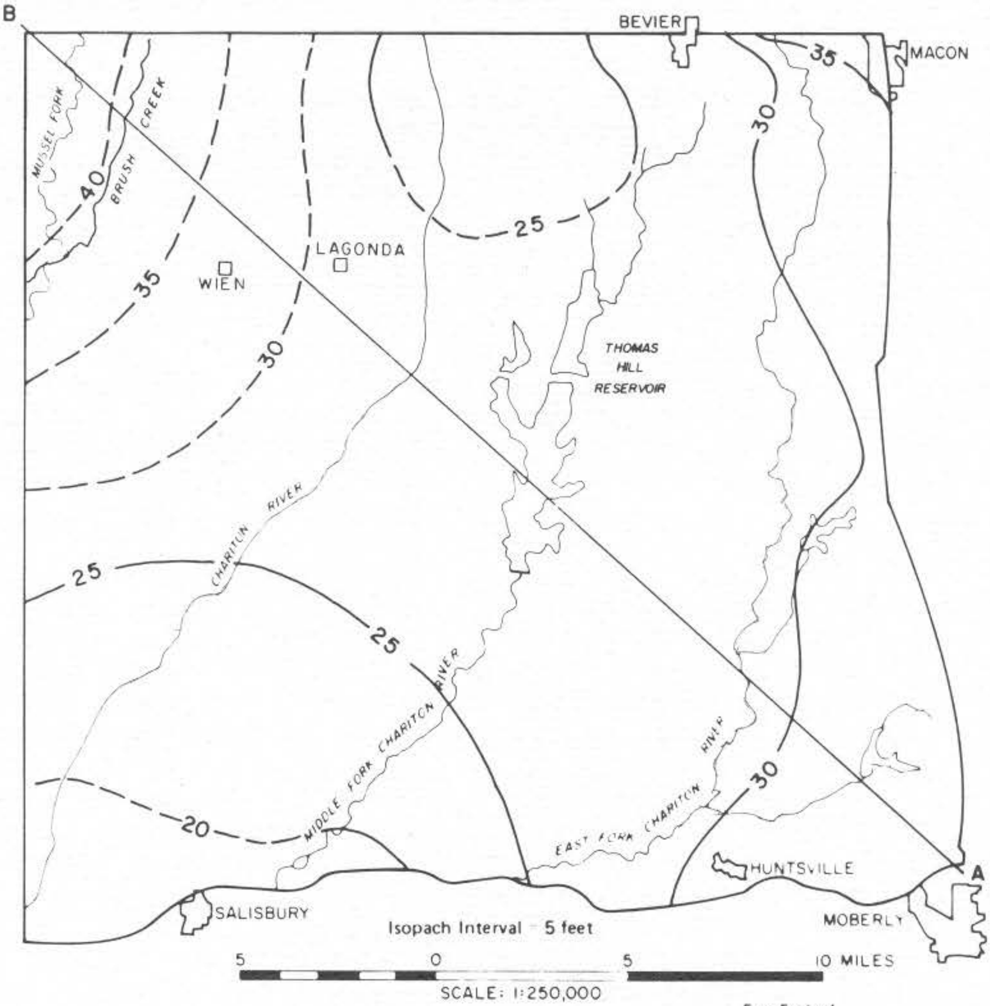
Distribution and Thickness - The Verdigris Formation averages 30 ft thick along the outcrop belt on the East Fork of the Chariton River, in the southeastern part of the study area (fig. 1a). To the west and north, complete exposures of the formation are not present, but subsurface data (fig. 1b) indicate that it generally thickens in that direction until, west of the Mussel Fork River, it exceeds 45 ft. It should be noted that abrupt deviations in this thickening trend occur locally.

Description - Over most of the study area, the Verdigris Formation can be subdivided from the base upward into five members: (1) a gray shale member (after Searight, 1959), (2) a black fissile shale member (after Searight, 1959), (3) a black platy shale member (after Searight, 1959), (4) the Ardmore Limestone Member, and (5) the Wheeler coal and its underclay. In the northwest quarter of the study area, limited subsurface data indicate that the lower three shale members seem to lose their individual character as they thicken and grade into 35 to 40 ft of dark-gray siltstone, with thin flags of limestone toward the top.

Gray Shale Member - The basal member of the Verdigris Formation is an extremely discontinuous gray calcareous shale that ranges, when present, from a feather edge to 3 ft thick. It weathers buff and is sparsely fossiliferous, containing small poorly preserved brachiopods, such as *Mesolobus*, in its upper beds.

Black Fissile Shale Member - Black fissile shale, averaging 1.5 to 2 ft thick generally overlies the gray shale member. In much of the study area, however, the gray shale is not present and the black, fissile shale rests directly on the Croweburg coal. This shale

Fig. 1a Isopach map of the Verdigris Formation



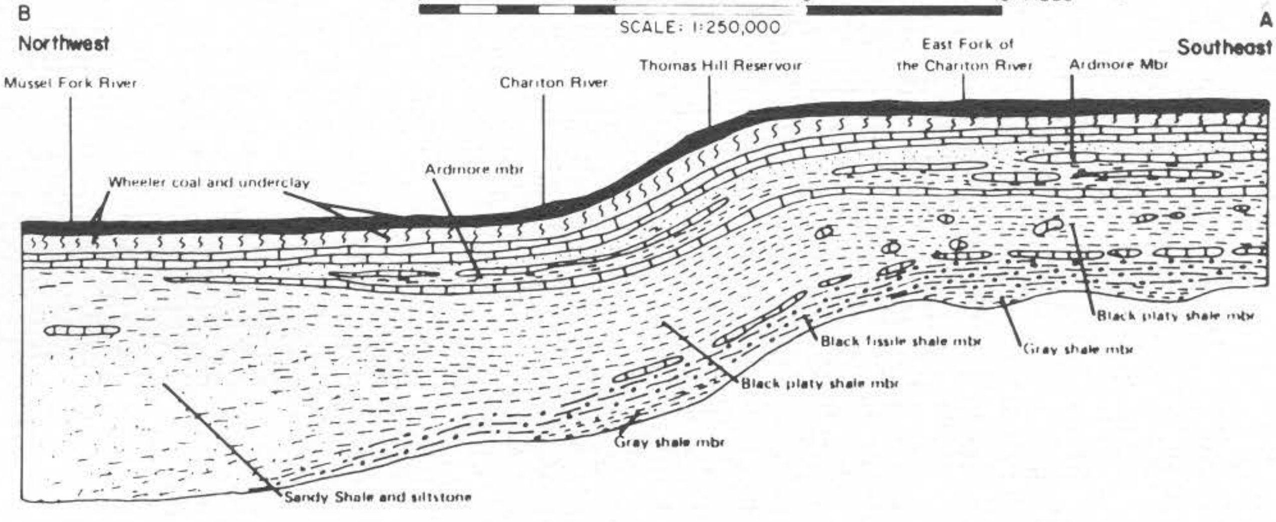


Fig. 1b. Northwest southeast generalized cross section across the study area showing the interrelationship of lithologic units of the Verdigris Formation. The vertical scale is greatly exaggerated.

contains abundant small, flattened phosphatic nodules and occasional stringers and nodules of pyrite. It is sparsely fossiliferous; small inarticulate brachiopods, conodonts, and carbonized plant fragments are the dominant forms. In places, overlying this black shale, there is a thin, discontinuous, concretionary limestone bed, mostly medium gray and fine grained, with spar and pyrite filling septarian fractures; it is sparsely fossiliferous, small brachiopods, such as *Mesolobus*, being the dominant forms. In outcrop the limestone bed weathers buff and is iron stained in many places.

Black Platy Shale Member - A soft, dark-gray to black, ferruginous, calcareous, platy shale averaging 7 ft thick rests conformably on the black fissile shale in the study area. North of Huntsville this unit locally thickens to 15 ft. It contains abundant dark-gray, subrounded to rounded, septarian limestone concretions, a few inches to 1.5 ft in diameter. The septarian fractures are commonly filled with calcite or pyrite. Many concretions contain abundant, sometimes pyritized, brachiopods; *Dictyoclostus* and *Neospirifer* are the most common in the shale itself. Small, poorly preserved specimens of *Mesolobus* are also present.

Ardmore Limestone Member - The Ardmore Limestone Member comprises a succession of limestone beds, with intervening beds of calcareous shale and sandstone. It averages 10 ft in thickness east of the Chariton River, but locally thickness varies considerably. Near College Mound, in south-central Macon County, the Ardmore thins to less than 6 ft. In other areas east of the Chariton River it thickens to as much as 20 ft or more. In general, the Ardmore thins west of the Chariton River, and individual beds lose their distinctive character.

Typically, the Ardmore Limestone Member is bounded top and bottom by limestone beds. The lower limestone rests upon the black platy shale member. It is irregularly bedded, light gray, finely crystalline, and fossiliferous. It weathers buff and is septarian in places, with pyrite and calcite filling the fractures. This bed ranges from a feather edge to 1.5 ft in thickness but averages about a foot.

The upper limestone is 6 in. to 4 ft thick but averages 3 ft. Bedding ranges from wavy in the lower part to nodular in the upper. Voids in joints and between beds and nodules are usually filled with clayey shale. The limestone is fossiliferous and is mottled with irregular, dark- and light-gray patches. The dark-gray areas are dense and fine grained, often showing subconchoidal to conchoidal fractures. The surrounding lighter gray areas are more argillaceous, less dense, and more easily erodible. This bed is the most persistent unit in the Ardmore succession and is commonly called the "sumprock" of the Bevier coal.

Between the upper and lower limestone beds of the Ardmore Member is a variable succession of calcareous shale and sandstone interbedded with thin, discontinuous limestone beds. The succession averages 7 ft thick but locally thickens and thins abruptly. Generally, the lower part of this succession consists predominantly of light greenish-gray, platy, fossiliferous shale that is calcareous in places. This grades upward into a thin-bedded, light-gray siltstone or fine-grained sandstone that is micaceous, fossiliferous, and weathers buff to brown when exposed. Thin, non-persistent beds of light-gray, blocky, fossiliferous limestone are distributed in many places throughout the succession. The individual limestone beds usually do not exceed one foot in thickness.

Both the limestone beds and the shale succession of the Ardmore Member have abundant fossils. The most common forms include crinoid columnals, branching bryozoans, and brachiopods such as *Mesolobus, Dictyoclostus, Neospirifer*, and *Composita.* Fusulinids are also common in the lower limestones and in the lower part of the upper limestone bed. Fossils in the nodular top part of the upper limestone are highly fragmented and therefore difficult to identify.

Wheeler Coal and Underclay Member - The top member of the Verdigris Formation is represented by the Wheeler coal bed and its associated underclay. The latter rests conformably upon the upper limestone of the Ardmore Limestone Member; it is typically medium gray, plastic, and averages 2 ft in thickness. It often contains carbonized plant remains in its upper few inches and is usually iron stained in outcrop. The Wheeler coal is black, blocky, and shaly in places. It often contains nodules and veinlets of pyrite. Gypsum is commonly present in the cleats of weathered exposures. East of the Chariton River the Wheeler averages 11 in. in thickness; west of the river it is generally thicker, attaining a maximum of 19 in. on the west bank, 4 to 5 miles northwest of Salisbury (SE¼ NE¼ sec. 25, T. 54 N., R. 18 W.).

Bevier Formation

Definition - As defined by Searight and others (1953), the Bevier Formation includes the beds from the top of the Wheeler coal bed to the top of the Bevier coal bed. The name Bevier was initially used to describe a coal bed mined extensively at Bevier in Macon County.

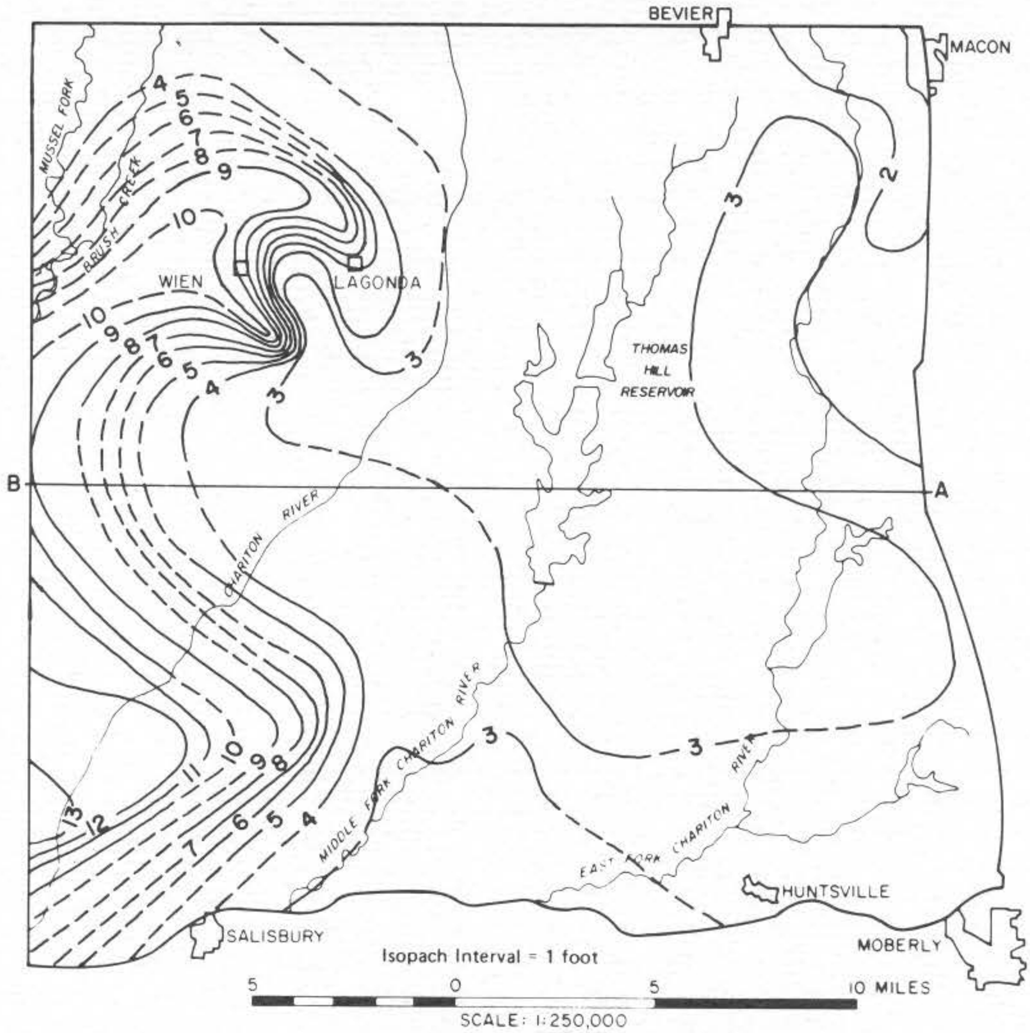
Distribution and Thickness - East of the Chariton River the thickness of the Bevier Formation ranges from 30 to 44 in. and is well exposed along both banks of the East Fork of the Chariton River, from Huntsville north to Ardmore (fig. 2). It thickens west of the Chariton River, attaining a maximum of 13 ft on the west bank, 4 to 5 miles northwest of Salisbury (SE¼ NE¼ sec. 25, T. 54 N., R. 18 W.). The Bevier Formation is also exposed in two other isolated localities west of the Chariton River: along Brush Creek in the northwest corner of the study area (NW¼ SW¼ sec. 21, T. 57 N., R. 17 W.) and along the west bank, near Lagonda.

Description - In the study area the Bevier Formation comprises two lithologically distinct members, typically represented by a sandy clay member below and the Bevier coal above.

Sandy Clay Member - Typically, the sandy clay member is dark gray, pyritiferous, contains carbonized plant remains, and averages 3 in. in thickness east of the Chariton River. In this part of the study area it is usually referred to as the "binder" or "parting" between the Bevier and underlying Wheeler coal beds. West of the Chariton River the sandy clay member thickens and grades laterally into a dark-gray, pyritiferous, sandy shale that attains a maximum exposed thickness of 11 to 12 ft on the west bank of the river, northwest of Salisbury (SE¼ NE¼ sec. 25, T. 54 N., 18 W.).

Bevier Coal and Underclay - The Bevier coal bed is commonly 24 to 42 in. thick east of the Chariton River and locally exceeds 50 in. between Prairie Hill and Thomas Hill. West of the Chariton River, the Bevier coal thins, reaching minimum exposed thicknesses of less than 20 in. on the west bank of the river, in the southwest corner of the study area.

Fig. 2a. Isopach map of the Bevier Formation.



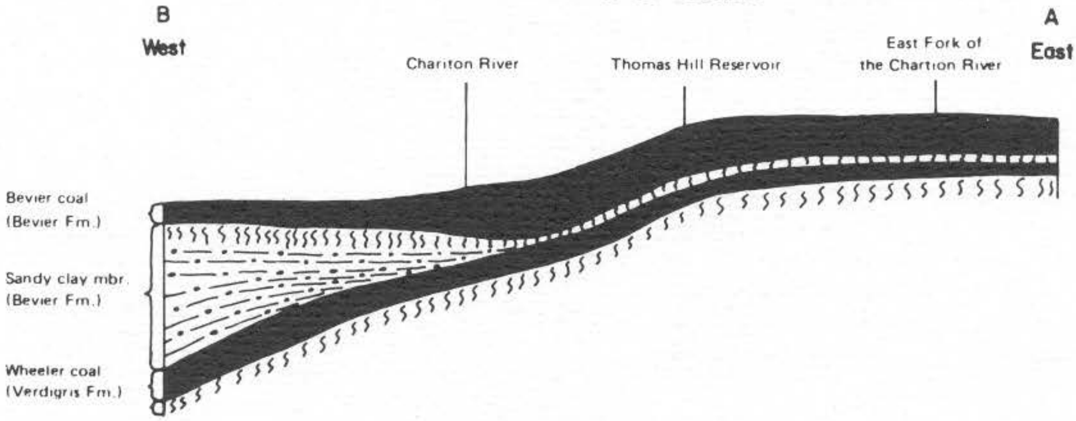


Fig. 2b. East-west generalized cross section across the study area showing the interrelationships of lithologic units of the Bevier Formation and the Wheeler coal. Vertical scale is greatly exaggerated.

The coal is black, blocky, banded, contains scattered nodules and veinlets of pyrite, and often has numerous thin shale partings. In weathered exposures, gypsum is usually found in the cleats. East of the Chariton River the Bevier coal bed is mined in tandem with the underlying Wheeler coal bed. In this area "Bevier coal" is a commercial name for both the Bevier and Wheeler coals.

