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Technical Completion Report Research Project G-893-24

Arkansas Water Resources Research Center
University of Arkansas
Fayetteville, Arkansas 72701

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A B S T R A C T

CHEMISTRY AND APPARENT QUALITY OF SURFACE WATER AND GROUND WATER ASSOCIATED WITH COAL BASINS

Personnel of the Arkansas Mining and Mineral Resources Research Institute conducted preliminary investigations on the chemistry and quality of surface and ground water associated with 12 coal-bearing sub-basins in the Arkansas Valley coal field. The coal field is approximately 60 miles long and 33 miles wide but only in 12 areas coal is thick enough and has proper quality to be termed commercial. Both surface and underground sample sites were established in each of the sub-basins with some minor variations in four areas where not all types of sites could be located. Water was collected from 19 surface points and 19 underground points in the established areas. Both field and laboratory analyses were made and elemental contents are reported herein. In the main, the chemistry and water quality suggests that all water is suitable for agricultural and industrial uses. To obtain potable water, treatment must be made to reduce calcium, magnesium, sodium sulfate and iron. The mineral content of the water is due to its contact with coal-bearing zones and, as such, reflects the mineral content of the coal. However, it is recommended that additional studies on the petrography and geochemistry of the coal, overburden and underburden is in order. Also, it is recommended that at least one detailed study be made of one of the coal sub-basins where geologic parameters can be completely established with regard to hydrogeology. This report is an important first step in determining the character and quality of Arkansas coal which must be fully understood to fully utilize this important mineral resource.

R. B. Stroud, J. L. Spellman, R. R. Potts and A. J. Oakley

Completion Report to the U.S. Department of the Interior, Washington, D.C., September, 1985.

Keywords -- Surface Water/Ground Water/Chemical Analysis/Atomic Absorption Analysis/Coal Mining

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ACKNOWLEDGEMENTS

This report is the product of the four authors listed. The senior author conceived the project and, through contacts with the Director of the Arkansas Water Resources Research Center at the University of Arkansas, developed an acceptable proposal that was funded by the U.S. Geological Survey of Washington, D.C. Senior staff of the Arkansas office of the U.S. Geological Survey concurred in the necessity of having such a report prepared and their helpful advise is appreciated. Jane Spellman, a graduate student in geology at the University of Arkansas, Fayetteville, Ark., was employed and also gave freely of her time and innovative ideas and was the author of the Appendix dealing with Geologic Criteria. Amanda (Duke) Oakley, a graduate student in geology at Texas A & M University, prepared the initial geology and location of sample sites illustration. Ms. Oakley made all sample collections and analyses from the fall of 1984 through June 1985, as an employee of the Institute. Her contributions and perseverance is gratefully appreciated. Ronald R. Potts, research engineer and staff member of the Mining Institute, was responsible for final collection of water samples from June 1985 through November 1985. Mr. Potts was the preparer of the Appendix on Water Analyses and Evaluation. Both Oakley and Potts were assisted by three student workers from Arkansas Tech University in the field and in the laboratory.

was directed to the effect mining had on water quality; therefore, degradation of water supplies may have already become a part of the hydrologic system of the Arkansas River Valley. The effects of mining on water supplies in the area of interest are little known, poorly understood, and the extent of any problems, duration and harmful aspects, if any, are largely unknown. A recent study of the hydrology of the area by Bryant and others[1] is indicative of the status of knowledge on ground and surface water resources in the area of interest. Bryant's report stresses the potential problems associated with surface mining on water supplies. In itself the report notes the paucity of water collection and indicates the need for water quality determinations.

It should be noted by the reader of this report that detailed geologic reports are not made for the Shinn and Ouita Districts in Appendix A simply because neither district is likely to be a source of coal in the forseeable future. It should also be noted by the reader that water analysis were not made for any specific sites in the Spadra District but rather this information for the Scranton District suffices. No reliable sites were selected therefore, in the Spadra District and thus some attention may need to be directed to this area in the future.

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1 C.T. Bryant and others, Hydrology of Area 42, Western Region, Interior Coal Province, Arkansas. U.S. Geological Survey, Water-Resources Investigations, Open File Report 82-636, 1983, p. 1.

INTRODUCTION

The extraction of minerals from the crust of the earth, whether there are surface or underground mine workings, exacts a profound influence on the physical, chemical and biological characteristics peculiar to any given region. This project attempts to measure the impact that coal extraction has had on surface and ground water in the Arkansas Valley Coal Field. This report presents geologic criteria that are fixed by nature and analytical data of water that is influenced by mining operations past and present. This information was not heretofore available from any source. The relationship between mining and the environment is naturally believed to be an adversative relation. However, to determine impacts that might result from mining, some measures must be established to quantify changes. Thus, this report in a sense, presents base line data from which other measurements can be made in the future to determine if good or undesirable changes occur from coal mining in Arkansas.