Lagonda Formation

Definition - As defined by Searight and others (1953), the Lagonda Formation includes the beds from the top of the Bevier coal bed to the base of the Breezy Hill Limestone Member of the Mulky Formation. When the Breezy Hill Limestone is absent, the upper boundary of the Lagonda is defined as the base of the underclay of the Mulky coal.

Distribution and Thickness - The Lagonda Formation crops out widely along most major drainages in the study area. Numerous excellent exposures of the complete formation abound on the valley walls of the East Fork of the Chariton River and its tributaries. There are also excellent exposures of the Lagonda Formation in the high walls of most strip mines in the study area. The Lagonda is 10 to 15 ft thick east of the East Fork of the Chariton River (fig. 3) and thickens westward until it usually exceeds 30 ft west of the Middle Fork of the Chariton. Maximum recorded thicknesses greater than 40 ft were encountered in shafts near Lagonda and in the Thomas Hill-Prairie Hill area.

Description - In the study area the Lagonda Formation comprises two lithologically distinct members: a silty shale member below and a sandstone member above. Locally, either member may predominate in the Lagonda succession; generally, however, the sandstone member thickens and becomes increasingly dominant in the western part of the study area (fig. 3).

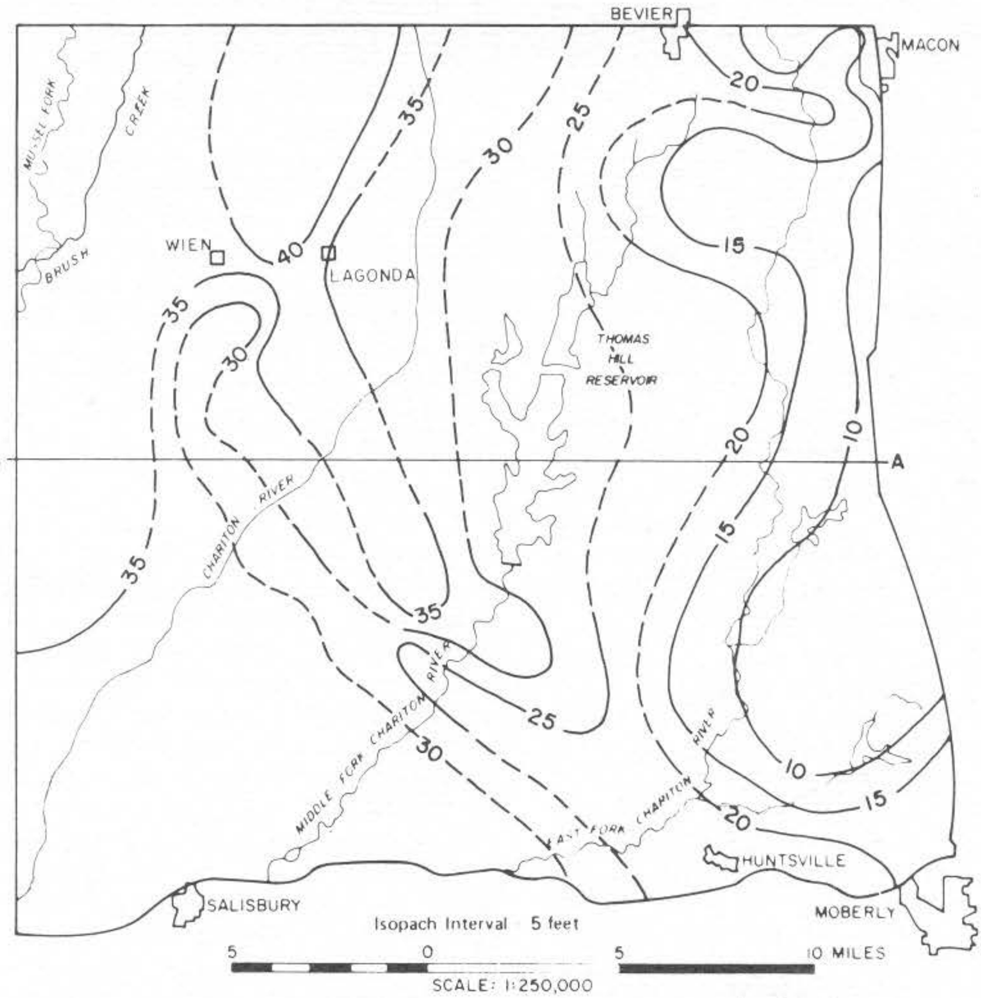
Silty Shale Member - The basal unit of the silty shale member is usually a dark-gray to black, soft, flaky, slightly calcareous, laterally discontinuous shale. When this unit is present, it ranges from a feather edge to 1 ft in thickness and grades upward into a medium-gray, noncalcareous, silty shale that is thinly laminated and weathers buff to brown. This shale is sparsely fossiliferous in its lower part, containing small, poorly preserved brachiopods such as *Mesolobus* and *Lingula*. The entire silty shale member averages 10 ft in thickness in the study area but locally thins and thickens erratically.

Sandstone Member - The upper member of the Lagonda Formation is mainly a light-gray, fine-grained, friable sandstone that is silty, micaceous, and, in places, ferruginous. Based upon the nature of the basal contact and the bedding character, two distinct, laterally equivalent facies have been recognized in this member. These have been termed the *sheet-sand facies* and the *channel-fill facies*. The former is the more common and is characterized by a conformable, often gradational, contact with the underlying silty shale member. The sheet-sand facies is laminated and its thickness ranges from a feather edge to 40 ft, but averages 8 ft.

The channel-fill facies is characterized by an unconformable basal contact and is often strongly cross-bedded in its lower part. The bedding becomes thinner and less pronounced higher in the unit. Grain size correspondingly decreases upward, and this facies is often capped by a poorly bedded clay or shale of high organic content.

Deposits of the channel-fill facies generally are more common in the

Fig. 3a. Isopach map of the Lagonda Formation



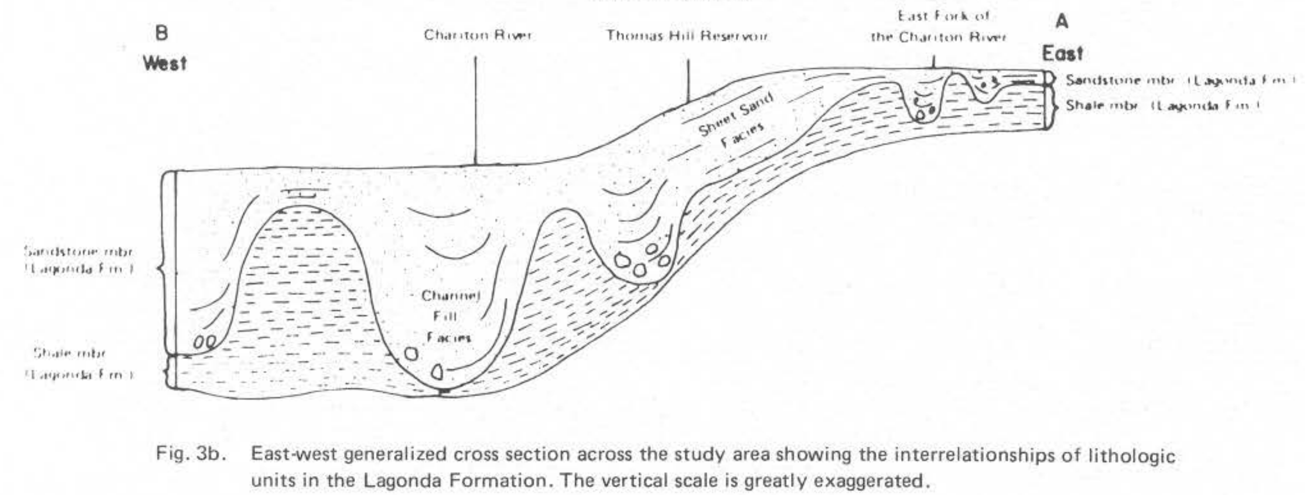


Fig. 3b. East-west generalized cross section across the study area showing the interrelationships of lithologic units in the Lagonda Formation. The vertical scale is greatly exaggerated.

western part of the study area, where they often exceed 40 ft in thickness and in places have replaced the Bevier coal.

Mulky Formation

Definition - As defined by Searight and others (1953), the Mulky Formation includes the beds from the base of the Breezy Hill Limestone to the top of the Mulky coal bed. If the Breezy Hill is absent, the base of the Mulky underclay defines the base of the formation.

Distribution and Thickness - The Mulky Formation is widely exposed in the valley walls of most major drainages in the study area. There are also numerous good exposures in the highwalls of strip mines. East of the Middle Fork of the Chariton River the Mulky Formation averages 5.5 ft thick (fig. 4), locally attaining a maximum exceeding 8 ft where exposed on the highwalls of a strip mine several miles northwest of Huntsville (NE¼ sec. 22, T. 54 N., R. 15 W.). Westward, the Mulky formation thins to less than 3 ft where exposed along the banks of the Mussel Fork River.

Description - The Mulky Formation comprises two lithologically distinct members: the Breezy Hill Limestone member below and the Mulky coal and its underclay above.

Breezy Hill Limestone Member - The Breezy Hill Limestone is a very discontinuous, light-gray, nodular to concretionary, argillaceous limestone. Megascopically, it is unfossiliferous, and is septarian in many places, spar usually filling the fractures. Green clay and shale fill the spaces between the nodules and beds. The Breezy Hill averages about 2.5 ft thick where exposed. Westward it becomes more laterally persistent and prominent (fig. 4).

Mulky Coal and Underclay - Overlying the Breezy Hill member is a medium-gray, structureless underclay varying from a few inches to over 5 ft in thickness and averaging approximately 1.5 ft. It contains abundant carbonized plant remains in its upper few inches and is frequently iron stained in weathered exposures. It generally thins and becomes somewhat laterally discontinuous west of the Chariton River.

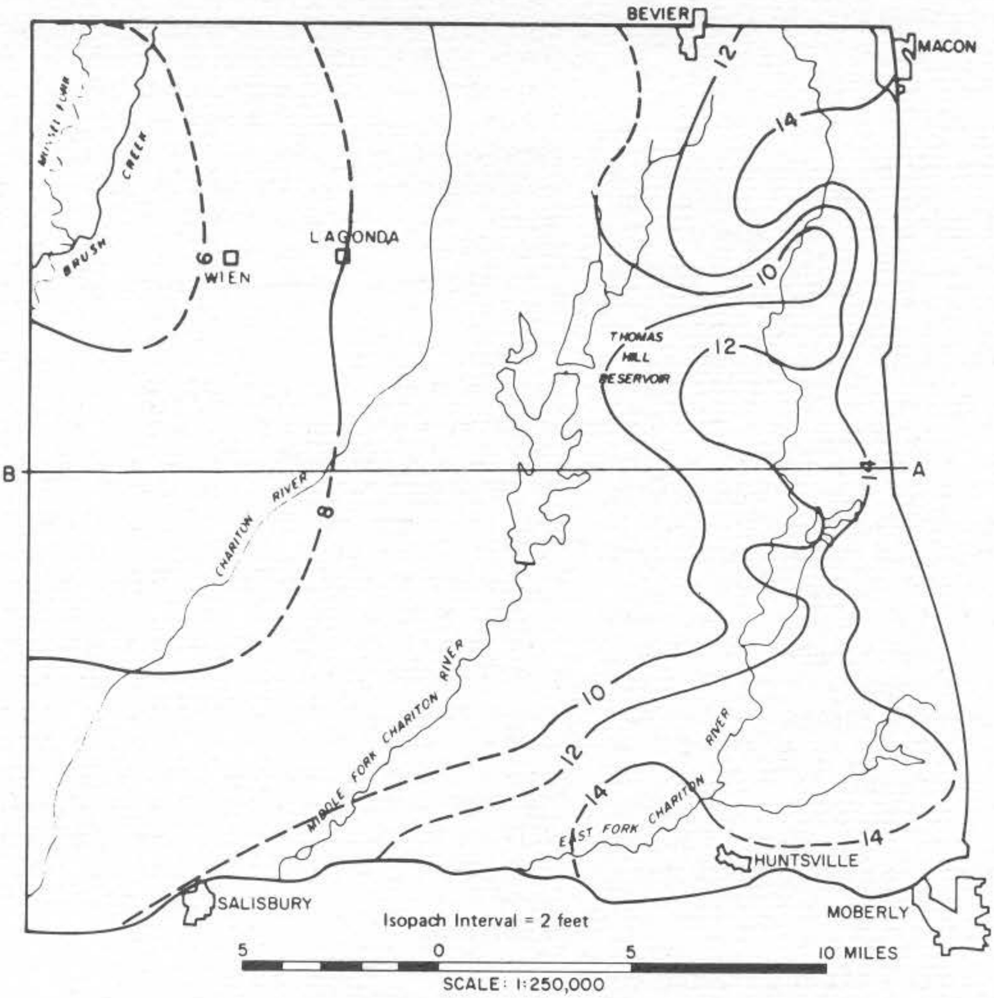
The Mulky coal is the uppermost unit in the Mulky Formation. Along the East Fork of the Chariton River it averages 16 in. thick, ranging from 12 to 22 in. (fig. 4). Generally, the thicker deposits of the Mulky coal are in the northeast corner of the study area, near Macon, where thicknesses of over 20 in. are common. The coal thins and becomes patchy in distribution west of the East Fork, thinning to less than an inch where exposed along the Mussel Fork River, in the northwest corner of the study area. The coal is black, blocky, finely banded, and contains scattered nodules and stringers of pyrite. Gypsum is often found in the cleats of weathered exposures.

Excello Formation

Definition - As defined by Searight and others (1953), the Excello Formation includes the beds from the top of the Mulky coal to the base of the Blackjack Creek Formation. The type section lies within the study area and was described by Searight (1953) from exposures in the highwall of a coal strip mine west of Excello, in NW¼ sec. 30, T. 56 N., R. 14 W.

Distribution and Thickness - The Excello Formation is widely exposed in the valley walls of many major drainages throughout the study area. The most complete exposures are along the valley

Fig. 4a. Isopach map of the Blackjack Creek, Excello, and Mulky Formations



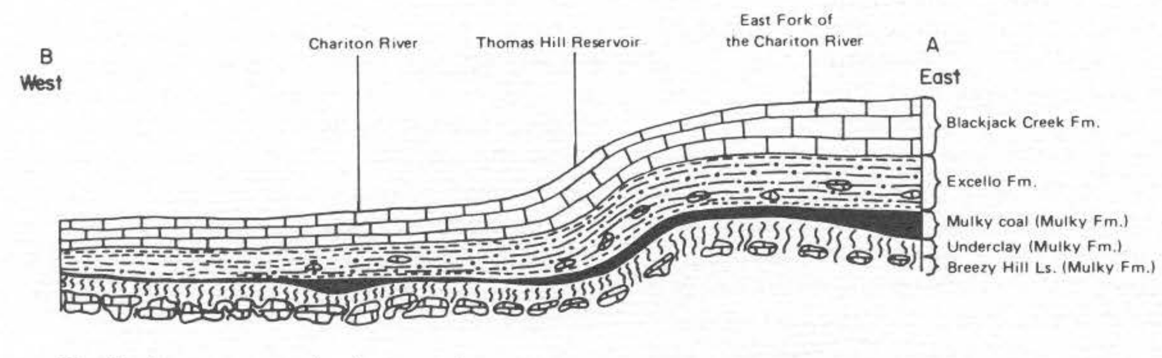


Fig. 4b. East-west generalized cross section across the study area showing the interrelationships of lithologic units in the Mulky, Excello, and Blackjack Creek Formations. The vertical scale is greatly exaggerated.

walls of the East Fork of the Chariton River and in the highwalls of most strip mines east of the Middle Fork of the Chariton River. In these areas the Excello averages 4 ft thick, attaining a maximum of 5 to 5.5 ft where exposed on highwalls of strip mines between Ardmore and Excello. The Excello thins westward, essentially exhibiting the same depositional pattern as the underlying Mulky coal and overlying Blackjack Creek limestone (fig. 4). Thicknesses of less than 3 ft have been observed in the Excello along the Mussel Fork River, in the extreme western portion of the study area.

Description - In the eastern part of the study area, where the Excello Formation is thickest and best developed, it is a succession of as many as four lithologically distinct shale beds. The basal bed is a laterally discontinuous, extremely thin unit averaging 1 to 3 in. in thickness where present. It is composed of dark-gray to black, soft, flaky, slightly calcareous, pyritiferous shale containing abundant, highly abraded productid brachiopods. The basal bed is overlain by a bed of black fissile shale that averages 20 in. thick but locally exceeds 3.5 ft in exposures on highwalls of strip mines in the College Mound-Ardmore-Excello area. The black shale contains numerous flattened phosphatic nodules 1 to 3 in. in diameter and subrounded to rounded, fine-grained, dark-gray limestone concretions up to 18 in. in diameter. The concretions are often fossiliferous, commonly yielding productid brachiopods and plant remains, and occasionally, cephalopods. Hard parts of many of the fossils have been replaced by pyrite and limonite. The black fissile shale bed is usually overlain by another such shale, essentially of the same lithologic character except that it lacks limestone concretions; its thickness varies locally but averages about 2 ft. Both lower and upper shales have few fossils, the only recognizable forms being conodonts, small inarticulate brachiopods, and carbonized plant fragments. The upper black shale grades upward into a tan to gray calcareous shale, averaging about 6 in. thick, that represents the top bed of the Excello succession. It weathers buff to brown and has few fossils, small specimens of *Mesolobus* being the dominant form.

West of the Chariton River the shale beds of the Excello Formation thin, become discontinuous, and in places lose their individual character, grading locally into a nondescript dark-gray to black calcareous shale. This lateral equivalent of the Excello is exposed at the lowest elevations on the banks of the Mussel Fork River, on the western edge of the study area.

Marmaton Group

In the study area the Marmaton Group is represented by a maximum of 100 ft of strata assigned to the Fort Scott and Appanoose Subgroups. Unlike the underlying Cherokee Group, the Marmaton Group is characterized by relatively thick, persistent, limestone units. Because of preglacial and later erosion, these units are far less widespread areally than rocks of the Cherokee Group.

Blackjack Creek Formation

Definition - As defined by Searight and others (1961), the Blackjack Creek Formation includes the beds between the top of the Excello Formation and the base of the Little Osage Formation. The Blackjack Creek was previously known informally as the "Mulky caprock," "cement rock," and "Lower Fort Scott Limestone."