The information presented can be used by mine operators and regulatory agencies for whatever purposes necessary to mine or regulate. It is also useful to have information on the geochemistry and quality of the water should water sources be sought for use by industrial or agricultural interests.

Commercial mining of coal has occurred in the Arkansas Valley coalfields since 1870. Until 1917, little or no attention was directed to the effect mining had on water quality; therefore, degradation of water supplies may have already become a part of the hydrologic system of the Arkansas River Valley. The effects of mining on water supplies in the area of interest are little known, poorly understood, and the extent of any problems, duration and harmful aspects, if any, are largely unknown. A recent study of the hydrology of the area by Bryant and others[1] is indicative of the status of knowledge on ground and surface water resources in the area of interest. Bryant's report stresses the potential problems associated with surface mining on water supplies. In itself, the report notes the paucity of water collection and indicates the need for water quality determinations.

It should be noted by the reader of this report that detailed geologic reports are not made for the Shinn and Ouita Districts in Appendix A simply because neither district is likely to be a source of coal in the forseeable future. It should also be noted by the reader that water analyses were not made for any specific sites in the Spadra District but rather, this information for the Scranton District suffices. No reliable sites were selected, therefore, in the Spadra District, and thus, some attention may need to be directed to this area in the future.

[1] C.T. Bryant and others, Hydrology of Area 42, Western Region, Interior Coal Province, Arkansas. U.S. Geological Survey, Water-Resources Investigations, Open File Report 82-636, 1983, p. 1.

APPENDIX A GEOLOGIC CONSIDERATIONS

BACKGROUND

In the fall of 1984, the Arkansas Mining and Mineral Resources Research Institute established a program to monitor surface and ground water at 19 surface sampling sites and in 19 wells within Arkansas coal mining districts in an attempt to establish a water quality data base for each commercial coal seam and associated structural basin. This appendix provides a structural interpretation and detailed descriptions of the stratigraphic section exposed at these sampling sites.

<u>Location</u>

The Arkansas coal fields lie predominantly within Area 42 of the Western Interior Coal Region, as defined by the U.S. Geological Survey which includes the Arkansas Valley region of west-

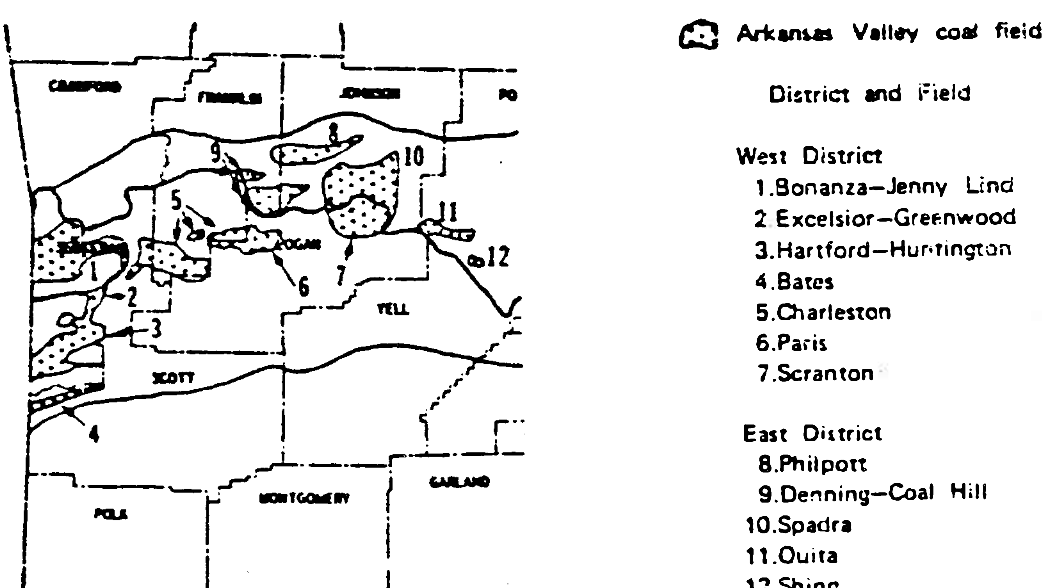


Figure 1. DISTRICTS AND FIELDS IN THE ARKANSAS VALLEY COAL FIELD

central Arkansas. Coal bearing formations in the region are Pennsylvanian in age and include the Atoka, Hartshorne, McAlester and Savanna Formations. Within these formations, 19 different coal beds have been described in past investigations, but only four, the Lower Hartshorne, the Upper Hartshorne, the Charleston and the Paris coal beds, have economic significance. These coal seams are discontinuous and separable into twelve districts. Each district is enclosed by a discrete structural basin that is usually delineated by a syncline. The western part of the Arkansas coal fields is south of the Arkansas River and includes the Bonanza-Jenny Lind, Excelsior-Greenwood, Hartford-Huntington, Bates, Charleston, Paris and Scranton Districts. The eastern part of the field is north of the Coal Hill, Spadra, Ouita and Shinn Districts (Figure 1).