Distribution and Thickness - Cropping out along most major drainages and well exposed in the highwalls of strip mines east of the Chariton River, the Blackjack Creek Formation is the most widely exposed and distinctive rock unit in the entire study area. The most complete, best exposed sections occur along the valley walls of the East Fork of the Chariton River, from Huntsville north to Bevier, where the formation averages 4 to 4.5 ft thick, locally reaching a maximum of 5.5 ft in exposures in the highwall of a strip mine 3 miles north of Ardmore. The Blackjack Creek thins westward, displaying a depositional pattern similar to those of the underlying Mulky and Excello Formations (fig. 4). Where exposed on the western perimeter of the study area, along the Mussel Fork River, the formation is commonly less than 3 ft thick.

Description - In the eastern part of the study area, where it is best developed, the Blackjack Creek Formation is represented by a single massive bed of gray to olive-gray, finely crystalline limestone. Both upper and lower surfaces are usually smooth and even. Locally, however, the basal few inches may be thin bedded and shaly. The weathered surface is a distinctive rusty brown color and is commonly iron stained in irregular patches. Fossils are abundant and well preserved; the most common forms are the tabulate coral *Chaetetes* and brachiopods such as *Phricodythyris*, *Composita*, and *Neospirifer*. Fusulinids, crinoid ossicles, branching bryozoans, and echinoid spines are less common but locally abundant (Searight, 1959). Neal (1968) indicated there is abundant phylloid algal debris in the Blackjack Creek limestone, in the eastern part of the study area.

In the western extremities of the study area, along Brush Creek and the Mussel Fork River, the Blackjack Creek is thinner, averaging 2 to 3 ft thick, and more argillaceous, burrowed, and dolomitic. In the west, the quantity, diversity, and state of preservation of fossils are diminished relative to the thicker facies of the Blackjack Creek to the east. The most intense dolomitization probably occurs selectively around burrows.

Little Osage Formation

Definition - The Little Osage Formation was defined by Jewett (1941) as including those beds from the top of the Blackjack Creek Formation to the base of the Higginsville Formation.

Distribution and Thickness - Complete exposures of the Little Osage Formation are restricted to areas east of the East Fork of the Chariton River, along the Middle Fork of the Chariton River near Thomas Hill, and along Brush Creek and the Mussel Fork River. In the north-central part of the study area, from the west bank of the East Fork to Brush Creek in the west and south to Thomas Hill, the Little Osage has largely been replaced by glacial deposits.

The Little Osage averages 35 to 40 ft thick over most of the study area. The lower part of the formation, below the Houx Limestone Member, thins slightly to the west, whereas the upper part of the formation, the Flint Hill Sandstone Member, thickens in the same direction.

Description - The Little Osage Formation has been subdivided into five lithologically distinct members from the base upward: (1) a calcareous shale and nodular limestone member (Searight, 1959), (2) the Summit coal and underclay, (3) a black fissile shale member (Searight, 1959), (4) the Houx

Limestone Member, and (5) the Flint Hill Sandstone member.

Calcareous Shale and Nodular Limestone Member - The basal member of the Little Osage Formation usually comprises two beds of calcareous shale separated by a bed of nodular to concretionary limestone. The member averages 12 to 18 ft thick east of the Chariton River but varies locally from 5 to 20 ft. West of the Chariton it thins, being commonly less than 10 ft thick in exposures along Brush Creek and the Mussel Fork River. The lower shale of the member is typically dark gray to gray, poorly bedded, and slightly calcareous, and locally contains abundant small limestone nodules less than 3 in. in maximum diameter. The lower part of the shale has few fossils, small, poorly preserved specimens of *Mesolobus* being the dominant form; it averages about 7 ft thick over most of the study area and weathers buff with irregular, iron-stained patches.

Where present, the limestone bed above the lower shale averages 2 to 3 ft thick. It is fine grained, argillaceous, nodular to concretionary, and light olive gray, weathering buff to brown. Megascopically it is nonfossiliferous and in places contains septaria often filled with coarse spar. Locally, this unit may diminish abruptly to a zone of scattered limestone nodules suspended in a clay matrix.

The upper shale, above the limestone, is calcareous, occasionally silty towards the top, and light to medium gray in color, weathering to light olive. It averages 5 ft thick but is discontinuous, often disappearing laterally over a short distance, particularly in the western portions of the study area, where the Summit underclay often rests directly upon the nodular limestone bed.

Summit Coal and Underclay - The underclay, a medium- to dark-gray bed averaging about 1.5 to 2 ft thick over much of the study area, is calcareous towards the base and contains carbonized plant fossils in many places in its upper few inches. Weathered surfaces are usually stained by sulfides and iron oxides.

The Summit coal is black, somewhat thinly bedded, parted in places, and contains scattered nodules and veinlets of pyrite. Gypsum is present in cleats in weathered exposures. The Summit persistently averages about 12 in. thick east of the Chariton River. West of the Chariton it thins to less than 9 in. where exposed along the Mussel Fork River. The coal has not been mined in any significant amount.

Black Fissile Shale Member - The Summit coal is overlain by a thin black shale sequence averaging 1.5 to 2 ft thick over much of the study area. The lower few inches of this member consist of a dark-gray to black, soft, flaky, slightly calcareous shale bed, locally containing highly fragmented productid brachiopod fossils. This "coquina-like" bed grades upward into a 1- to 1.5-ft-thick bed of sparsely fossiliferous, black fissile shale containing numerous small flattened phosphatic nodules. The only fossils identified in this bed are poorly preserved orbiculoid brachiopods, and conodonts. At the top of the sequence, on the black fissile shale, there is a medium-gray, slightly calcareous, poorly bedded shale unit, which averages about 7 in. thick and weathers buff to brown.

Houx Limestone Member - The Houx Limestone, the "caprock" of the Summit coal, is a thin but prominent dark-gray limestone averaging 2 ft in thickness but ranging locally from 1.5 to 4 ft. Weathered surfaces are buff colored, platy, and display a distinctive rectangular joint pattern. The Houx comprises two limestone beds separated by a thin clay or shale parting less than 4 in. thick and generally about a foot above the base. This clastic wedge thickens, coarsens, and becomes more persistent northward. Lithologically, the limestone of both beds is laterally uniform over much of the study area and is characteristically fine grained, argillaceous, and fossiliferous. The matrix enclosing the fossils is predominantly recrystallized spar containing minute blebs of silica and pyrite (Jeffries, 1958). The Houx fauna is rich and diverse, yielding abundant fusulinids, conodonts, corals, algal debris, and brachiopods, of which *Composita*, *Dictyoclostus*, and *Neospirifer* are the most common. *Chaetetes* is locally abundant on the upper surface of some exposures.

Flint Hill Sandstone Member - The Flint Hill Sandstone, at the top of the Little Osage Formation, is a succession of shale and sandstone. It averages about 15 to 20 ft thick in the eastern portions of the study area but thickens in the western portions to as much as 25 ft. The lower part is a gray calcareous shale with few fossils, small, poorly preserved brachiopods such as *Mesolobus* being the dominant forms. This shale unit averages about 10 ft thick but varies locally, depending on the amount of scouring during deposition of the overlying sandstone.

The upper beds of the Flint Hill are micaceous, ferruginous siltstone, and fine-grained sandstone that is light gray but weathers buff to brown with irregular iron-stained patches. The nature of the basal contact and the geometry of the bedding allow two laterally adjacent facies to be recognized in these upper beds. They are analogous to the facies previously recognized in the Lagonda Formation and like them have been designated the *sheet-sand* and *channel-sand facies*. The sheet-sand facies, the more common of the two, has a gradational basal contact with the lower shales of the Flint Hill Member. Its bedding is thin to laminated and it averages about 5 to 10 ft thick in the eastern portions of the study area. Westward it thickens, averaging 10 to 15 ft.

The channel-sand facies is local in occurrence and is characterized by an unconformable basal contact that extends downward into channels in the underlying shale beds of the lower Flint Hill. This facies is often strongly cross-bedded in its lower part. The bedding becomes progressively thinner and grain size decreases toward the top of the unit, where a poorly bedded shale or clay is present in places. Maximum thicknesses of the channel-sand facies exceed 20 ft where channeling has eroded underlying beds to the top of the Houx limestone. In the study area, channels filled with deposits representing this facies were not observed to extend below the Houx Limestone.

Higginsville Formation

Definition - As defined by Searight (1959), the Higginsville Formation includes the beds between the top of the Flint Hill Sandstone and the base of the Pawnee Formation. The Higginsville has been referred to in the past as the "Chaetetes limestone" (Broadhead, 1874; Hinds, 1912).

Distribution and Thickness - Because of its relatively high stratigraphic position, lateral distribution of the Higginsville Formation has been severely limited by Pleistocene and post-Pleistocene erosion. Exposures are in confined areas east of the East Fork of the Chariton River, in the vicinity of Thomas Hill, and northwest of Bynumville. In the central two-thirds of the study area, the Higginsville has largely been replaced by glacial deposits. Excellent exposures of the Higginsville occur in and east of Huntsville, where it forms prominent ledges that cap many hills and ridges.

The Higginsville averages 5 to 6 ft thick east of the East Fork of the Chariton River, between Moberly and Jacksonville, but thickens locally to as much as 10 ft; it thins to 3 ft in exposures near Macon. Near Thomas Hill and northwest of Bynumville, the Higginsville is 4 to 4.5 ft thick.

Description - The Higginsville Formation is a light-gray, fine- to medium-grained, dense, argillaceous, fossiliferous limestone that weathers tan to brown. Bedding is thin and wavy to nodular and crinkly, with greenish clay or shale filling joints and spaces between bedding planes and nodules. The abundance of hemispherical *Chaetetes* colonies in the upper beds serves as an excellent field criterion by which to recognize the formation. Other common fossils include fusulinids, small crinoid columnals, algal pellets, and brachiopods, of which *Chonetes*, *Composita*, *Derbyia*, and *Dictyoclostus* are the most common. Locally (NW¼ NW¼ sec. 5, T. 56 N., R. 17 W.), brachiopod remains are so numerous in the upper beds, as to impart a coquina-like character to them.

The Higginsville becomes more argillaceous and thinly bedded toward the northern part of the study area. Its erodibility also increases, and abrupt lateral gradations into calcareous shale become more common.

Labette Formation

Definition - As defined by Searight and others (1953), the Labette Formation includes the beds from the top of the Higginsville Formation to the base of the Anna Shale Member of the Pawnee Formation.

Distribution and Thickness - Lateral distribution of the Labette Formation is restricted to portions of the study area east of the East Fork of the Chariton River, and in the extreme northwest corner, along Brush Creek and the Mussel Fork River. The Labette is present only where protected from erosion by the overlying limestone of the Pawnee Formation; elsewhere it has been removed by glacial and postglacial erosion. Thicknesses of up to 4 ft have been recorded for the Labette where exposed in the extreme eastern portion of the study area. It is thinner, averaging 2 to 3 ft, where exposed in the northwest corner.

Description - East of the East Fork of the Chariton River the best and most typical exposure of the formation occurs on the south face of the N.J. Cooksey Quarry, (NE¼ NE¼ sec. 14, T. 54 N., R. 14 W.), 3 miles north of the city limits of Moberly. There the Labette consists of 3.5 ft of dark-gray calcareous clay-shale with a hackley fracture, overlain by strata containing three thin coal smuts with two thin clay partings. This succession does not exceed 3 in. in thickness and has been correlated as the Lexington coal (Gentile, 1967).

In the northwest corner of the study area the Labette is not exposed, but limited subsurface data indicate that the lower dark-gray clay-shale has thinned to 2.5 ft, and that the overlying Lexington coal bed is represented by an unparted smut 0.25 in. thick.

Pawnee Formation

Definition - As defined by Searight and others (1953), the Pawnee Formation includes the beds between the top of the Lexington coal and the base of the Bandera Formation.

Distribution and Thickness - Lateral distribution of the Pawnee Formation is extremely limited because of glacial and postglacial erosion. The complete formation is present in restricted areas east of the East Fork of the Chariton River and in the extreme northwest corner of the study area, along Brush Creek and the Mussel Fork River. The lower two members, the Anna Shale and the Myrick Station Limestone, are also present in a small area near Thomas Hill.

The Pawnee averages about 12 ft thick in complete exposures east of the East Fork of the Chariton River. It averages 16 ft thick in outcrops in the northwest corner of the study area.

Description - From the base upward, the Pawnee Formation comprises four members: (1) the Anna Shale, (2) the Myrick Station Limestone, (3) the Mine Creek Shale, and (4) the Coal City Limestone. The shale members are exposed only where the overlying limestone members have protected them from erosion.

Anna Shale Member - East of the East Fork of the Chariton River the Anna Shale usually comprises 1 to 9 in. of greenish-gray clay-shale. In exposures near Thomas Hill and in the northwest corner of the study area, it averages 11 in. thick and consists of greenish-gray platy shale containing in the upper few inches abundant flattened phosphatic nodules, averaging less than 2 in. in maximum diameter.

Myrick Station Limestone Member - The Myrick Station Limestone averages about 4 ft thick in the northwest corner of the study area and in the vicinity of Thomas Hill. East of the East Fork of the Chariton River and south of Jacksonville, the Myrick Station averages 4.5 ft thick, but locally it thickens abruptly to as much as 7 ft.

The Myrick Station Limestone is medium gray, fine grained, argillaceous, and weathers deep yellow to orange. Bedding is thick and irregular to nodular, with clay occupying spaces in joints and between nodules and beds. The Myrick Station generally becomes increasingly argillaceous to the north. Between Jacksonville and Macon, abrupt lateral gradations into calcareous shale are common.

Fossils in the Myrick Station are abundant and dominated by brachiopods such as *Composita*, *Mesolobus*, *Neospirifer*, and *Chonetes*. *Chaetetes* is locally abundant in the upper part of the member.

Mine Creek Shale Member - East of East Fork of the Chariton River the Mine Creek Shale averages 3.5 to 4.5 ft thick. In this area it is composed of tan to greenish-gray shale that is soft and flaky and weathers grayish-brown. The shale often contains abundant light-gray, argillaceous, fine-grained limestone nodules that locally coalesce to form wavy, nodular beds. Fossils in the shale are abundant, predominantly small brachiopods such as *Mesolobus*, locally so numerous that they form coquina-like beds.

In the northwest corner of the study area the Mine Creek thickens to over 8 ft. Its lithology is essentially the same as described above except that the limestone nodules more commonly coalesce to form thicker, more prominent beds.

Coal City Limestone Member - In exposures east of the East Fork of the Chariton River, the Coal City Limestone is typically a light-gray, fine-grained, shaly limestone, 6 to 12 in. thick, that weathers buff. Bedding varies from blocky to nodular; fossils are locally abundant, particularly large productid brachiopods.

In the northwest corner of the study area the Coal City is thicker, averaging 2 to 3 ft, and less argillaceous. Fossils, mostly fusulinids, crinoid columnals, and large productid brachiopods, are abundant. In this area, the Coal City weathers brown to orange.

Marmaton Beds above the Pawnee Formation

Marmaton beds stratigraphically higher than the Pawnee Formation are poorly exposed and occur only in the extreme southeast and northwest corners of the study area. They are represented by about 10 to 25 ft of strata that have been assigned to the Bandera, Altamont, Nowata, and Lenapah-Holdenville Formations (plate 1). Because of their severely limited lateral extent, detailed summary of them seems unwarranted.

In general, these upper Marmaton beds are predominantly shale. Limestone, sandstone, and coal beds are mostly thin and discontinuous. The only laterally persistent, reasonably thick limestone bed in this succession is the Worland Limestone Member at the top of the Altamont Formation (plate 1). The Worland averages about 1.5 ft thick where present in the southeast corner of the study area and ranges from 2 to 3 ft thicker where present in the northwest corner. The Worland is typically light gray, fine grained, and dense, with wavy to nodular bedding. It weathers buff to brown and is quite fossiliferous, small crinoid columnals predominating.

The Marmaton succession above the Worland mainly comprises red and green shales, which typically contain abundant siderite concretions and limestone nodules that locally coalesce to form thin, discontinuous beds. The maximum observed thickness of the shales is about 10 to 15 ft.

Below the Worland the upper Marmaton succession is more variable, containing thin beds of black fissile shale, greenish-gray shale, and clay. A thin, discontinuous coal smut is also present in this part of the succession. The total maximum observed thickness of these lower beds is about 8 to 10 ft.

PENNSYLVANIAN SYSTEM - MISSOURIAN SERIES

Pleasanton Group (Undifferentiated)

Rocks of the Pleasanton Group are the youngest Pennsylvanian strata in the study area. They are predominantly channel-fill deposits up to 100 ft thick, genetically and chronologically related to the main body of the Moberly channel fill south of the study area. It seems highly probable that in southern parts of the study area, where these deposits are more numerous and extensive, many of them are actually outliers of the Moberly channel fill.

Lithologically, channel-fill deposits of the Pleasanton Group are mainly thick successions of shale and fine- to medium-grained sandstone. The beds are usually micaceous, ferruginous, and weather light buff to red. They are often strongly cross-bedded, well cemented, and form prominent ledges. Thick lenticular deposits of conglomerate often occur near the base of the succession. Clasts in the conglomerate range from pebbles to boulders and are mostly derived locally from the underlying Desmoinesian bedrock. Thin, discontinuous beds of limestone and coal have also been observed in the succession. The limestone is typically dark gray, fine grained, argillaceous, and nonfossiliferous. The coal is usually shaly and too thin to be of economic value.

QUATERNARY SYSTEM - PLEISTOCENE SERIES

General Statement

Pleistocene deposits, up to 200 ft thick, are present over most of the study area. Largely the result of glacial processes, they are mostly Kansan in age and overlie thinner, laterally discontinuous pre-Kansan glacial drift. The youngest Pleistocene deposits consist of Wisconsinan loess, which typically forms a thin veneer over older materials. Distribution of Pleistocene deposits in the area is shown on the map on plate 1 (it should be noted that the inferred faults illustrated on the map refer only to the underlying, pre-Pleistocene rocks).

Glacial Drift

In general, materials deposited by glacial processes are called *glacial drift*, or *drift*. Lillesand and Kiefer (1979) defined four principal types: (1) *till*, composed of unsorted, unstratified material deposited directly from glacial ice; (2) *ice-contact stratified drift*, composed of material partly water sorted and poorly stratified, deposited adjacent to melting ice; (3) *outwash*, water-sorted, stratified material deposited by glacial meltwater; and (4) *glaciolacustrine deposits*, fine-grained material deposited in lakes fed by meltwater. In the study area, till is the dominant type of drift material. Ice-contact stratified drift deposits and glaciolacustrine deposits have not been identified in the study area. Outwash deposits occur beneath till in drift-filled preglacial valleys.