Previous Investigations

The development of Arkansas's coal resources provided the impetus for early surface geology studies. The earliest geological information recorded in the literature concerning the occurrence of coal beds in Arkansas was by Winslow (1888). This work was later supplemented by a more detailed study of the coal fields (Collier, 1907). Steele's (1910) comprehensive description of the coal industry in Arkansas included mined areas encountered in this study. Reconnaissance and generalized geologic reports pertaining to the Arkansas coal fields have been written by Croneis (1930), Hendricks and Paris (1939) and Haley (1960).

Five unpublished master's theses have been concerned with the geology and coal resources of Arkansas. They include maps and cross sections for portions of the Philpott District (McRae, 1950), the Spadra District (Hille, 1951; Hopkins, 1951) and the Scranton District (Eby, 1952; Downs, 1952).

Hendricks, Dane and Knechtel (1936) and Hendricks (1937) established the stratigraphic nomenclature for rocks of the Atoka and Des Moines series, but it was Hendricks and Parks (1950) who mapped these rocks in the western part of the Arkansas Valley. These stratigraphic divisions have since been outlined on surface geology maps in a number of information circulars prepared by the Arkansas Geological Commission in cooperation with the U.S. Geological Survey (Haley 1961, 1966, 1968; Haley and Hendricks, 1968, 1972; Merewether, 1967; and Merewether and Haley 1961, 1969).

The most recent coal studies in Arkansas include a proximate and ultimate analysis of coal in west-central Arkansas (Haley, 1977), an inventory of surface and underground coal mines (Bush and Gilbreath, 1978) and a tabulation of all available data on Arkansas coals for resource management planning (Bush and Colton, 1983).

The writer wishes to acknowledge the information and assistance furnished by William V. Bush of the Arkansas Geological Commission and Boyd R. Haley of the U.S. Geological Survey. Access to unpublished material has been invaluable in preparing this report.

Regional Geologic Setting

The area of the investigation is located in the Arkansas Valley section of the Ouachita Province. It lies in a strip 33 miles wide and 60 miles long. The Arkansas Valley is topographically and structurally a trough that lies between the Ozark Mountains on the north and the Ouachita Uplift on the south. Topography is the result of a folded and faulted surface submitted to long periods of stream erosion and is controlled by the character and attitude of the rock strata. In general, resistant sandstones form east-west trending ridges and outcrops of shale form valleys and low lands. The region is characterized by a gradation in topography from anticlinal and synclinal ridges and valley sections in areas of steeply dipping rocks. Elevations in the Arkansas Valley province range from 310 to over 2100 feet above sea level.

The Arkansas River flows east across the state from the Arkansas-Oklahoma state line to the Mississippi River. Sampling sites in ten of the districts are within the Arkansas River drainage basin. The Huntington and Bates districts are in the Poteau River drainage basin. The headwaters of the Poteau River rise on the south slope of Poteau Mountain where the river flows northwest to a point near Hackett, where it enters Oklahoma. From here the river flows northeast and joins the Arkansas River in Fort Smith.

The major streams in the districts are dendritic, while many smaller streams have a trellis drainage pattern related to the underlying geologic structure. Furthermore, many of the smaller streams flow only during wet seasons.

General Stratigraphy

Rocks of the Pennsylvanian and Quaternary systems are exposed in the coal mining districts. The Pennsylvanian rocks are from oldest to youngest the Atoka Series, represented by the Atoka Formation, and the Des Moines Series, represented by the Hartshorne, McAlester, Savanna and Boggy Formations (Figure 2). The Quaternary rocks are stream and terrace deposits of Pleistocene age (Hendricks and Parks, 1950) and recent stream and river alluvium.

The exposed rocks consist largely of a thick sequence of shale, siltstone and sandstone, which vary locally but, overall, are of somewhat the same lithologic character. The coal beds are the most continuously recognized horizon in the section, but exposures of these seams are rare, except in areas where some of the coal beds have been extensively mined.

This thick sequence of sandstone, siltstone, shale and coal, which is present in the Arkansas Valley, was originally studied by Taff and Adams (1899, 1900), who defined the formations of the southeast Oklahoma coal fields and traced them from the McAlester district eastward to the Arkansas state line. They defined the boundaries of the Atoka Formation up through the Boggy Formation as now recognized in Oklahoma.