The glacial drift was deposited upon a mature bedrock topography of gently undulating hills and dissected plains of less relief than the present Ozark topography to the south. The deepest valleys of this preglacial terrain have the thickest drift deposits; on hills and ridgetops, deposits are thinner. Drift may be more than 150 ft thick in some preglacial valleys in the northern part of the study area (fig. 8). In at least one small area, north of Lagonda, Pennsylvanian rocks were eroded away, and drift rests on Mississippian rocks.

Knowledge of preglacial topography is vitally important to coal exploration in the study area, because in many of the deeper preglacial valleys, economically valuable coal beds have been eroded away. Accurate delineation of these buried drainages depends on subsurface data. In much of the study area, however, especially in areas of thick drift accumulation, subsurface data are lacking. Consequently, the areal pattern of preglacial drainages, as depicted in figure 10, is largely speculative. In some places, modern drainage roughly parallels preglacial drainage.

Pleistocene Stratigraphy

The oldest Pleistocene deposits in the study area are pre-Kansan in age. Kansan drift overlies them and is covered by a thin blanket comprising Wisconsinan loess overlying Yarmouth and Sangamon paleosols. A generalized stratigraphic succession is shown in figure 5 and should be referred to in the following descriptions.

Pre-Kansan Deposits

Distribution and Thickness - Lateral distribution of pre-Kansan deposits in the study area is discontinuous. In the deeper parts of preglacial topographic depressions they probably exceed 50 ft in thickness, but there is insufficient subsurface data to confirm this. On intervening preglacial highs they presumably thin, or disappear completely.

Description - Pre-Kansan deposits preserved in preglacial channels are mostly water-sorted, stratified alluvial sands and gravels with low, variable amounts of clay and silt; on intervening preglacial highs, they are mostly residuum with moderate amounts of clay and silt. Locally there are outwash deposits of water-sorted, stratified sand and gravel (personal communication, James Hadley Williams, September 21, 1981).

Kansan Stage

Distribution and Thickness - Kansan drift covers much of the study area. It is absent only in the major valleys, where streams have removed it and exposed the underlying bedrock. The Kansan drift is much more widely exposed, considerably thicker, and more laterally continuous than the pre-Kansan deposits. The maximum thicknesses of Kansan drift exceed 100 ft and probably occur in the deeper preglacial drainages, but, as with pre-Kansan deposits, this remains unconfirmed because of inadequate subsurface control. In general, the Kansan drift seems to thin southward.

Description - Kansan till is characterized by a matrix composed mainly of clay, with lesser, variable amounts of silt and sand. Extensive lenses of stratified fine-to coarse-grained sand are present locally. Embedded within the clay matrix is a poorly sorted array of pebbles, cobbles, and boulders derived locally and from distant sources to the north. Secondary accumulations of calcareous nodules are very abundant in parts of the unleached and unoxidized zones.

Kansan till shows three gradational zones from the base upward: (1) unleached, unoxidized till; (2) unleached, oxidized till, and (3) leached, oxidized till. The unleached, unoxidized zone is typically dark olive gray, and jointed in its upper part. The unleached, oxidized zone is yellowish brown, and jointed in its lower part, the joints commonly filled with secondary calcareous nodules. The leached, oxidized zone is yellowish brown and generally decalcified.

Yarmouthian, Illinoian, and Sangamonian Stages

Sangamon and Yarmouth paleosols superposed on accretion-gleys (Ferrelview Formation) on uplands rest on Kansan till. A Sangamon paleosol also occurs on slopes. The Ferrelview Formation grades from yellowish brown at the base to light olive gray in the upper portions. It is mostly impermeable clay containing a few scattered, resistant grains and pebbles of quartz.

In places, a thin layer of deeply weathered Illinoian loess, perhaps up to 2 ft thick, lies between the Sangamon and Yarmouth paleosols. Lithologically, it resembles the younger, Wisconsinan loess.

Wisconsinan Stage

Thin deposits of Wisconsinan loess averaging 5 to 10 ft thick overlie older Pleistocene materials. The loess is mainly reddish-brown, noncalcareous, medium-to coarse-grained silt containing very fine grains of sand. Generally the sand content is greatest near the base.

CLASSIFICATION		NOTES
Wisconsinan	Loess 0-10 ft	Peoria silt (Farmdalian not certainly identified in north-central Missouri).
Sangamonian	Paleosol	Sangamon soil.
Illinoian	Loess 0-2 ft	Loveland silt; thin, not persistent, deeply weathered.
Yarmouthian	Paleosol	Yarmouth soil. Sangamon and Yarmouth paleosols superposed on accretion-gleys (Ferrelview Formation) on uplands. Sangamon paleosol present on slopes.
Kansan	Oxidized and leached 5-10 ft	Till; sandy clay matrix with erratics (locally, and perhaps regionally, includes a lower till and an intervening Afton? paleosol). May include outwash deposits at or near base.
	Oxidized and unleached 30-60 ft	
	Unoxidized and unleached 0-40 ft	
Pre-Kansan	0-50+ ft	Sands and gravels. May include alluvial, residual, and outwash deposits.

Fig. 5. Generalized stratigraphic column – Pleistocene succession in north-central Missouri. (Personal communication, Howe and Williams, September 21, 1981).

QUATERNARY SYSTEM - HOLOCENE SERIES

The youngest deposits in the study area are unconsolidated alluvial deposits of silt, clay, sand, and gravel adjacent to all major streams and most of their tributaries. The largest of these deposits occur along the Chariton River, where alluvium about 50 ft thick forms a floodplain up to 4 miles wide. Other significant alluvial deposits occur along the Middle and East Forks of the Chariton River. Lenses of gravel and sand are often present in the basal portions of these larger deposits.

Structural Geology

TECTONIC SETTING

Regionally, Pennsylvanian sediments of the study area were deposited upon a broad, northwest-southeast-trending syncline, bounded on the northeast by the Lincoln anticline (Lincoln fold), on the southwest by the Saline County arch, and on the south by the Ozark uplift (fig. 6). To the northwest, the syncline plunges into the Forest City Basin; hence, Pennsylvanian rocks in the study area dip northwestward approximately 10 feet per mile.

Within the major syncline are many smaller, minor tectonic features, which have a primary northwest-southeast trend and a secondary northeast-southwest trend. These elements conform to the general structural pattern within the state.

MINOR TECTONIC FEATURES

Pennsylvanian rocks in the study area contain a high percentage of clastics and thus tend to fail by folding rather than faulting. Folding, although very common in the study area, is generally of minor structural significance. Only four folds (figs. 6 and 7) are of sufficient magnitude and lateral extent to warrant individual discussion: the College Mound-Bucklin anticline (McCracken, 1971), the Macon-Sullivan trough (McCracken, 1971), the Salisbury-Quitman anticline (McCracken, 1971), and a fourth fold, herein named by the author of this section (Sumner) the Thomas Hill monocline.

The College Mound-Bucklin anticline is the most extensive of these three folds. Although structurally unimposing, it has greatly influenced the existing distribution pattern of Pennsylvanian strata. Along its northwest-trending axial crest, Pennsylvanian strata have been selectively eroded to a much greater extent than in adjacent areas to the southwest and northeast. Gordon (1893) estimated that the northeast limb of the anticline dips 11 ft per mile, whereas on the southwest limb the dip is 18 feet per mile.

The Macon-Sullivan trough is a broad, shallow syncline adjacent to and northeast of the College Mound-Buckline anticline. The axis trends northwest, cutting across the northeast corner of the study area at Macon. Within this trough the effects of postdepositional erosion of Pennsylvanian rocks are diminished, and many of the individual bedrock units thicken slightly.

The Salisbury-Quitman anticline is in the southwest corner of the study area. Along its northwest-trending axial crest, Pennsylvanian rocks have been selectively eroded, although not to the extent of those on the College Mound-Bucklin anticline.

The Thomas Hill monocline, in the central part of the study area, beneath the Thomas Hill reservoir trends roughly north-south and is the most intensively deformed and best defined of these minor folds (fig. 7). Subsurface data indicate that on the average, beds on the west side of the reservoir are approximately 50 to 100 ft lower than identical beds on the east side. This drop in elevation over a horizontal distance of 0.5 to 1 mile is equivalent to an average dip of 50 to 200 ft per mile, which far exceeds the regional dip.

Faulting in the study area is much less common than folding. Because thick deposits of glacial drift largely obscure local structures such as faults, their location, magnitude of displacement, and very existence can only be inferred at best. Only two areas where faulting could be inferred were recognized in the study area. One is in the south-central part of the area north of the East Fork of the Chariton River (fig. 7). West of this inferred fault system strata appear to have been downthrown 40 to 70 feet. Such a fault would probably be genetically related to the Thomas Hill monocline. Faulting is also inferred northeast of Lagonda and southeast of Wien, in the northwest part of the study area (fig. 7). South of the axial crest of the College Mound-Bucklin anticline the two faults appear to define a graben-like structure.

The south side of the inferred northern fault appears to be downthrown approximately 100 ft; the north side of the inferred southern fault, approximately 30 to 50 ft. Areas of postulated faulting are also shown on figure 7.

The more competent underlying Mississippian rocks, in contrast to the Pennsylvanian rocks, presumably tend to fail by faulting and fracturing rather than by folding. Position and magnitude of displacement of these faults and fractures is unknown, however, because of inadequate subsurface control.

STRUCTURAL HISTORY

Folding and faulting in the study area accompanied two probable periods of deformation. An initial post-Mississippian-pre-Pennsylvanian period is indicated by lithologic and thickness changes in individual Pennsylvanian units. A second occurred after deposition of Desmoinesian strata but before deposition of Missourian channel sands, because the latter are unfolded and unfaulted. This second period of deformation rejuvenated and/or accentuated structures generated during the first period of deformation.

Figure 6

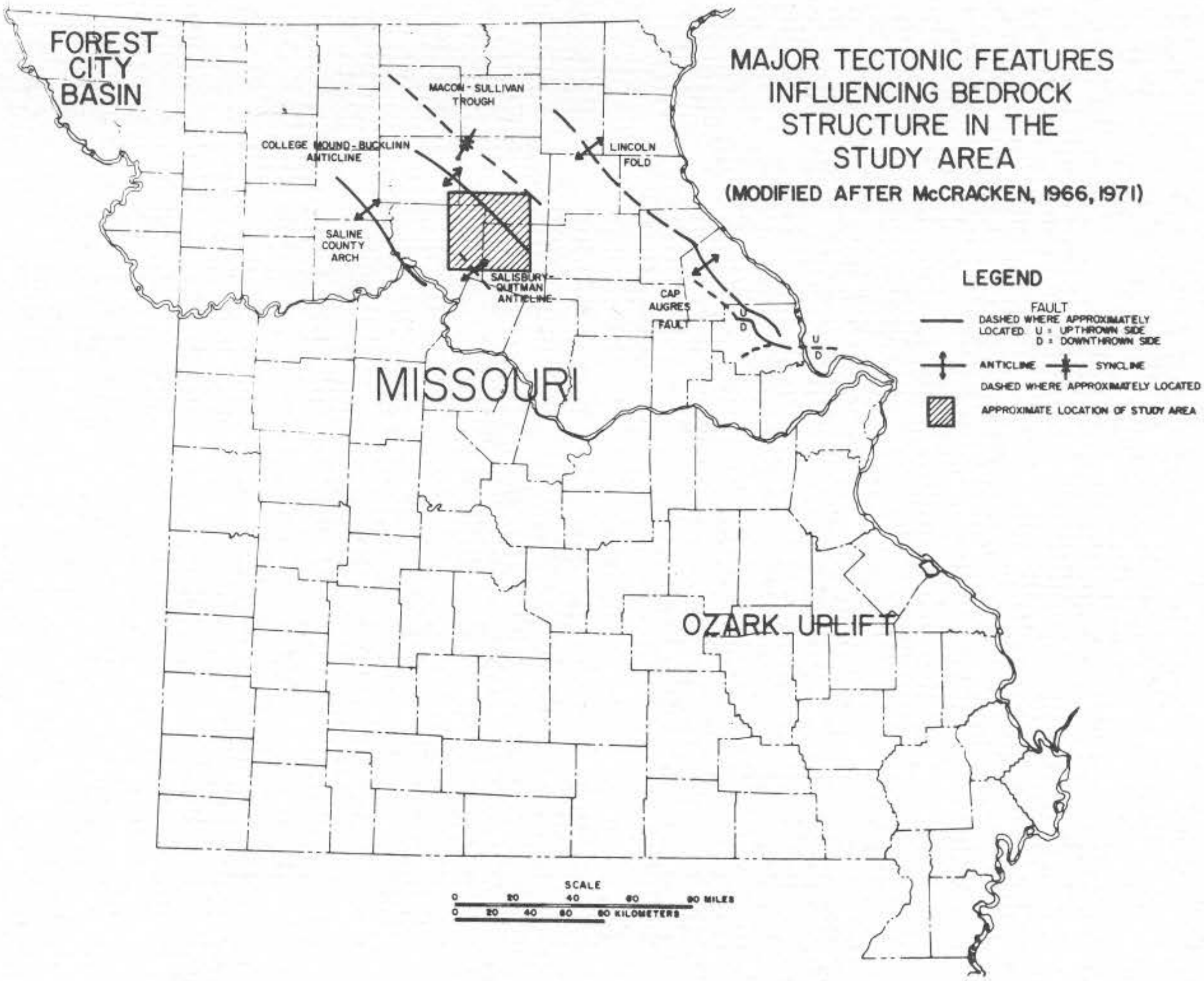
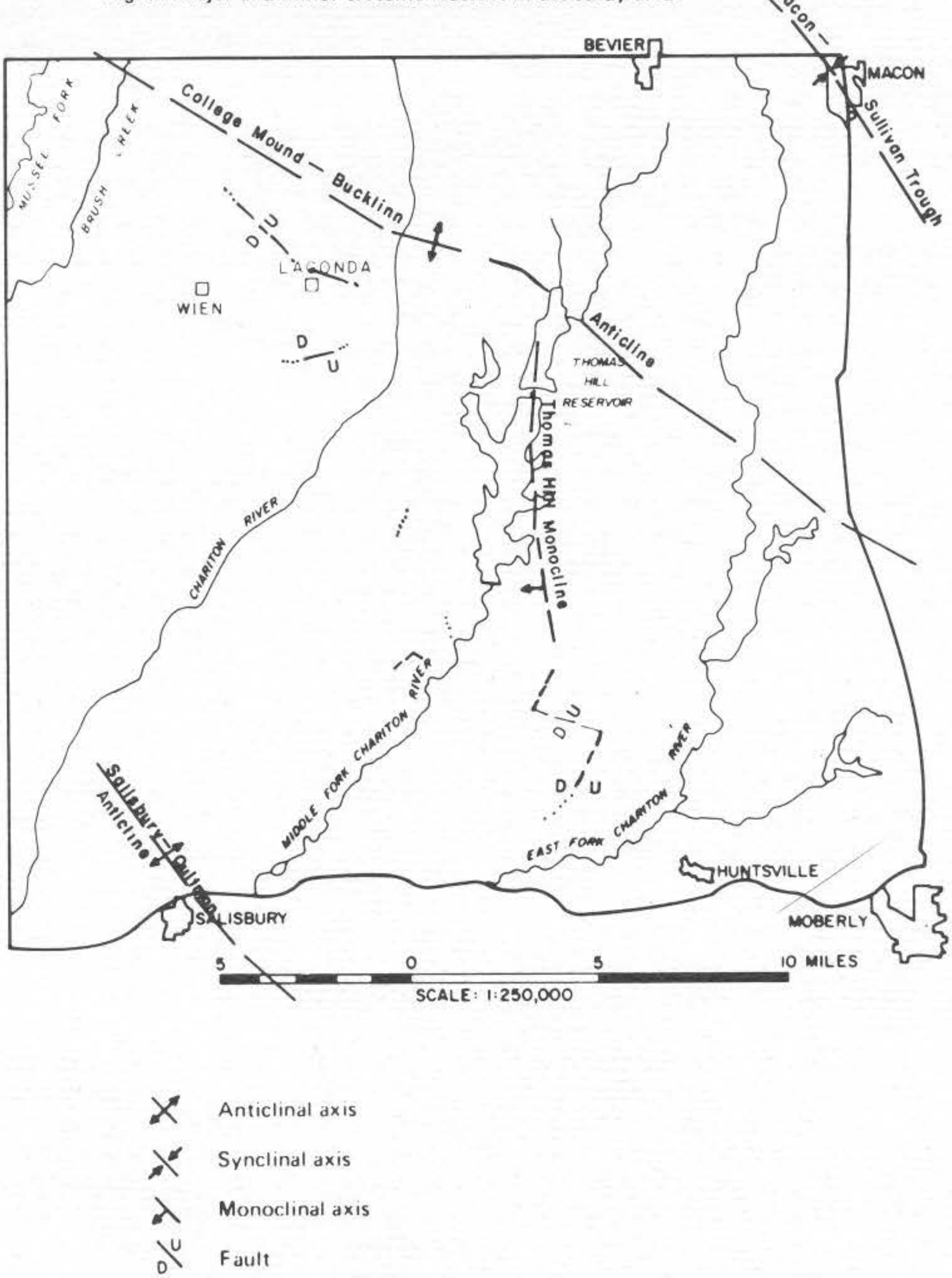

MAJOR TECTONIC FEATURES INFLUENCING BEDROCK STRUCTURE IN THE STUDY AREA
(MODIFIED AFTER McCRACKEN, 1966, 1971)
FOREST CITY BASIN
MACON - SULLIVAN TROUGH
COLLEGE MOUND - BUCKLINN ANTICLINE
LINCOLN FOLD
SALINE COUNTY ARCH
SALISBURY-QUITMAN ANTICLINE
CAP AUGRES FAULT
U
D
MISSOURI
OZARK UPLIFT
LEGEND
FAULT
DASHED WHERE APPROXIMATELY LOCATED U = UPTHROWN SIDE D = DOWNTHROWN SIDE
ANTICLINE
SYNCLINE
DASHED WHERE APPROXIMATELY LOCATED
APPROXIMATE LOCATION OF STUDY AREA
SCALE
0 20 40 60 80 MILES
0 20 40 60 80 KILOMETERS

Fig. 7. Major and minor tectonic features in the study area.



Economic Geology

The most valuable mineral resource in the study area is coal. Limestone is second in importance, whereas sand, clay, and shale are less important economically and are not discussed in this report. Gentile (1967) prepared a detailed report on the mineral resources of Macon and Randolph Counties. A more recent report that specifically evaluates coal reserves and resources in the study area was prepared by Robertson and Smith (1979). Both reports are available at the Missouri Department of Natural Resources, Division of Geology and Land Survey and should be consulted for more detailed information about mineral resources in the study area.

COAL

History - Coal mining in the study area probably began shortly after the founding of Huntsville in 1831. It was on a local scale, by slopes and drifts into the hillsides along the East Fork of the Chariton River.

The first large-scale coal mining in the study area was by shaft 1.5 miles west of Bevier in 1860. Not until after the Civil War, however, did underground mining begin significant development. The federal government did not keep records of coal production until 1886; therefore, the history and evolution of mining before that time is largely speculative.

By 1887 several large underground mines had opened near Bevier and annual production in Macon County exceeded 500,000 tons. Several large underground mines near Huntsville were also producing vast quantities of coal. Peak production by underground methods was attained in 1902, when more than 1.5 million tons of coal were produced from mines near Macon and Huntsville.

After World War I, coal mining declined until 1932, when modern surface-mining technology was introduced into the study area. These new methods, revitalized the waning mining industry, but it was not until the late 1960's that production again approached the levels attained in the early 1900's.

Since the late 1960's, coal production has not increased markedly in the study area. With the planned expansion of the Prairie Hill mine, however, production is expected to increase significantly in the next few years. Plate 3 shows former mined areas, both stripped and underground. It also shows areas underlain by economically important deposits of coal.

Descriptions of individual coal beds and of their production potentials are included in the section "Future Coal-Mining Potential of the Area."

LIMESTONE

The study area is underlain by several locally significant limestone beds, the most important of which are the Higginsville and Myrick Station limestones. They are present in much of the area east of the East Fork of the Chariton River, where they are separated by about 3 to 5 ft of clay and shale. Between Moberly and Jacksonville, where they have been quarried, the total limestone thickness of the Higginsville-Myrick Station interval is generally 8 to 10 ft; locally it is thicker. North of Jacksonville, toward Macon, the limestones thin, and diminish in quality.

In the extreme northwest corner of the study area the Myrick Station and Higginsville are present, but they are thinner and not as potentially valuable. The overlying Coal City Limestone Member, however, may be thick and persistent enough to quarry, but more detailed stratigraphic work is needed to confirm this.

The Blackjack Creek Limestone is 35 to 40 ft below the Higginsville limestone in the study area. Along the East Fork of the Chariton River, where it has been quarried in small operations, it averages 4 to 4.5 ft thick. It may be possible to quarry the Blackjack Creek in tandem with stripping of the Mulky and Bevier coals.

PART II
ENVIRONMENTAL GEOLOGY

Planning proper and efficient mining and reclamation requires detailed knowledge of the composition, distribution, and thickness of bedrock and surficial materials overlying, underlying, and adjacent to coal seams. The cost of overburden removal partly depends on thickness and degree of consolidation of overburden materials. The facility, cost, and effectiveness of reclamation also largely depend on overburden composition and thickness. Hydrologic conditions, land-use patterns, and geologic hazards also affect mining and reclamation.

Proper interpretation of the geologic (bedrock) and environmental geologic maps, cross sections, and text presented in this report can help in choosing suitable mining and reclamation plans. The following sections of this report discuss environmental geologic conditions related to mining and reclamation.

<u>The Environmental Geologic Map</u> - The environmental geologic map (plate 2) is designed to show the distribution and thickness of unconsolidated surficial materials important to environmentally and economically sound mining and reclamation. Information on this map, when properly interpreted, can help avoid or minimize some of the problems normally encountered during surface mining in the Prairie Hill area. It (1) identifies and delineates environmentally sensitive areas, (2) provides a regional background evaluation for the site-specific environmental studies required by federal and state regulations, and (3) provides basic data for mining and reclamation planning. The environmental geologic map provides an inventory of substrate, soils, and topography in the project area.

<u>Mapping Methods</u> - Preliminary environmental geologic mapping was done by identifying topographic landforms and types of surficial materials on standard U.S. Geological Survey black and white photographs. Tonal patterns, topography, gully and stream cross sections, and cultural features were the important identifying factors.

Data were transferred to standard U.S. Geological Survey 7½-minute topographic maps and field checked for accuracy. In this way a workable set of map units based on substrate composition and soil type was chosen. After field checking and subsequent revision, the information was transferred to a 1:100,000-scale base map for publication. The original 7½-minute, 1:24,000-scale base maps are filed, for use by the public, at the Missouri Department of Natural Resources, Division of Geology and Land Survey.

<u>Environmental Geologic Units</u> - Environmental units mapped in this report are based on types of unconsolidated

surficial materials and their topographic expression. Unconsolidated materials that have a profound effect on mining, reclamation, and agricultural productivity include loess, till, and alluvial materials.

These surficial materials essentially mantle the entire map area and control soil characteristics. Even in areas of bedrock exposure, a thin patchy cover of loess or drift is usually present. These materials effectively cover any preglacial soils developed on bedrock units. Twelve environmental geologic units, summarized in table 1, have been defined, based on the following characteristics:

1) *Composition of substrate: Substrate* is defined as the geologic materials from which soils are derived. Substrate units in the map area include loess, drift, alluvium, and undifferentiated alluvium-colluvium.

2) *Geomorphology:* Topographic expression and relief.

3) *Vegetation:* Each environmental geologic unit is characterized by a native or secondary assemblage of vegetation. Over most of the area, however, human activity has partly or entirely replaced native vegetation by a secondary assemblage.

4) *Land Use:* Each environmental geologic unit tends to support a characteristic suite of land uses.

Each unit, therefore, is formed on a characteristic substrate, possesses a characteristic soil and topographic expression, and tends to support characteristic plant communities and land uses.

Description of Environmental Geologic Units

Four classes of environmental geologic units have been defined in the Prairie Hill study area (table 1): 1) alluvial, 2) glacial-drift, 3) loess, and 4) man-made units. These classes and their constituent units are discussed below.

Alluvial Units

Alluvial environmental units include flood plains, terraces, and undifferentiated alluvium and colluvium, all three resulting from postglacial erosion, stream deposition, and mass wasting.

Flood Plains (map-legend unit 1A) - Designation of a map unit as a flood plain is based on geomorphic evidence of high-water erosion or deposition. No implications are intended as to frequency or extent of flooding.

Alluvial materials that form the flood plain substrate were derived by erosion and redeposition from the loess and glacial till that mantle the area and, to a lesser degree, from scattered exposures of bedrock. These materials were eroded from uplands, carried in suspension by streams, and redeposited during flooding. Alluvium in the Prairie Hill area is a mixture of distinct but discontinuous deposits of silt-clay, sand, and gravel sorted and deposited by running water.

Soils derived from alluvial substrate are loamy and clayey and usually very fertile. They are often extensively cultivated, corn, soybeans, and wheat being the common crops. Native vegetation comprises deciduous hardwood forests and water-tolerant grasses. Cultivation is the main land use.

Table 1

ENVIRONMENTAL GEOLOGIC UNITS OF THE PRAIRIE HILL AREA, NORTH-CENTRAL MISSOURI

ALLUVIAL UNITS

	Flood Plains	Terraces	Undifferentiated Alluvium-Colluvium
UNIT MAP Designation	1A	1B	1C
Substrate Composition	Clay, silt, sand, gravel	Clay, silt	Alluvium/colluvium, clay, silt, sand
Soil Characteristics A & B Horizons	Variable, fine sandy loam and clay	Silt loam and clay	Sandy loam and silty clay
Topography	Flat to gently undulating (slope less than 3%)	Flat to gently undulating (slope less than 3%) where not dissected by erosion	Flat to gently rolling (slope less than 3%)
Vegetation	Water-tolerant grasses and deciduous hardwoods	Tall prairie grass	Oak-hickory forest and mixed grasses
Current Land Use	Cropland, pastureland	Cropland, pastureland, woodland	Cropland, pastureland, woodland

GLACIAL-DRIFT UNITS

	Drift-Covered Prairie	Gently Dissected Drift-Covered Uplands	Highly Dissected Drift-Covered Uplands
UNIT MAP Designation	3AD	2BD	2AD
Substrate Composition	Glacial till/clay, sand, gravel	Glacial till/clay, sand, gravel	Glacial till/clay, sand, gravel
Soil Characteristics A & B Horizons	Loam and sandy clay	Silt and clay loam	Loam and clay loam
Topography	Flat to gently rolling (slope less than 3%)	Undulating to steep hills (slope 3-6%)	Steep hills - eroded slopes (slope greater than 6%)
Vegetation	Tall prairie grass	White oak - hickory forest, some prairie grass	White oak - hickory forest
Current Land Use	Cropland, pastureland, coal mining	Pastureland, cropland, woodland, coal mining	Pastureland, coal mining, woodland, and minor cropland

LOESS UNITS

	Loess-Covered Prairie	Gently Dissected Loess-Covered Uplands	Highly Dissected Loess-Covered Uplands
UNIT MAP Designation	3AL	2BL	2AL
Substrate Composition	Loess/silt	Loess/silt	Loess/silt
Soil Characteristics A & B Horizons	Silt, loam, and clay	Silt, loam, and clay	Silt, loam, and clay poorly developed A & B horizons
Topography	Flat to gently undulating (slope less than 3%)	Gently undulating (slope 3-6%)	Steep hills - eroded slopes (slope greater than 6%)
Vegetation	Tall prairie grass	White oak - hickory forest, tall prairie grass	White oak - hickory forest
Current Land Use	Cropland, pastureland, coal mining, urban development	Cropland, pastureland, woodland, coal mining	Pastureland, woodland, coal mining

Note: The following environmental geologic units are not shown on this table:

4A - Strip Mined Land
4B - Urban Areas
4C - Water Impoundments

As larger streams meander across their flood plains, various types of deposits are formed, including point-bar deposits, natural levees, backswamp deposits, and channel deposits. Hence, the flood plain is a patchwork of these unconsolidated deposits of varying composition. Channel and point-bar deposits consist largely of sand and gravel, natural levees of sand and silt, and backswamp deposits of silt and clay, or very poorly drained organic soils.

Permeability of alluvial substrate and derived soils is variable and directly related to substrate composition. Sand-rich zones are permeable and may constitute local aquifers. Clay-rich zones are impermeable, and soils developed on them are poorly drained.

Development of mines, tipples, or haulroads on flood plains must take into account certain inherent problems. For example, the poorly drained organic soils of backswamp deposits may not support heavy equipment, and the unconsolidated deposits will probably be difficult to hold in a highwall. In addition, the building of foundations may be hampered by variable soil types and a high water table.

Terraces (map-legend unit 1B) - Terraces or "second bottoms" are former flood plains, abandoned by downcutting rivers, standing as low benches above modern flood plains, in most cases above the common overflow levels of the rivers. The origin and composition of substrate and derived soils are similar to those of flood plain deposits. The topography of undissected terraces is also similar to that of flood plains. However, terraces may be severely dissected and in such cases are difficult to distinguish from adjacent gently undulating loess and drift topography. This is especially true of older terraces bearing primary loess deposits. Even younger terraces may be covered by thin deposits of reworked loess derived from adjacent eroded uplands.

In general, terrace soils are loamy, clayey, fertile, better drained than flood-plain soils, and highly productive. They are often extensively cultivated and are very similar to flood-plain soils, except for their much reduced susceptibility to flooding.

Native vegetation includes tall prairie grasses and various types of woodland, mostly of the oak-hickory association. Current land-use categories include cropland (corn, wheat, soybeans, and hay), pastureland, and woodland. Because terraces generally stand above flood level, farm dwellings are often built on them.

Terrace substrate composition, consisting of clay-silt, with some sand and gravel, is quite variable, both horizontally and vertically. The materials are better drained than those of flood plains. Permeability varies. They are easily excavated but may prove to be unstable in cuts and highwalls. Suitability for septic tanks and foundation stability varies with the composition of substrate materials.

Undifferentiated Alluvium and Colluvium (map-legend unit 1C) - These deposits occur in narrow valley strips along the headwaters of smaller streams. Both the alluvial and colluvial materials are derived by erosion and mass wasting from the glacial and eolian (loess) materials that mantle the local topography. Substrate composition is variable but is essentially clay, silt, sand, and gravel. Soils consist of fine sandy loam and clay. Many areas covered by these deposits remain in a natural wooded state. Besides woodland, current land use includes small-scale cropping or grazing.

Areas covered by undifferentiated alluvium and colluvium often occur in steep narrow valleys and are therefore subject to flash flooding.

Glacial-Drift Units

Three glacial-drift units have been distinguished on the basis of substrate composition and topographic relief. The substrate of each is predominantly glacial till, a highly heterogeneous mixture of unsorted, unstratified, generally unconsolidated clay, sand, gravel, cobbles, and boulders. Some deposits of glacial outwash occur in deeper preglacial valleys, buried beneath till. Meltwater flowing beyond glacial margins filled the valleys with clay, silt, sand, and gravel. Buried outwash deposits sometimes contain lenses of sand or gravel that may serve locally as aquifers.

After the glaciers receded, a nearly level till plain remained, covering all preexisting topography, the thickest glacial deposits occupying buried preglacial valleys. Almost all the Prairie Hill area is covered with moderate to thick deposits of drift. Almost all strip mines in the area intersect a layer of drift above bedrock overlying the coal seams. In some instances, all overlying bedrock has been removed by preglacial erosion, and the drift lies on the coal. The drift mantle also conceals deep preglacial channels, many of which have dissected and removed the important coal seams of the area.

Drift-Covered Prairie (map-legend unit 3AD) - Remnants of flat prairie remain between major drainage divides. Many of these relicts are covered by a thin layer of loess, but others lack such a cover and are classified as drift-covered prairies.

Drift-covered prairies are flat to gently undulating (less than 3 percent slope). Soils are loamy and clayey, and the substrate is clay, sand, and gravel till, with clay predominating. Original vegetation consisted of tall prairie grass. Land use includes cropland, pastureland, and coal mining.

Soils and substrate have low permeability and poor internal drainage. Both are easily eroded if disturbed by mining or other human activity. There is a danger of slope failure on hillsides or in highwalls. In winter, freeze-thaw action can cause the breaking up of roads and foundations.

Gently Dissected Drift-Covered Uplands (map-legend unit 2BD) - Streams cutting into the upland prairies have resulted in various degrees of dissection. Because the degree of dissection greatly affects land use, dissected uplands have been classified *gently dissected* and *highly dissected.*

Gently dissected drift-covered prairies consist of undulating to relatively steep hills with slopes of 3 to 6 percent. Soils and substrate are similar to those of upland prairies, but, because of the steeper slope, they are subject to gullying and erosion. Natural vegetation consists primarily of white oak-hickory forest assemblages with prairie grasses on the gentler slopes. The land is currently used for pasture, crops, woodland, and coal mining.

The engineering characteristics of the soils and substrate are similar to those of drift-covered prairie, with impermeable soils and substrate, high erodibility, danger of slope failure, and freeze-thaw problems.

Highly Dissected Drift-Covered Uplands (map-legend unit 2AD) - These uplands are steep hills with eroded slopes having gradients of more than 6 percent. Soils and substrate are similar to those of other drift units, but the steep slopes limit land use to pastureland, woodland, and coal mining. Cropland is minor. Natural vegetation consists of white oak-hickory forest assemblages.

The engineering characteristics of the soils and substrate are similar to those of the other drift units, but because of the steep slopes, problems of slope failure and erosion are more severe.

Coal strip mines that follow coal seams cropping out low in the valleys are often developed in the unit, because it tends to occur along river breaks. In many areas the lower parts of highwalls are developed in Pennsylvanian bedrock and the upper parts of the highwall in unit 2AD. Mine development must address the slope-stability, permeability, erosion, and drainage problems inherent in the unit.

Loess Units

Three loess units have been identified: 1) loess-covered upland prairies, 2) gently dissected loess uplands, and 3) highly dissected loess uplands.

The substrate of each unit is loess, which in its unweathered state consists of finely granular, largely silt-size material, light grayish brown to yellow brown in color. It is coherent when undisturbed but gullies severely when eroded and breaks down readily into brown silt. Loess may be readily identified on aerial photographs by its light tone, typical modified dendritic (pinnate) drainage pattern, and U-shaped gullies.

Loess-Covered Upland Prairie (map-legend unit 3AL) - Between major drainage divides, loess-covered upland prairies exist as remnants of the original till-loess plains. The loess was originally deposited as a windblown silt over most of the area, its thickness ranging between 4 and 8 ft over the uplands. Because loess is the latest surficial deposit in the area, and covers all previous deposits, it is the parent material of upland soils over most of the area.

Loess prairies are flat to gently undulating, with gradients of less than 3 percent. Soils are silt and clay with well-developed A and B horizons. Original natural vegetation consisted of tall prairie grasses. Current land uses include cropland and pastureland. Loess-derived soils are favorable for corn and wheat. Most urban centers in the area are on the loess prairies. Loess soils and substrate are permeable and well-drained in their natural state, but when disturbed by mining, road building, or other human activity, they become poorly drained and easily eroded. Potential engineering problems include septic-tank failure, excessive foundation settlement, severe water erosion, frost damage, and loss of strength when wet (Lillesand and Kieffer, 1979).

Gently Dissected Loess-Covered Uplands (map-legend unit 2BL) - Gently dissected loess uplands are intermediate between highly dissected loess uplands and prairies. Soils and substrate are similar in composition to those of loess prairies. However, the topography is gently undulating, with gradients of between 3 and 6 percent. Tall prairie grasses originally covered the gentler slopes, and woodland the steeper slopes. Currently, cropland and pasture predominate, while the steeper slopes remain wooded. Some larger strip mines have progressed into unit 2BL.

The potential engineering problems are similar to those of the loess prairies; the possibility of slides resulting from soil creep is an additional problem, especially on the steeper slopes.

Highly Dissected Loess-Covered Uplands (map-legend unit 2AL) - Highly dissected loess uplands consist of steep slopes, vertical bluffs, and pinnacles, and contain gullied areas. Because of erosion, soils are poorly developed. Natural vegetation consists of a white oak-hickory forest assemblage. The land is still mostly wooded, with some pastureland. Because this unit tends to occur on the streamward edge of river breaks, it is often disturbed by strip mining in coal seams cropping out in the valleys. The soil and substrate composition and potential engineering problems are similar to those of other loess units. The potential for slides is more severe because of the steep slope gradients.

Where the unit directly overlies impermeable Pennsylvanian shales or clays, a water saturated zone may develop at the loess/bedrock contact, which may subsequently act as a slide plane, resulting in potentially serious slope failures.