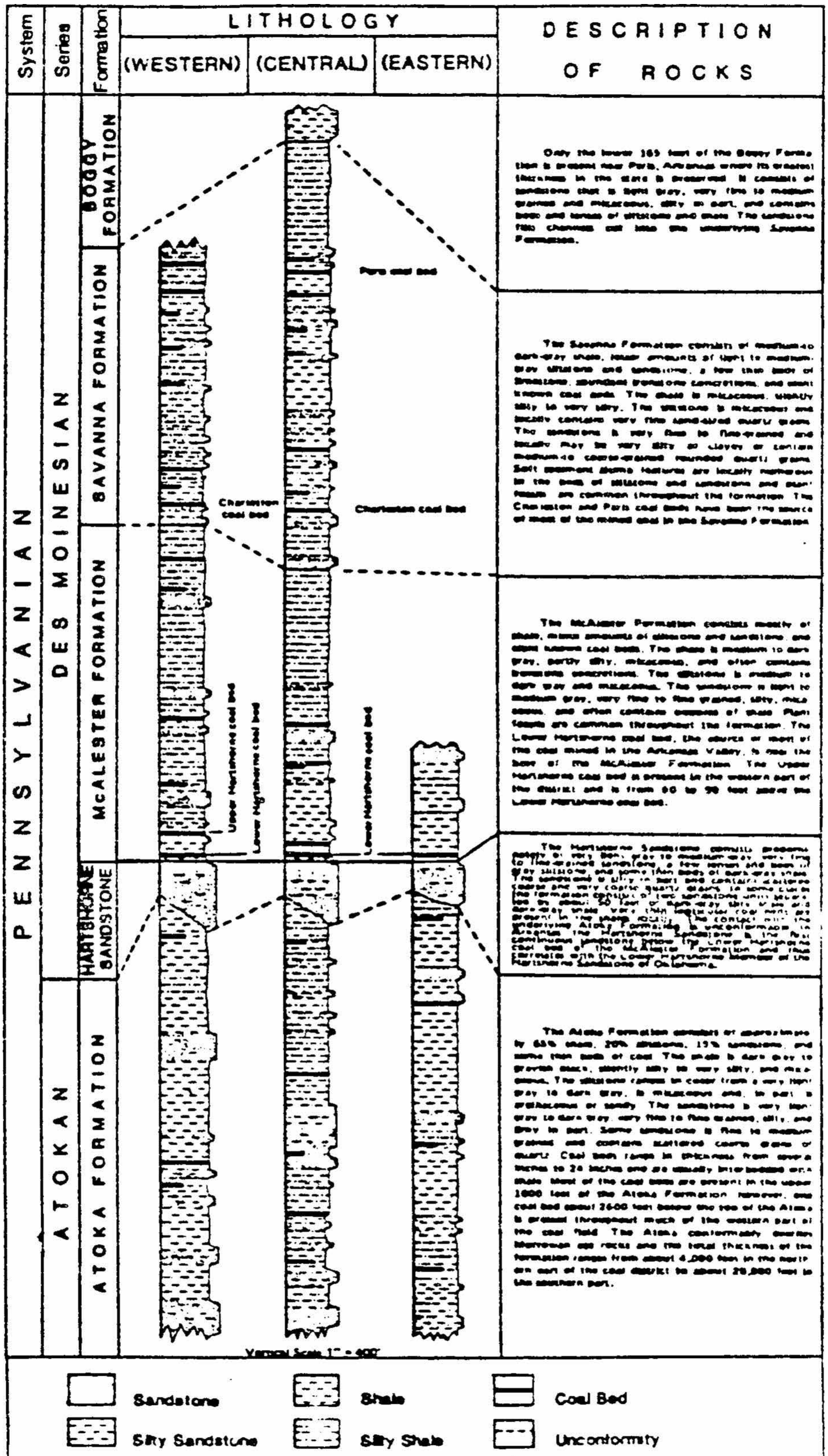


Figure 2 Generalized stratigraphic sections in the Arkansas Valley coal field.
(From Bush & Colton, 1983)

Collier (1907) placed the boundaries of these formations at different horizons in Arkansas. For example, at Hartshorne, Oklahoma, the type locality, the top of the Hartshorne Formation lies above the Lower Hartshorne coal. As mapped in Arkansas, however, the upper boundary of the formation is placed at the top of the sandstone that underlies the Lower Hartshorne coal, that is 30-50 feet below the top of the formation as traced from its type locality.

The boundaries of the Atoka Formation and Hartshorne Formation recognized by Hendricks and Parks (1939, 1950) and used by the U.S. Geological Survey are identical to Collier's. Collier, however, used the name McAlester Group instead of McAlester Shale and subdivided the group into the Spadra, Fort Smith and Paris Formations, and he mapped an overlying sandstone as Savanna Sandstone. The base of the Savanna Formation was subsequently mapped in Arkansas to coincide with the base of the second sandstone below the top of the Savanna Formation in Oklahoma. This meant that the Spadra, Fort Smith and Paris Formations as mapped were equivalent to the upper 30-50 feet of Hartshorne Sandstone, the whole of the McAlester Formation and the lower two-thirds of the Savanna Sandstone in Oklahoma (Hendricks and Read, 1934). These names were rejected and the McAlester Group was dropped to formation rank. Stratigraphic nomenclature and boundaries were subsequently established by Hendricks and Parks (1950) for use in Arkansas. Oakes (1953) and

Miser (1954) revised the base of the Boggy Formation and included beds in the Savanna Formation that Hendricks (1934) placed in the Boggy Formation. Formation boundaries thus used in U.S.G.S. reports on the coal areas of Arkansas, with the exception of the Hartshorne Formation, are stratigraphically equivalent to the formations in type areas in Oklahoma.