Man-Made Units

Man-made environmental units include land disturbed by surface mining for coal, urbanized areas, and water impoundments. Smaller areas such as quarries, roads, ponds, etc., are not included.

Strip-Mined Land (map-legend unit 4A) - Coal stripping began in the study area in the 1930's and has continued essentially without interruption. Most of the stripped land is located in the eastern one-fourth of the area, along the East Fork of the Chariton River. A smaller but growing area of stripped land, in the south-central part of the project area, just south of Thomas Hill Reservoir, is producing coal for Associated Electric Cooperative's Thomas Hill generating station. Production is scheduled to reach nearly 4 million tons per year by 1982. By the year 2000, nearly 80 million tons of coal will have been produced from this mine, and an estimated 14,000 acres will have been disturbed.

Strip mining disturbs all overburden above the coal. In most cases this includes bedrock, and till or loess or both. Bedrock consists of interbedded shales, limestones, and sandstones above the coal. Till and loess cover bedrock in most of the area, and in some places lie on the coal, having replaced the original bedrock. Spoil from strip-mining is a mixture of overlying bedrock, till, and loess removed from coal seams before recovery. In areas where bedrock is thick and covered with little till or loess, spoil consists of mixtures of shale, sandstone, and limestone. In areas of thick till and loess, these materials make up the greater portion of the spoil.

Much of the mined land in the area was stripped before the advent of modern reclamation practices. Stripping with pre-law methods literally "turned the land upside down," burying the original soil and surficial materials beneath deeper overburden, usually bedrock materials that originally lay on the coal seams. The landscape resulting from earlier stripping was a series of earth windrows: blocks of shale, sandstone, and limestone strewn over the surface.

Modern strip mining methods remove and stockpile soil and unconsolidated loess and till, replacing these materials in their original position on graded bedrock materials. Eventually, mined areas are replanted, leaving reclaimed landscapes and soil profiles very similar to the originals.

Urbanized Land (map-legend unit 4B) - All or parts of the towns of Moberly, Huntsville, Macon, and Bevier, and smaller communities are within the project area. Most of these urban areas are on upland prairies, predominantly on loess-covered upland prairies. Flood plains have been especially avoided for urban development.

Water Impoundment (map-legend unit 4C) - Thomas Hill Reservoir, a 6000 acre lake was created primarily to serve as a water source for Associated Electric Cooperative Thomas Hill Generating Station. The Lake is now used also for recreational purposes.

Environmental Characteristics of Bedrock Units

Although most of the project area is mantled by varying thicknesses of surficial materials, including alluvium, glacial drift, and loess, there are bedrock outcrops within it, in many places a few feet or tens of feet from the surface. Outcropping or near-surface bedrock profoundly influences mining and engineering activities. Figure 8, which shows the combined thickness of drift and loess, also shows depth to bedrock in the project area. Plate 1 shows areas of bedrock exposure. Note especially cross sections A-A', and B-B', (plate 1), which show the relationship of bedrock to surficial materials.

Outcropping or near-surface bedrock units in the area are Pennsylvanian in age. They comprise a series of interbedded shales, sandstones, and thin limestones, with coal seams and associated underclays. Detailed descriptions of these units and their stratigraphic relationships are discussed in the section on stratigraphy. Reference should be made to the stratigraphic section, geologic map, and cross sections on plate 1.

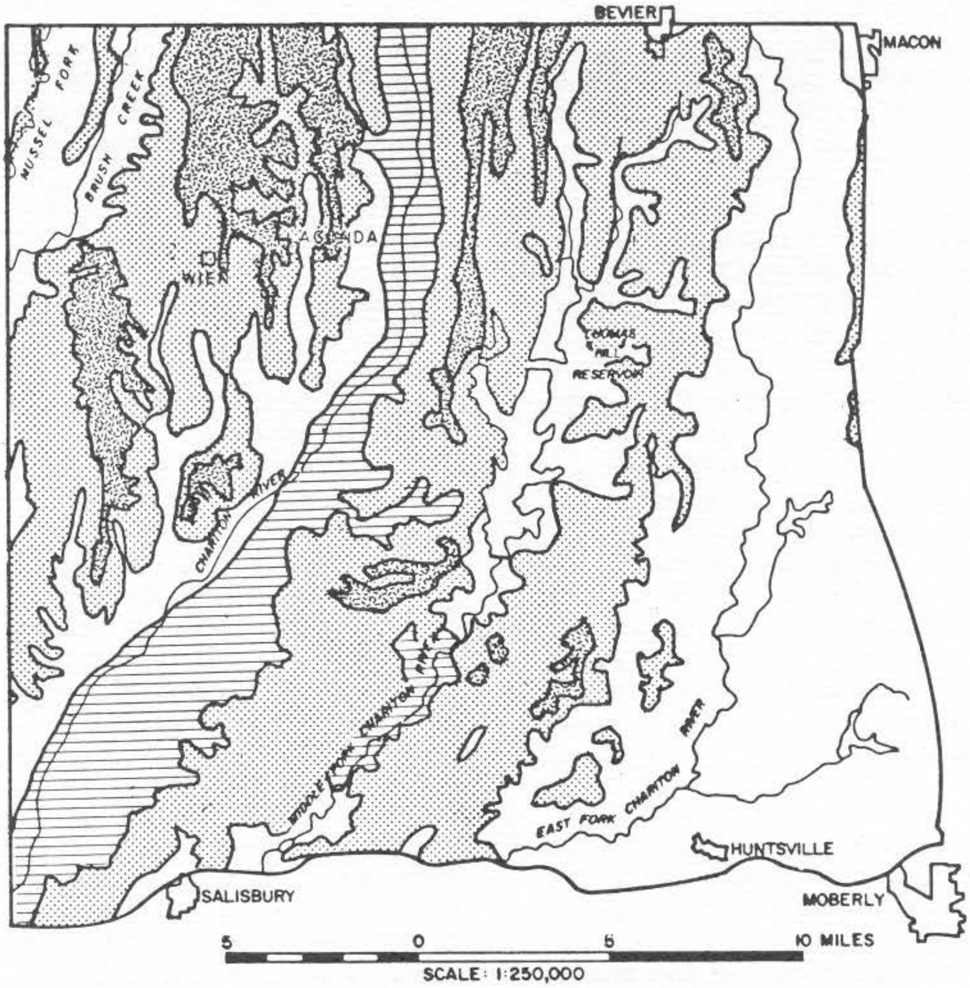
Channel sandstones of the Pleasanton Group represent the youngest and stratigraphically highest bedrock units in the project area. They are limited areally and may be up to 100 ft thick. Characterized by thin soils and relatively high permeability, they may serve locally as low-yield aquifers. Their permeability also causes areas underlain by them to be unsuitable for solid- or liquid-waste disposal. Where well-cemented, they can provide excellent foundation support, because they are more resistant to erosion than shale but less resistant than limestone.

The Marmaton Group consists primarily of shale, but with prominent thin- to medium-thick limestone units, sandstones, and thin coal seams and associated underclays. The shale units have low permeability, induce high surface runoff, and are easily eroded.

Limestone units may be permeable from fracturing or solution activity; they are stable in cuts, and they provide excellent foundation supports. Limestones may serve as local aquifers if permeability and recharge conditions are favorable. The Higginsville and Myrick Station limestones constitute a prominent zone 8 to 14 ft thick. Where exposed, they may contain solution permeability and act as local aquifers.

The Cabaniss Subgroup, which lies next below the Marmaton, consists primarily of shales, with a few thin limestones, sandstones, and coal seams and associated underclays. Because of the predominance of shales the Cabaniss Subgroup is characterized by low permeability and high surface runoff.

Fig. 8. Combined thickness of drift and loess in the study area.



Isopach interval = 50 feet

- 100 ft thick
- 50 to 100 ft thick
- 0 to 50 ft thick
- Drift beneath alluvium

The Cabaniss is easily eroded. A prominent limestone zone, the Ardmore Limestone, lies directly beneath the Wheeler coal seam and about 20 ft above the Croweburg coal. The expense of removing this limestone as overburden is a major impediment to mining the Croweburg coal, which is about 30 ft beneath the important Bevier-Wheeler coal seam. Rocks below the Cabaniss are seldom exposed in the project area. They consist of shales, sandstones, conglomerates, coal, and clay.

Mining and Reclamation Problems

Modern surface-mining techniques combine mining and reclamation into a single operation. The objectives are to (1) remove overburden from one or more coal seams, (2) recover the coal seam or seams, and (3) to replace the overburden in such a manner that productivity is restored to the land. All this must be done with minimum adverse effect on the environment, and within definite economic limits.

Development of an integrated mining and reclamation plan is essentially an engineering problem, but geologic factors influence mining plans, the economics of mining, and the selection of mining equipment. The following paragraphs discuss geologic factors that influence these and related aspects of mining.

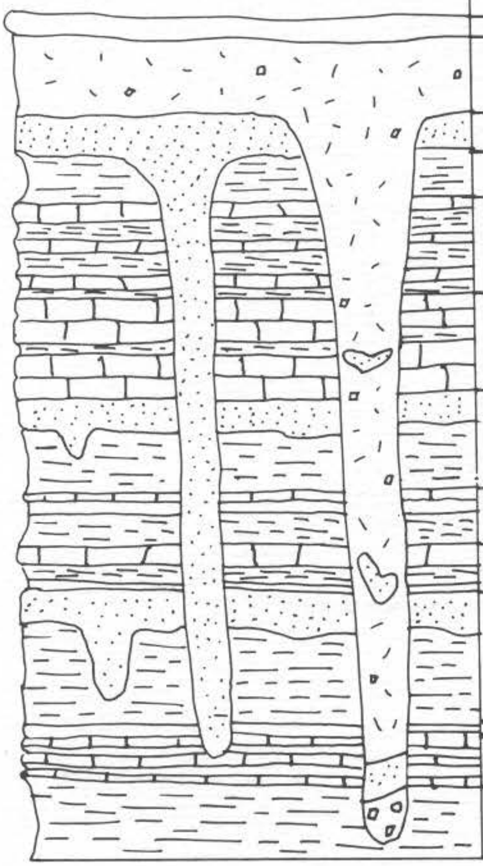
The cost of mining coal by surface-mining methods is essentially the cost of removing, handling, and replacing overburden. The composition and thickness of overburden directly affect the cost of each step.

Characteristics of a material which affect the cost of its removal include excavatability and load factor. *Excavatability*, as used in this report, refers to the relative ease of digging with conventional mining equipment. For example, a material such as loess, which may be loaded in its natural state without blasting or ripping, has high excavatability, but a hard limestone which requires blasting before loading has low excavatability. The load factor accounts for the tendency of earth materials to swell as they are excavated and is defined as the weight per cubic yard of loose overburden divided by the weight per cubic bank yard of overburden (Caterpillar Tractor Co., 1968). Figure 9 indicates the relative excavatability and load factors for various overburden materials likely to be encountered in the project area. The estimates given for each unit in figure 9 are theoretical and may vary in actual practice.

Surface mines in the project area are likely to encounter two basic types of overburden: (1) surficial deposits composed of glacial drift or loess or both, and (2) bedrock which consists of interbedded shale, sandstone, and limestone, with thin coals and underclays. In some instances, overburden may consist of alluvial materials. Loess deposits are the uppermost deposits in the area and vary in thickness from 0 to 8 ft. Glacial drift deposits consist primarily of clay-rich till and vary considerably in thickness (fig. 8). In the areas of thicker drift, outwash deposits of gravel and sand may be encountered. In some localities, overburden consists entirely of surficial materials; in others, entirely of bedrock. More often, however, overburden consists of bedrock overlain by surficial materials.

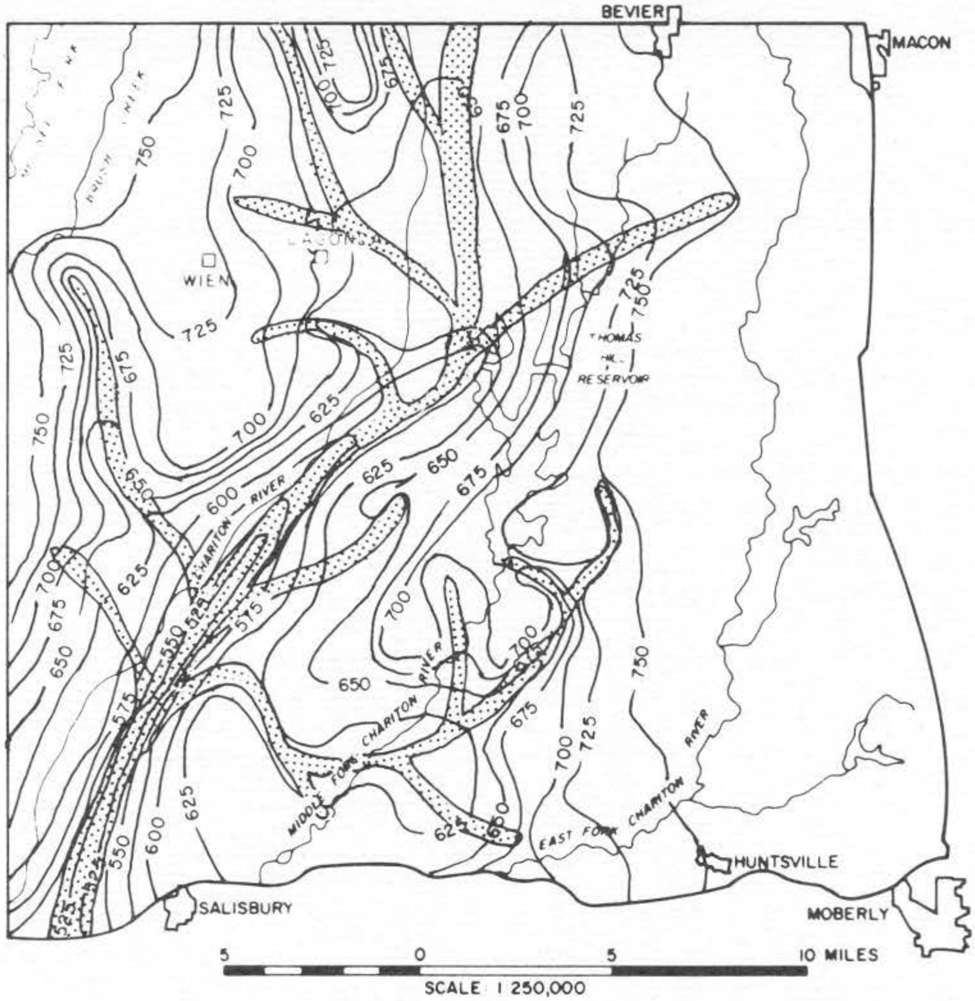
Removal of loess and till overburden is likely to be cheaper than removal of bedrock overburden. Loess consists of soft, easily removed silt. It does not require loosening and has a high load factor. In reclamation work, loess is an excellent subsoil material, easy to haul,

Figure 9 – Characteristics of overburden materials affecting mining and reclamation



Unit	Thickness (ft.)	Lithology	Favorability for digging	Postulated relative load factor
Loess	0-8	Silt some clay	good	high
Till	0-200	Clay, some sandstone, gravel, and boulders	medium	medium to high
Pleasanton	0-150	Sandstone some shale	medium to poor	medium to high
Lenapah Nowetta Holdenville	5-15	Shale	medium	medium
Worland Lake Neosho Amoret Bandera Coal City Mine Creek	8-10	Interbedded thin limestone and shale	poor	low
Myrick Station Anna Higginsville	4-8 2 3-10	Limestone minor shale	poor	low
Little Osage	15-30	Shale and sandstone	medium	medium
Houx Summit	2 1 5	Interbedded limestone and some shale, Summit coals	poor	low
Blackiack Creek Excello Mulky	3-5 2-3 0-2	Mulky		
Lagonda	10-45	Sandstone and shale	medium	medium
Bevier	2-5	Coal		
Ardmore	6-25	Limestone, some shale	poor	Low - medium
Verdigris	20-30	Shale	medium	medium
Croweburg	2	Coal		

Fig. 10. Topography of the bedrock surface and postulated areal pattern of preglacial drainage in the study area.



Contour interval 25 feet

Postulated preglacial drainage pattern

grade, and revegetate. However, loess tends to lose strength upon wetting and may present slope-stability problems. Loess also erodes easily, and measures must be taken to reduce erosion during mining and reclamation.

Glacial deposits in the project area consist primarily of till, which is variable in composition but is mostly clay. Till may also contain boulders and sand and gravel lenses. Compared to bedrock, it is soft and more easily removed. Till rich in clay has poor internal drainage and may be prone to slope failure on steep slopes. The high erodibility of till must be considered during mining and reclamation.

In areas of thick drift (fig. 8), there are likely to be buried preglacial valleys filled with coarse-grained, highly permeable outwash deposits. Figure 10 shows postulated preglacial drainage in the study area. Outwash deposits in buried preglacial valleys are likely to be increasingly encountered in mining as changing economics and technology make it possible to recover coal lying beneath thicker overburden. Such deposits present unique mining problems. Permeable lenses of sand and gravel may serve as local aquifers and present mine dewatering problems (O'Rourke and O'Connor, 1979), and they may also cause highwall and spoil instability. Because of the high variability of glacial materials, thick drift deposits in buried valleys should be thoroughly investigated before mining and reclamation plans are completed. Bedrock consists primarily of interbedded shale, sandstone, and thin limestones. Each coal seam has its characteristic overburden (fig. 9). For example, the Bevier seam is characteristically overlain by soft shale (soapstone) and sandstone, the Mulky by a thin shale and limestone caprock, and the Croweburg by shale and a relatively thick limestone. Thickness, lithology, and distribution of these units can be better understood by referring to the stratigraphic section of this report. In some areas, because of erosion, drift-filled preglacial channels or Pleasanton sandstone may replace the original overburden over the coal seams.

Bedrock is consolidated and tougher than surficial materials and more likely to require blasting or ripping, thereby increasing the cost of removal. However, the consolidated nature of the bedrock makes the highwall easier to hold. Swell is generally higher for bedrock materials, thereby increasing the load factor and the cost of removal and handling per cubic yard of overburden. Relatively thick limestone zones like the Ardmore may be particularly troublesome and require blasting. Laminated shales and sandstones may be cheaper to rip than to blast. Thick, well-cemented sandstone zones may be abrasive and increase bucket wear on draglines and shovels.