Atoka Formation: Deposited in marginal marine to marine environments, the Atoka Formation consists of alternating beds of sandstone, siltstone, shale and a few thin, discontinuous streaks of coal. This is the oldest coal-bearing formation exposed in the Arkansas Valley region; though the coal beds in the Atoka Formation are not mined on a large scale because of thinness and poor quality of the coal. The Atoka Formation reportedly ranges in thickness from 9,000 feet near Fort Smith to 20,000 feet in central Arkansas (Branson, 1961). No formal stratigraphic subdivisions of the Atoka Formation exists; however, various informal nomenclature is used by other investigators and industrial geologists to describe the sandstone units within the formation (e.g. Haley and Hendricks, 1971). The upper part of the formation predominantly outcrops in the coal districts.

The ratio of sandstone to shale is variable from place to place, but in general, the sandstone is more abundant towards the northeast, whereas, the shale component increases to the southwest (Croneis, 1930). The shale is mostly dark gray to black and fissile. It may be micaceous and is often associated with thin, lenticular beds of ripple-marked sandstone. The siltstone is micaceous, argillaceous to very sandy in part and is well indurated. Bedding is thin to thick, foreset in part, lenticular in part and commonly ripple marked. The Atoka sandstone units range in thickness from a few inches to more than 100 feet. Hendricks and Parks (1939) maintain that these thicker units were deposited in stream channels that cut downwards into the underlying shale. The sandstone is brown to light gray, very fine to fine grained, silty and locally contains medium to coarse grained quartz. Fossil remains in the Atoka Formation are generally well macerated and include plants and poorly preserved marine invertebrates.

Hartshorne Sandstone: The Hartshorne Sandstone, the oldest formation of the Des Moines Series, is defined as the first laterally continuous sandstone underlying the Lower Hartshorne coal bed (Hendricks and Parks, 1939). It is one of the most persistent sandstone units in the Arkansas Valley and for the most part, represents broad, shallow channel deposits. The contact between the Atoka and Hartshorne has been interpreted as being conformable (Hendricks, 1937), a minor unconformity (Haley, 1961) and a local disconformity (Merewether and Haley, 1969). The Hartshorne Formation is conformably overlain by the McAlester Formation of Des Moines age.

The Hartshorne Formation is variable in its thickness and lithology. The thickness ranges from 1 to 300 feet in the western areas to 20 to 220 in the eastern areas. The formation is composed of very light to light gray, very fine to medium grained sandstone and contains a few gray siltstone beds and lenses of dark gray shale. Bedding is thin to massive, regular to irregular, lenticular in part, foreset in part, cross bedded and commonly ripple marked. Haley (1961) cites several factors which distinguish the Hartshorne Sandstone from sandstone units in overlying McAlester and the underlying Atoka formations. They include lighter color, coarser grain size, less silty or clayey and more widespread. Positive identification of the Hartshorne Formation, however, is possible only by tracing the formation from an area where it is known. Fossil remains include fragments of stems and twigs and some poorly preserved brackish water invertebrates.

McAlester Formation: The McAlester Formation conformably overlies the Hartshorne Sandstone. Thickness of the formation ranges from 500 feet to more than 1,000 feet (Haley, 1960). The formation consists predominantly of dark gray to gray black, fissile shale and silty shale, but includes some siltstone and silty, very fine grained, lenticular beds of sandstone, which may attain a thickness of 160 feet (Haley, 1961). Plant fossils are abundantly present with locally, poorly preserved invertebrate fossils.

Eight coal beds are reported to occur in the McAlester Formation (Hendricks and Parks, 1950). They are, from oldest to youngest, a thin unnamed coal, the Lower Hartshorne coal, the Upper Hartshorne coal, three thin, unnamed beds, the McAlester coal and the Stigler coal. The Lower Hartshorne, Upper Hartshorne, McAlester and Stigler seams have been mined, but only the Lower and Upper Hartshorne coals are of economic importance.

The Lower Hartshorne coal, which occurs at the base of the formation, is the most widespread within the districts. It is considered to be of low volatile to semi-anthracite in rank (Haley, 1960). The Upper Hartshorne coal is known only in the western part of the Arkansas Valley, particularly in the Hartford-Huntington District, where it occurs 60 to 90 feet above the Lower Hartshorne coal bed.