In general, during reclamation, bedrock materials are more difficult to handle than surficial materials. They are more difficult to break up and to grade. Limestones and well-cemented sandstones are particularly troublesome when they remain as large blocks scattered over the surface. Soft silty or clayey shales and poorly cemented sandstones are more easily graded and shaped to the approximate original contour of the land. Crushing thin limestones to produce calcium fertilizer for revegetation may be a way to eliminate the problem of burying limestone blocks.

Alluvial overburdens in flood plains sometimes present especially difficult mining problems. Alluvial materials are variable vertically and horizontally and are composed of a mixture of distinct but discontinuous unconsolidated deposits of silty clay, sand, and gravel. They often lie at least partially below the water table. Sand-rich lenses may serve as aquifers. Such deposits may be the source of water inflow problems and highwall instability. The moisture content of water-saturated sandstone also adds to the weight of the overburden and therefore to removal costs.

Groundwater Hydrology

Potential sources of groundwater in the study area are limited to three very different aquifer types: alluvial sands and gravels, glacial drift, and bedrock. Figure 11 shows their distribution. Figure 12 is an idealized block diagram showing aquifer types in the project area.

Alluvial sands and gravels in the Chariton River Valley and locally in other stream valleys in the study area are capable of yielding more than 100 gallons per minute to wells. The Chariton River alluvium has a particularly high potential for future groundwater development. In 1980 the city of Salisbury constructed two wells with capacities of 150 to 200 gallons per minute, in Chariton River alluvium, to replace older wells in the alluvium of the Middle Fork of the Chariton River, east of Salisbury. These alluvial deposits are heterogeneous; yields depend on the amount of permeable sand and gravel encountered in drilling. Yields also depend on the extent to which sand and gravel deposits are interconnected, and connected with sources of recharge. Sustained flow in the Chariton River and in other perennial streams in the study area is maintained by groundwater flow from the alluvium. Recharge to the alluvium comes from three sources: local rainfall in the valley, which moves as soil moisture into the aquifer materials; more discrete recharge from tributaries flowing across the alluvium from upland areas; and recharge from the river during high river stages, when the natural groundwater gradient towards the river is reversed.

Small to moderate amounts of water (10 gpm to 100 gpm) can be obtained from glacial drift that contains sufficient permeable sand and gravel. These deposits, composed of sand, gravel, clay, silt, and boulders, are very heterogeneous vertically and horizontally, with permeable lenses of sand and gravel separated by silt and clay. Larger quantities of water can be obtained only from areas where thick sands are present (Stout and Hoffman, 1973). Such areas are usually confined to buried preglacial valleys, which in general underlie areas of thicker glacial drift (figs. 8, 10). Figure 11 shows the distribution of yields that can be expected from glacial drift in the study area. Water supplies in the areas shown as having yields of less than 10 gallons per minute are usually not dependable and are subject to failure during prolonged drought conditions. Since yields are usually small, many residents in these areas depend upon large-diameter dug wells to supply large surface-area infiltration and for storage. Cisterns are used in areas where drift is nonproductive.

Water from glacial drift is hard and sometimes contains much iron. The concentration of dissolved substances is extremely variable, probably reflecting upward movement of saline water from bedrock in places. Some of the water has not proved usable (Stout and Hoffman, 1973).

Exposed bedrock is Pennsylvanian in age and consists of shale, sandstone,

Fig. 11. Areal distribution pattern of possible groundwater yields in the Prairie Hill project area.

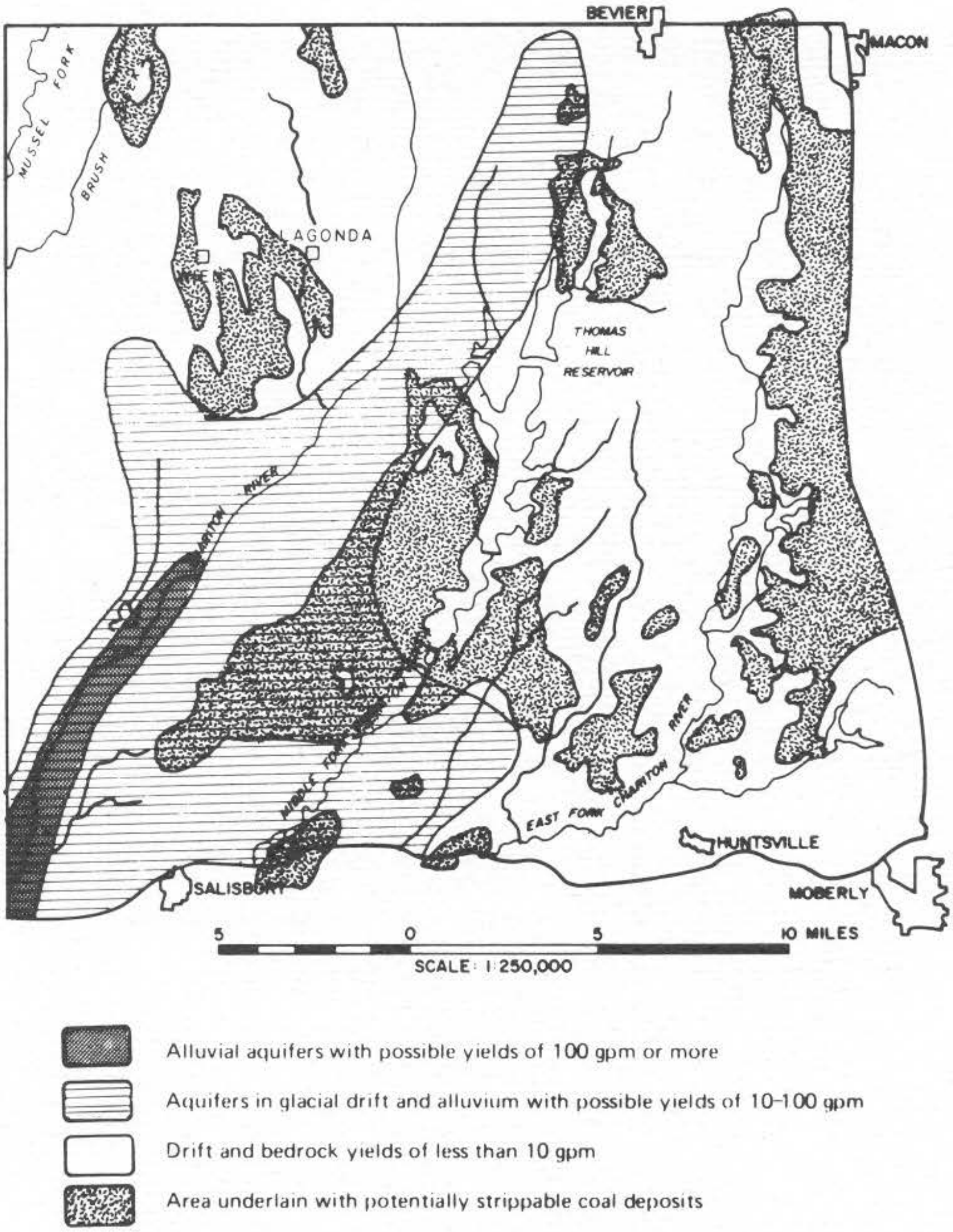
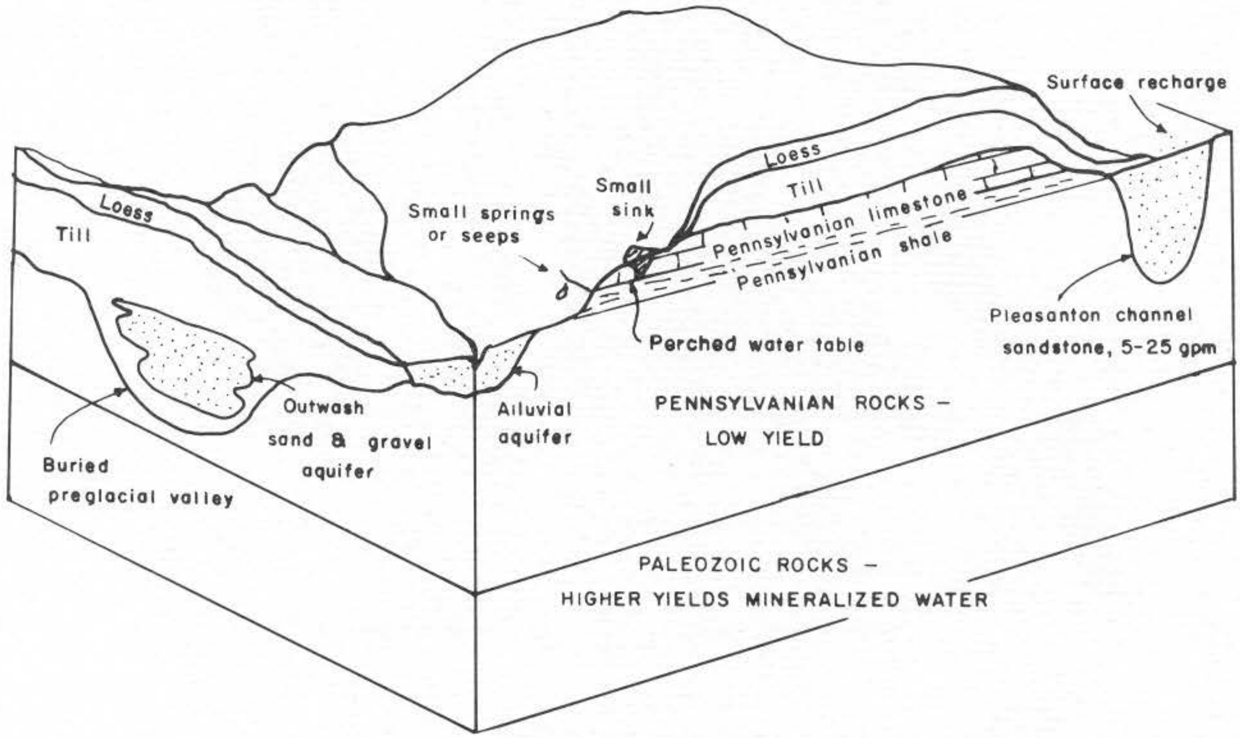


Fig. 12. Idealized block diagram showing relationship of aquifer types in the project area.



limestone, and coal seams; shale and sandstone are the most abundant rock types. Only very small quantities of water are available from these Pennsylvanian rocks, which, because of low permeabilities and consequent low recharge rates, are subject to failure during dry weather. Somewhat higher yields (5 to 25 gpm) may be obtained locally from Pleasanton channel sandstones.

A few small springs and seeps occur at contacts between some of the thicker limestone units, such as the Higginsville and Myrick Station limestones, and underlying shales and clays. These fine-grained materials prevent downward movement of water and form local perched water tables. Recharge areas for these small seeps and springs are exposures of limestone upslope from the discharge areas, usually no more than a few hundred yards away. Small sinks sometimes pond water for a short time after rainfall, but in a few days the water has moved through joints in the limestone to the discharge areas and flow begins to subside. In dry weather, flow ceases altogether. These small hydrologic systems exist only locally in areas where limestones are exposed or covered by only a thin cover of glacial drift. Dug wells intersecting this type of system may supply a small amount of water but are subject to surface pollution.

Wells drilled through Pennsylvanian rocks into deeper, higher yielding bedrock units would produce water too highly mineralized (1000 mg TDS) to be considered potable. In addition to calcium and magnesium carbonate, which produce ordinary hardness, these waters contain variable concentrations of sodium sulfate and sodium chloride (Stout and Hoffman, 1973).

Effective drillhole plugging should prevent contamination of potable water supplies by saline groundwaters. The glacial-drift-Pennsylvanian contact should be sealed to protect potable water supplies in glacial-drift aquifers. In drillholes that penetrate alluvial fill and Pennsylvanian bedrock, the alluvium-Pennsylvanian contact should be sealed to prevent contamination of alluvial aquifers. Suggested plugging procedures may be obtained from the following:

Water Resources Section
Missouri Department of Natural Resources
Division of Geology and Land Survey
P.O. Box 250
Rolla, MO 65401

The Effect of Strip Mining on Groundwater Hydrology

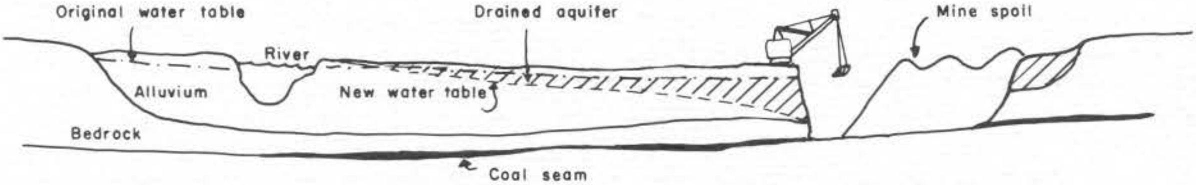
Figure 11 compares the area of potentially strippable coal deposits and groundwater regimes. The strip mining of coal will have the greatest effect in areas with the greatest potential groundwater yields.

Because all coal deposits in the area occur in Pennsylvanian strata, mining should have very little effect on groundwater supplies in rocks below the Pennsylvanian. Underclays and shales should serve as impermeable barriers to prevent contamination of aquifers underlying Pennsylvanian rocks.

Because groundwater yields from Pennsylvanian rocks are very small and because the hydrologic systems in them are usually limited in extent, only minimal local hydrologic effects should be expected when overburden is removed from these rocks. It is possible that local hydrologic systems related to perched water tables or channel sandstones might be affected (fig. 12). In most cases, channel sandstones with sufficient areal extent and thickness to serve as aquifers fill deep valleys from which the coal has been eroded; therefore, they are unlikely to be disturbed by mining. Occasionally, however, coal seams may underlie these sand-filled channels. In such cases, mining of an underlying coal seam may cause local lowering of the water tables in, or partial draining of, any aquifers adjacent to the mine. Figure 13 illustrates the probable effect of strip mining below an idealized alluvial aquifer. Wells within the area of water table depression may fail or require deepening. It should be emphasized, however, that alluvial fill is inhomogenous and that aquifers within alluvium are discontinuous. Before mining in alluvial fill, a thorough testing program, including drilling and, if practical, geophysical methods, should be carried out to determine the character, distribution, and extent of aquifers. Care must be taken during mining to avoid introducing acid waters into alluvial aquifers.

Strip mining in areas of thin or impermeable glacial drift with very small groundwater yields causes only minimal local effects on groundwater hydrology. However, in areas of high yield the effects are quite similar to those affecting high-yield alluvial aquifers, i.e., lowering of the water table could cause the failure of nearby wells. Of course, care must also be taken not to introduce acid waters into glacial-drift aquifers.

Fig. 13. Idealized diagram showing potential drainage of an alluvial aquifer, by mining.



FUTURE COAL-MINING POTENTIAL OF THE AREA

The boundaries of the Prairie Hill study area correspond very closely to the boundaries of the north half of the Bevier Field as defined by Robertson and Smith (1977). Therefore, coal resource and reserve estimates in that report give an accurate picture of coal potential in the Prairie Hill study area.

Coal Seams

In the study area, the Bevier seam is the important potential source of recoverable coal; the Mulky, Croweburg, and Summit seams are less important. The Weir-Pittsburg (Eureka) is present at depth but is too deep for stripping in the area. Not enough information is available on the Weir-Pittsburg to determine its potential as a deep (subsurface) reserve.

The Bevier seam ranges between 24 and 60 in. in thickness in the area. Near its base there is usually a thin binder or parting, varying in thickness from less than one inch to slightly more than a foot in most of the area. The parting thickens abruptly 2 to 4 miles west of the Chariton River, in northeast Chariton County, where it becomes more than 5 ft thick, and the Bevier becomes, in effect, two coal seams, the upper seam (bench) retaining the name Bevier, and the lower seam (bench) becoming the Wheeler seam.

Disregarding the binder or parting, the Bevier-Wheeler seam contains between 24 and 57 in. of clean coal in most of the area. It has been mined on a large scale in Macon and Randolph Counties and on a smaller scale in Chariton County.

Figure 14 is an isopach map showing the thickness of the Bevier coal. The isopachs cover only the eastern two-thirds of the study area, where the parting is sufficiently thin that both benches (Bevier and Wheeler) can be mined as a single seam.

The Mulky seam is important along the divide east of East Fork and in some places just west of East Fork. It lies 12 to 15 ft above the Bevier in the eastern part of the area, where it is often mined in tandem with that seam. The interval between the two increases to 40 to 50 ft in the western part of the area. Along East Fork, the Mulky ranges between 14 and 22 in. in thickness and, with the Bevier, is an important source of coal.

The Croweburg seam, ranging in thickness from 6 to 30 in. or more, lies 25 to 40 ft beneath the Bevier, but very few drillhole data are available for it. Under current mining practice and economic conditions, very little of the Croweburg seam is being mined; however, it is a very large resource, which under improved economic conditions could become more practical to mine.

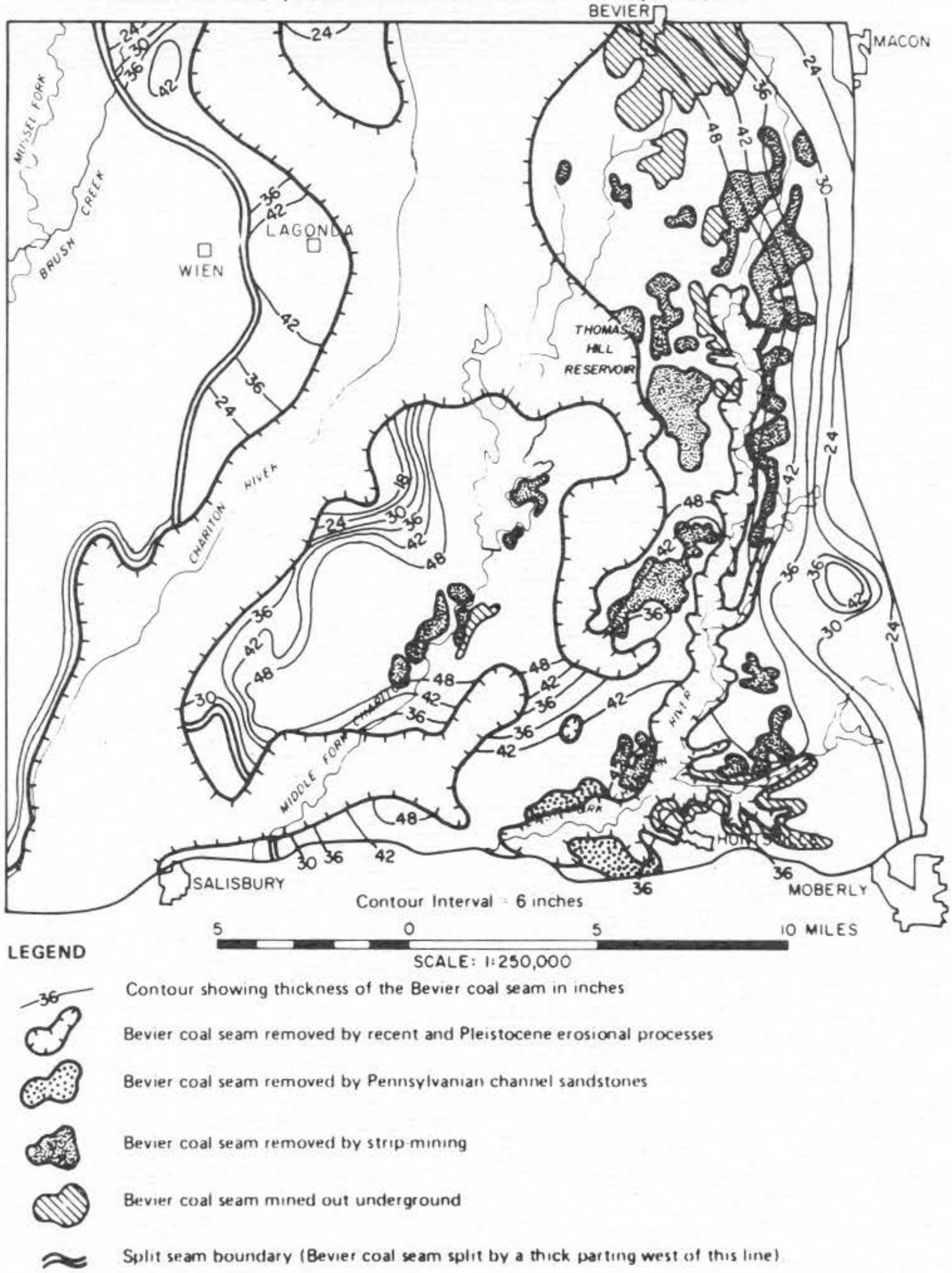
The Summit, a thin coal seam, one foot or less thick over most of the area, lies directly above the Mulky. Minor tonnages are occassionally recovered from the Summit, in Bevier-Mulky tandem operations.

Strippable Reserves

Plate 3 shows areas of potentially strippable coal in the Prairie Hill study area. A cutoff depth of 150 ft of overburden over the Bevier coal seam was used to define areas of strippable coal.

The demonstrated recoverable reserve of strippable coal for the area has been estimated at 192 million tons (Smith and Robertson, 1977). Geologic evidence indicates that this estimate

Fig. 14. Isopach map of the Bevier coal seam (includes Bevier coal bed, bench rock, and Wheeler coal bed) (modified after Robertson and Smith, 1979).



will be revised upward by continued exploration.

Underground (Subsurface) Reserves

The Bevier coal seam was mined extensively by underground methods in the past. Since much coal remains in this seam, which is more than 28 inches thick, underground mining could be resumed if economic conditions become favorable. An estimated recoverable underground reserve of 25 million tons remains in the Bevier seam where it is more than 150 ft below the surface and therefore not considered minable by surface methods.

Future Mining Potential

With a demonstrated combined reserve of deep and strippable coal amounting to 217 million tons, the Prairie Hill area might support a sustained annual coal production of more than 7 million tons for 30 years. Geologic evidence indicates that exhaustion of the demonstrated reserve base would not deplete the total coal resource base of the area but that additional reserves remain to be proved by exploration.

GEOLOGIC HAZARDS

Geologic hazards recognized in the area include 1) flood plains, 2) mined-out underground areas, and 3) possible subsidence of mined land.

Flood Plains

Flood plains are depositional landforms created by overbank flooding of meandering streams. In the area, major drainages with wide flood plains include the Chariton River and its Middle and East Forks, each of which possesses extensive drainage basins and is subject to flooding during periods of heavy rainfall or periods of rapid snowmelt following winters with heavy snowfall. Flooding on these streams can be severe and constitutes a major danger to mining on flood plains. Smaller streams in the area, including Muncas Creek, Dark Creek, and Sugar Creek, are all susceptible to flooding from heavy rainfall.

Flood plains are shown on the environmental geologic map (plate 2). Flood plains along the major streams are subject to more severe floods of longer duration than are the smaller flood plains of secondary streams. Any stream can flood, however, and the smaller streams may be subject to dangerous flash floods from sudden downpours.

Areas Mined Out Underground

Even though there are no operating underground coal mines in the area today, there are hundreds of abandoned shafts and drifts from such mining in the past, and they present several types of hazards.

Many of these abandoned workings are quite extensive and have become filled with acid water, which may be released into surface streams if water-filled abandoned mines are intersected by surface mining activity. Mined-out areas also are potentially hazardous to heavy equipment operators working above, unaware of them. Dangerous open shafts and drifts may be present in areas that were mined intensively in the past.

Plate 3 shows areas known to have been mined by underground methods. Areas for which mine maps have been located are shown in solid black. Shafts and drifts are shown in areas where no mine maps exist, but undoubtedly there are many more of these abandoned structures, their locations currently unknown. The extent to which the area around each drift or shaft has been mined is undetermined. Many abandoned shafts and drifts are not now open and present no obvious danger, but an unknown number may remain open. Because of time restrictions, a search for open shafts and drifts was not part of this study.

Possible Subsidence of Mined Land

When roof supports in underground mined-out areas collapse, at least some overlying rock may collapse and fall into the excavated area. Depending on the extent of failure, this may cause potholes, cracks, or general settling of the surface (Johnson, Walton and Miller (no date)). Collapse may not be immediate but may occur after mining is discontinued. Factors controlling the time for collapse to occur includes 1) the nature of the overlying rocks, 2) the depth and thickness of excavation beneath the surface, and 3) the method of mining.

The effect of subsidence on the surface is difficult to predict. In some urban areas in the eastern United States, it has resulted in very costly damage to buildings, subsurface utilities, and other improvements. Sometimes damage is minor, and in some cases subsidence has been uniform and imperceptible, resulting in little or no surface damage. In rural areas the adverse effects of subsidence are likely to be damage to croplands, altered drainage patterns, and reduced land values.

There was no special analysis of subsidence problems during the course of this study. However, it should be pointed out that in areas that have been mined out extensively underground, the possibility of surface subsidence problems exists. Areas of collapse have been recognized, especially near the openings to drift mines, where the cover is very thin. Such collapse areas, though apparently rare, are potential hazards to man and livestock. A few low, depressed areas and areas of "hummocky" ground exist over some extensively mined areas, which in most cases present no particular hazard, particularly where overburden is relatively thick.

Precautions should be taken in building heavy structures in areas where there has been underground coal mining. The weight of such structures may induce accelerated subsidence, causing major structural damage.

Coal Refuse Ponds and Waste Banks

Fine coal-reject material, consisting primarily of clay, silt, fine coal, and pyrite, resulting from the washing and sizing of coal, is impounded in settling ponds, which are usually abandoned after they are filled. Eventually the ponds dry out leaving a deposit composed entirely of reject material. Gullies develop, and acid drainage from the refuse deposits moves into natural surface drainages. The locations of the five abandoned settling ponds discovered in the project area are shown on Plate 3.

The refuse deposits contain considerable quantities of fine coal, the possible recovery of which should be considered as part of the reclamation plan for these deposits.

Coal waste banks, or gob piles, are common in the project area. Those from shaft or slope mines are conical or ridge shaped and range in height from 10 to 20 ft to 100 ft or more. Many of them are primarily shale or other waste material removed as gob during mining and contain little coal refuse. Piles from coal preparation plants contain much coal and pyrite as coarse refuse. The larger gob piles located are shown on Plate 3. Many small waste banks occur throughout the area and are not shown. Many gob piles have been removed through the years and used as road surfacing material. Oxidized shale, or "red dog," resulting from the burning of the coal fraction of the piles, forms a fairly weather resistant road material. A few coal refuse piles might contain sufficient coal for possible secondary recovery. Most, however, are primarily shale and clay.

GEOCHEMISTRY

Trace Elements in Coal

Coal contains a number of trace elements that are potentially harmful to the environment. The possibility exists of releasing these elements into the environment during mining, cleaning, transportation, and utilization of coal. Awareness of the presence of certain trace elements and proper care in the mining and handling of coal can prevent environmental contamination.

A report of the National Research Council (1980) discusses the environmental effects of trace elements and related problems in the mining, handling, and utilization of coal. It classifies trace elements in coal and in coal residues, according to degree of environmental concern. Trace elements of greatest concern are arsenic, boron, cadmium, lead, mercury, molybdenum, and selenium. Data from trace element analyses of 28 coal samples from the project area (Wedge, Bhatia, and Rueff, 1976) indicate that, of these seven elements, only boron and lead occur in concentrations significantly greater than the world-wide averages for bituminous coal and that none occur in concentrations greater than the averages for the Interior Coal Region (table 2). Boron averages approximately 100 ppm in coals from the project area, compared to 50 ppm for the world-wide average for bituminous coal and an average of 100 ppm for Interior Province coals. The average concentration of lead in coals from the project area is 44 ppm, about twice the world-wide average for bituminous coals and 11 ppm less than the average for coals of the Interior Province.

Table 2

TRACE ELEMENT CONCENTRATIONS

	elements of greatest concern							elements of moderate concern						Uranium
	Mo	Cd	Hg	B	Pb	As	Se	V	Cr	Ni	Cu	Zn	F	U
World-wide coverage for bituminous coals	3	1.6	0.2	50	22	25	4.6	20	15	20	22	53	77	1.9
Average Interior Coal Province	5	7.1	0.14	100	55	21	4.6	20	15	30	20.2	37.3	71	3.3
Earth's crustal average	2.5	0.2	0.08	10	12.5	1.8	0.05	135	100	75	55	70	625	2.7
Average for Prairie Hill Project Area	4.1	0.72	0.16	96.4	44.3	8.9	4.7	21.9	14.5	19.2	16.7	63.0	72	6.5

Data from Wedge, 1976

Trace elements of moderate concern include chromium, vanadium, copper, zinc, nickel, and fluorine. Of these only zinc is higher in coals of the project area than the world-wide average for bituminous coals, and none are higher in concentration than the averages for the Interior Province. The average concentration of zinc in project area coals is less than the average crustal abundance of that element (table 2).

The average uranium content of the project area coals is 6.5 ppm, 2.4 times the average crustal abundance of uranium, 3.4 times the world-wide average for bituminous coals, and twice the average for the Interior Province.

The National Research Council report (1980) states that levels of radioactivity associated with uranium and other radioactive elements in coal are not significantly different from those commonly found in nature and that, because these elements are in a geochemically immobile form, their effects on health are thought to be negligible. In addition, when coal is burned, the uranium is almost entirely concentrated in the bottom ash. However, the report suggests that for mines and coal-fired plants where the uranium content of the coal mined and burned is as much as three times the earth's average content, special investigations be carried out to define the rates, amounts, routes of travel, and long-term residence sites of the uranium.

The average uranium content of project area coals is somewhat less than this suggested limit. For example, the average uranium content of the Bevier seam, the area's principle producer is 2.9 ppm, only slightly greater than the earth's average content of 2.7 ppm. Such concentrations should present no special environmental problems.

The other three coal seams in the area, however, average more than three times the earth's average uranium content. Based on six samples, the Mulky seam, an important producer in the eastern part of the area, averages 8.9 ppm uranium, just slightly more than three times the earth's average. Since the Mulky is usually mixed with Bevier for combustion, however, no significant environmental problems are anticipated.

Only one sample was available from the Summit coal and two from the Croweburg. Based on these samples, the Summit contains a concentration of 26 ppm uranium; the Croweburg, 24 ppm. Currently, little is produced from either of these seams. The Croweburg, however, is potentially a significant future producer.

In summary, the overall average uranium content of project area coals indicates that the uranium content of coal produced in this area is not a great environmental hazard. In particular, it should be noted that the Bevier seam, from which the bulk of the areas coal is produced, has a uranium content only slightly greater than the average uranium content of the earth's crust; however, additional samples from the area's other seams should be analyzed to provide a better assessment of their uranium content and any potential environmental hazards.

Need for Chemical Data on Overburden - The minor and trace element content of overburden materials has not been determined. During this study, three cores from holes drilled through overburden were prepared for analysis. Because of equipment failure and budgetary limits, however, it was impossible to obtain chemical analyses on the samples, but they will be obtained when possible.

Overburden in the area consists of surficial and bedrock materials typical of the north Missouri coal fields. There is no reason to suspect the presence of any undue amounts of environmentally hazardous trace elements in these materials. Nevertheless, for thoroughness, chemical analyses of overburden samples should be obtained.

REFERENCES

Broadhead, G.C., 1873, Macon County: Missouri Geol. Survey, Reports on the Geological Survey of Missouri, 1855-1871, p. 74-92.

_________, 1873, Randolph County: Missouri Geol. Survey, Reports on the Geological Survey of Missouri, 1855-1871, p. 93-110.

Caterpillar Tractor Company, 1968, Fundamentals of Earth Moving, 68 p.

Gentile, Richard J., 1967, Mineral commodities of Macon and Randolph Counties: Missouri Geological Survey and Water Resources, Report of Investigations 40, 106 p.

_________, 1976, The geology of Bates County, Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigations 59, 89 p.

Gordon, C.H., 1896, Report on the Bevier Sheet, including portions of Macon, Randolph and Chariton Counties: Missouri Geological Survey, 1st ser., v. 9, Sheet Report 2, 85 p.

Hinds, Henry, 1912, Coal deposits of Missouri: Missouri Bureau of Geology and Mines, 2nd ser., v. 11, 503 p.

_________, and Greene, F.C., 1915, The stratigraphy of the Pennsylvanian Series in Missouri: Missouri Bureau of Geology and Mines, 2nd ser., v. 13, 407 p.

Howe, W.B., and Koenig, J.W., 1961, The stratigraphic succession in Missouri: Missouri Division of Business and Administration, Division of Geological Survey and Water Resources, 2nd ser., v. 40, 185 p.

______, and Searight, W.V., 1953, Coal in northeastern Carroll County and southeastern Livingston County, Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Report of Investigations 14, 8 p.

Heim, G.E., 1961, Quaternary system, in The stratigraphic succession in Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, 2nd ser., v. 40, p. 130-136.

Jeffries, N.W., 1958, Stratigraphy of the lower Marmaton rocks of Missouri: unpublished Ph.D., dissertation, University of Missouri.

Johnson, Wilton, and Miller, George C., (no date), Abandoned coal-mined lands, nature, extent and cost of reclamation; Bureau of Mines, U.S. Department of the Interior, 29 p.

Lillesand, T.M., and Kiefer, R.W., 1979, Remote sensing and image interpretation: New York, John Wiley and Sons, Inc., 612 p.

Marbut, C.F., 1898, Geology of the Huntsville Quadrangle including portions of Randolph, Howard, and Chariton Counties in areal geology: Missouri Geol. Survey, 1st ser., v. 12, Sheet Report 10, 111 p.

McGee, W.J., 1888, Notes on geology of Macon County, Missouri: St. Louis Academy of Science Transactions, v. 5, p. 305-336.

Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, 1961, The stratigraphic succession in Missouri: Rolla, Missouri, v. 40, 2nd ser., 185 p.

National Research Council, 1980, Panel on the Trace Element Geochemistry of Coal Resource Development Related to Health, 1980: Trace-element geochemistry of coal resource development related to Environmental Quality and Health, 153 p.

Neal, W.J., 1968, Petrology and paleogeography of the Blackjack Creek Formation (Pennsylvanian), Missouri: unpublished Ph.D. dissertation, University of Missouri.

O'Rourke, J.E. and O'Connor, K., 1979, Dewatering systems for surface coal mines: prepared for Bureau of Mines, U.S. Department of the Interior by Woodward-Clyde Consultants; final report, 259 p.

Robertson, C.E., 1971, Evaluation of Missouri's coal resources: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Report of Investigations 48, 92 p.

_________, 1973, Mineable coal reserves of Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Report of Investigations 54, 71 p.

_________, and Smith, D.C., 1979, Evaluation of the mineable coal reserves of the northern Bevier, Mendota, and Novinger coal fields in north-central Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, OFR-79-2-ER, 9 figs., 4 tbls.

Schmaltz, J.L., 1959, Pebble lithology of glacial till, north-central Missouri: unpublished Ph.D. dissertation, University of Missouri.

Searight, T.K., 1959, Post-Cheltenham Pennsylvanian stratigraphy of the Columbia-Hannibal region, Missouri: unpublished Ph.D. dissertation, University of Illinois.

Searight, W.V., 1955, Guidebook, Field Trip, Second Annual Meeting, Association of Missouri Geologists: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Report of Investigations 20, 44 p.

_________, 1959, Pennsylvanian (Desmoinesian) of Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Report of Investigations 25, 46 p.

_________, and Howe, W.B., 1961, Pennsylvanian System, in The stratigraphic succession in Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, 2nd ser., v. 40, p. 78-122.

_________, Howe, W.B., Moore, R.C., Jewett, J.M., Condra, G.E., Oakes, M.C., and Branson, C.C., 1953, Classification of Desmoinesian Pennsylvanian of northern Mid-Continent: American Association of Petroleum Geologists Bulletin, v. 37, p. 2747-2749.

Stout, Larry N., and Hoffman, David, 1973, Missouri's geologic environment: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, Educational Series No. 3, 44 p.

Unklesbay, A.G., 1953, Geology of Boone County, Missouri: Missouri Department of Business and Administration, Division of Geological Survey and Water Resources, v. 33, 2nd ser., 159 p.

Watkins, W.I., Deardorff, C.E., Krusekopf, H.H., and DeYoung, W., 1921, Soil Survey of Chariton County, Missouri: U.S. Department of Agriculture, 34 p.

Wedge, W.K., Bhatia, D.M.S., and Rueff, A.W., 1976, Chemical analyses of selected Missouri coals and some statistical implications: Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigations 60, 36 p.

Wedge, W.K., and Hatch, Joseph R., 1980, Chemical composition of coals: Missouri Department of Natural Resources, Division of Geology and Land Survey, Report of Investigations 63, 102 p.

P.O. Box 250
Rolla, MO 65401
314-364-1752
837-4082, 4083 (tie line)

R.I. 68 *Geology of Potential Coal Stripping Areas: Prairie Hill Area, Missouri*

MISSOURI DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND LAND SURVEY

Wallace B. Howe, Director and State Geologist, P.O. Box 250, Rolla, MO 65401