Savanna Formation: The Savanna-McAlester contact has been reported to be a minor unconformity in some areas (Haley and Hendricks, 1971) and to have a conformable, interfingering relationship in other areas (Haley, 1961). The Savanna Formation consists of 500 to 2200 feet of alternating beds of sandstone and shale in which a limestone bed and eight coal beds are reported (Haley, 1960). The formation is predominantly a dark gray, silty shale, which contains abundant plant fossils and ferruginous concretions. The siltstone is light to medium gray, micaceous and very finely sandy. The sandstones are very thin to fine grained, thickly bedded to massive and are considered to be channel deposits. Haley and Hendricks (1972) maintain that sedimentary flow features are too prevalent in these sandstones that they aid in differentiating this sandstone from sandstone units in other formations. A thin bed of fossiliferous limestone occurs above the Paris coal in the upper part of the formation (Hendricks and Parks, 1950; Haley, 1966).

The Savanna Formation contains the Charleston and Cavanal coal beds in the lower part of the formation, the Paris coal bed in the middle part and five unnamed coal beds (Haley, 1960). Only the Charleston and Paris beds are considered to be of economic importance. The Charleston coal occurs 800-900 feet stratigraphically above the Lower Hartshorne coal (Stroud, 1969). It is low volatile to semi-anthracite in rank (Haley, 1960). The Paris coal is 1,000 to 1,200 feet stratigraphically above the Lower Hartshorne coal and is low volatile bituminous in rank.

Boggy Formation: The Boggy Formation, which overlies the Savanna unconformably, is the youngest formation exposed in the area. Thickness of the formation ranges from 100 feet as exposed on top of Poteau Mountain (Hendricks and Parks, 1950) to 900 feet in the Paris syncline on Short and Horseshoe Mountains, where basal sandstones fill channels cut into the underlying Savanna Formation (Haley, 1961). The formation is predominantly a fine to medium grained sandstone that exhibits much cross bedding and ripple marks. Coal has not been found in the Boggy Formation in Arkansas.

Quaternary system: Unconsolidated deposits of Quaternary age occur throughout the entire valley. These deposits are of two types: terrace and alluvial. Stream terrace deposits consist of clay, silt and sand, pebbles, cobbles and boulders. Higher level gravel deposits are composed of well rounded fragments of chert and sandstone and can be observed 50 to 200 feet above the present level of the Arkansas River (Merewether, 1967). Alluvium covers the floodplains of major tributaries and consists mostly of fine sand and silt. Thickness of these deposits are reported from a feather edge to over 100 feet in stream channels (Hendricks and Parks, 1950). Because of the extent of surficial deposits, outcrops were poor in the study areas.

Regional Geologic Structure

The Arkansas coal fields lie within the Arkoma Basin structural province. The Arkoma Basin is a broad, east-west trending synclinorium composed of anticlines, synclines, normal faults, reverse faults and imbricate thrust faults. The basin is bounded on the north by the northern Arkansas structural platform (Chinn and Konig, 1973). The Ouachita Mountain foldbelt lies to the south. Structural relief, as measured on the Lower Hartshorne coal, is more than 2,350 feet and ranges between an elevation of 600 and 1,750 feet (Haley, 1960).

Based on the intensity and type of faulting and folding, Diggs (1961) divided the Arkoma Basin into five tectonic zones, as follows (Figure 3):

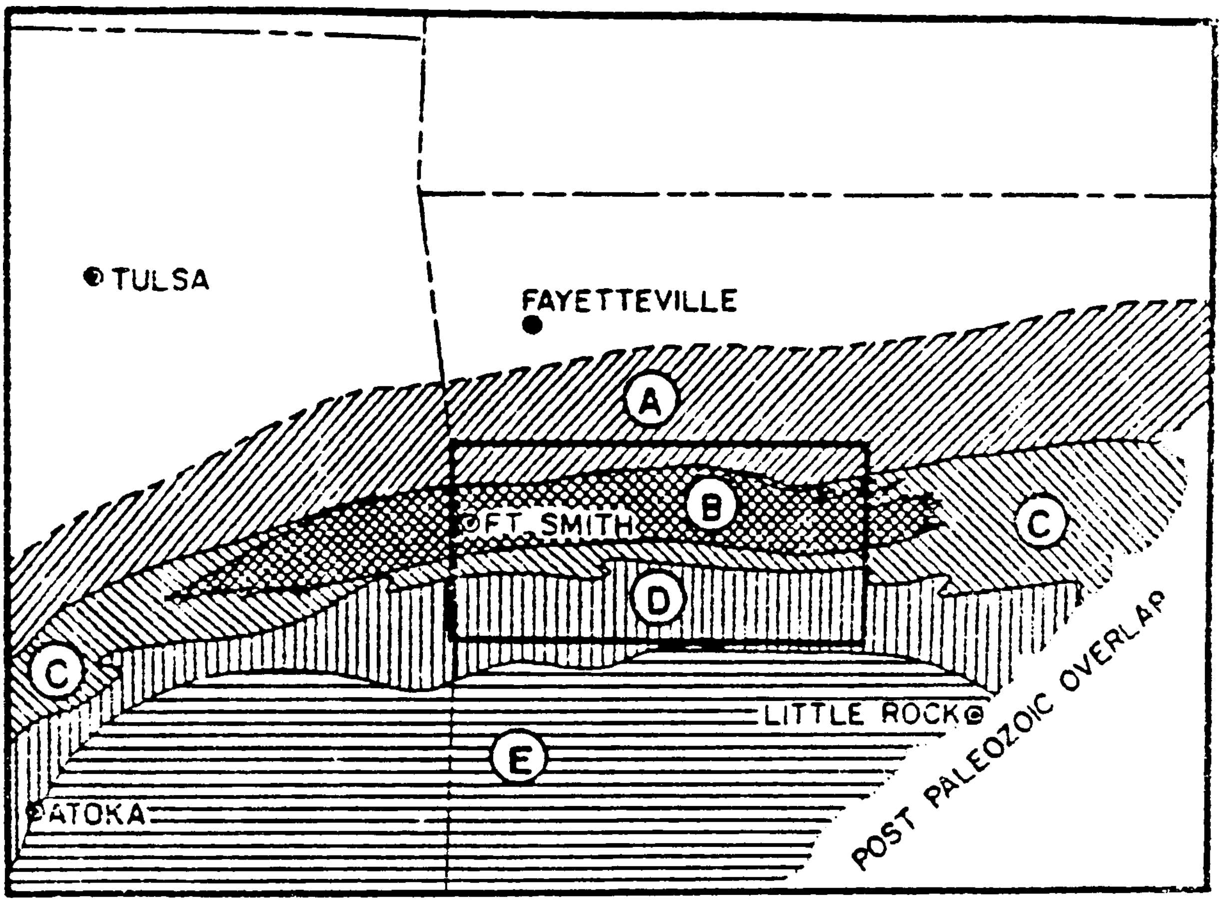


Figure 3 Tectonic provinces of the Arkoma basin. Heavy line designates study area. (after Diggs, 1961)

Zone A - South flank of the Ozark uplift, typified by regional south dip (1 to 3 degrees) that has been modified by normal faulting and minor compressional folding.

Zone B - Area of normal faulting with strata later modified by moderate compressional folding. Vertical displacement on the principal normal faults in this area is between 300 and 2,500 feet.

Zone C - Area of moderate compressional folding with little or no evidence of normal faulting. Compressional folds are expressed by dips ranging from 3 to 25 degrees.

Zone D - Area composed of elongated, tightly folded structures devoid of normal faults at the surface but showing evidence of incipient thrust faults.

Zone E - North flank of the Ouachita Mountain Province, typified by strong compressional folding, crenulation and imbricate thrust faulting.

Two joint sets were observed along outcrops in the study areas. One set was within a one degree strike of N 10 W and had spacings of less than an inch to 3 feet or more. The other was a set of east-west trending joints spaced 1 to 15 feet apart.

Site Geology

Field work was accomplished between January 3 and April 21, 1985. The original objective of the field study was to measure sections at surface sampling sites. This, however, was possible only in the Bates District, as elsewhere, rock exposures were limited by a surficial cover of terrace and alluvial deposits. Lithologic descriptions and the attitude of strata were noted in strip mines and at outcrops in the vicinity of these sites. Where geologic maps were available for these study areas, contacts between formations and structural information were verified. A general geologic map of each study area follows the discussion of that area. The explanation for the symbols used on these maps is given in Figure 4. Surface sampling sites and monitoring wells, which are within the districts, are referred to as up gradient or down gradient sites, depending on their relationship to the coal seam being studied. Refer to Plate 1 for the location of the water sampling sites with reference to overall geologic structure.

<u>Jenny Lind District</u>

Surface Sampling Sites: 1070, 1071 and 1072

The study area is located in west-central Sebastian County in the southern half of Township 7 North, Range 31 West. Vache Grasse Creek, with its tributaries, drains the area and flows approximately 8 miles northeast, where it empties into the Arkansas River. All three monitoring points are surface sampling sites on the Bear Creek tributary. Both 1071 and 1072 are down gradient sites, which are located in SW¼, SE¼, Sec. 29, T7N, R31W and SW¼, SW¼, Sec. 27, T7N, R31W, respectively. The latter receives drainage from Prairie Creek, which flows through strip mines to the west of the study area. Site 1070 is an up gradient site, which is situated in the valley between Long Ridge and Backbone Mountain in the NW¼, NW¼, Sec. 5, T6N, R31W.

EXPLANATION FOR THE GEOLOGIC MAPS OF THE STUDY AREAS

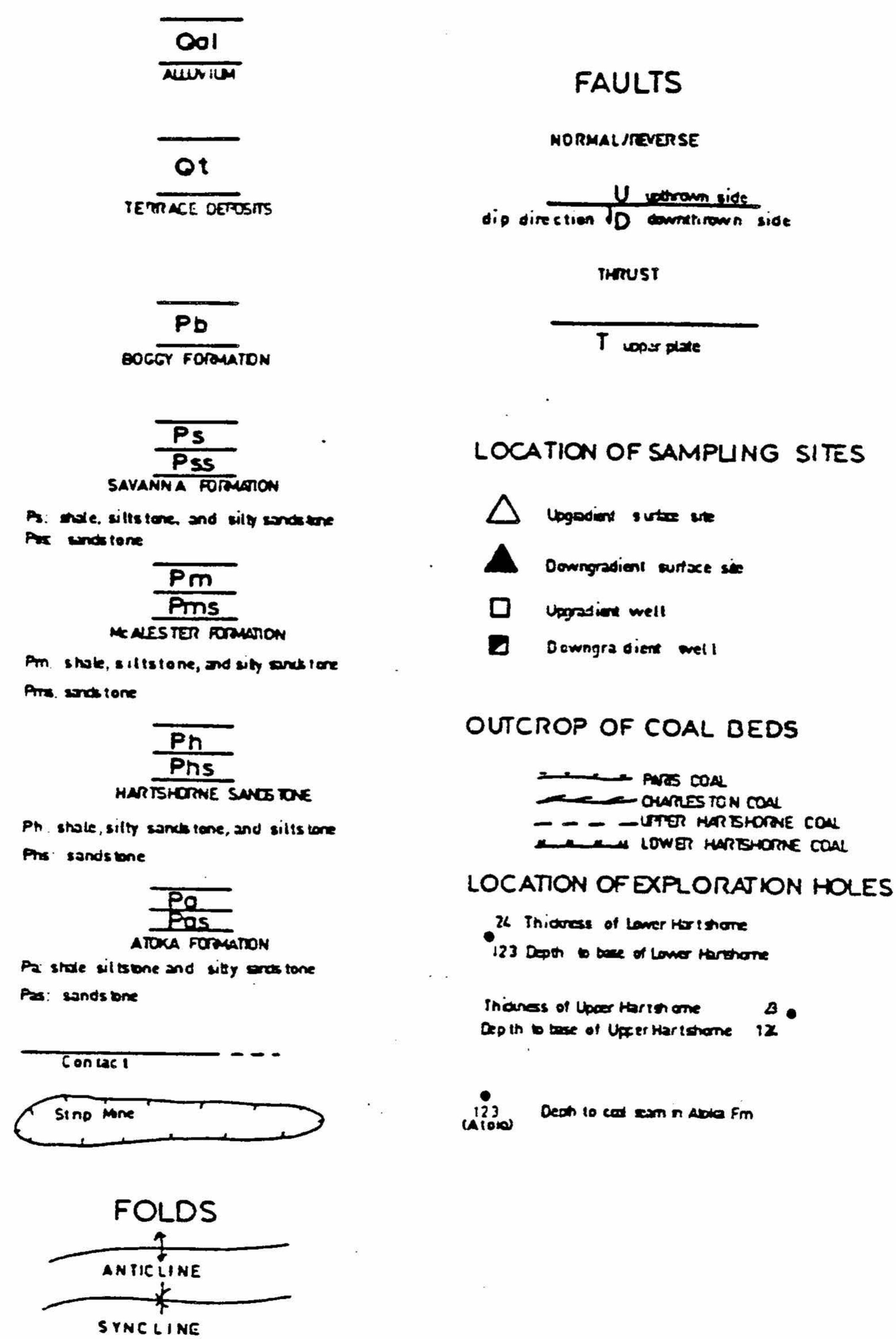


FIGURE 4

Lithology. Upstream from 1070, Bear Creek flows in alluvium and across the shales and siltstones of the Atoka Formation. In the road cut at 1070, the formation is interbedded black shale and siltstone. Where the formation is exposed in the creek bed downstream, it is a bluish-gray, very fine grained, medium bedded sandstone. The Hartshorne Sandstone is also exposed in Bear Creek, where it flows through the town of Jenny Lind in SE¼, NE¼, SW¼, Sec. 32, T7N, R31W. Here, it consists of 110 feet of light gray, thin to medium bedded sandstone and some shale layers (Figure 5).

The McAlester Formation is exposed in the strip mine in the northeast part of the study area and it consists of dark gray shale and siltstone containing some pyrite and iron concretions. Haley and Hendricks (1968) maintain a presistant zone of shale, 25 to 60 feet thick, is present about 100 feet above the base of the formation. The Lower Hartshorne coal is present near the base of the formation everywhere. This is estimated to be at a depth of 190 feet beneath site 1071. A seven inch coal seam is exposed on the southeast bank of Bear Creek, just downstream from 1072. This coal may represent an upper bench of the Lower Hartshorne coal bed.

Structure. Sampling sites 1071 and 1072 are located on the flanks of the Biswell Hill anticline. This anticline extends through the northeast part of the study area and is expressed topographically as Biswell Hill. The Biswell Hill anticline is

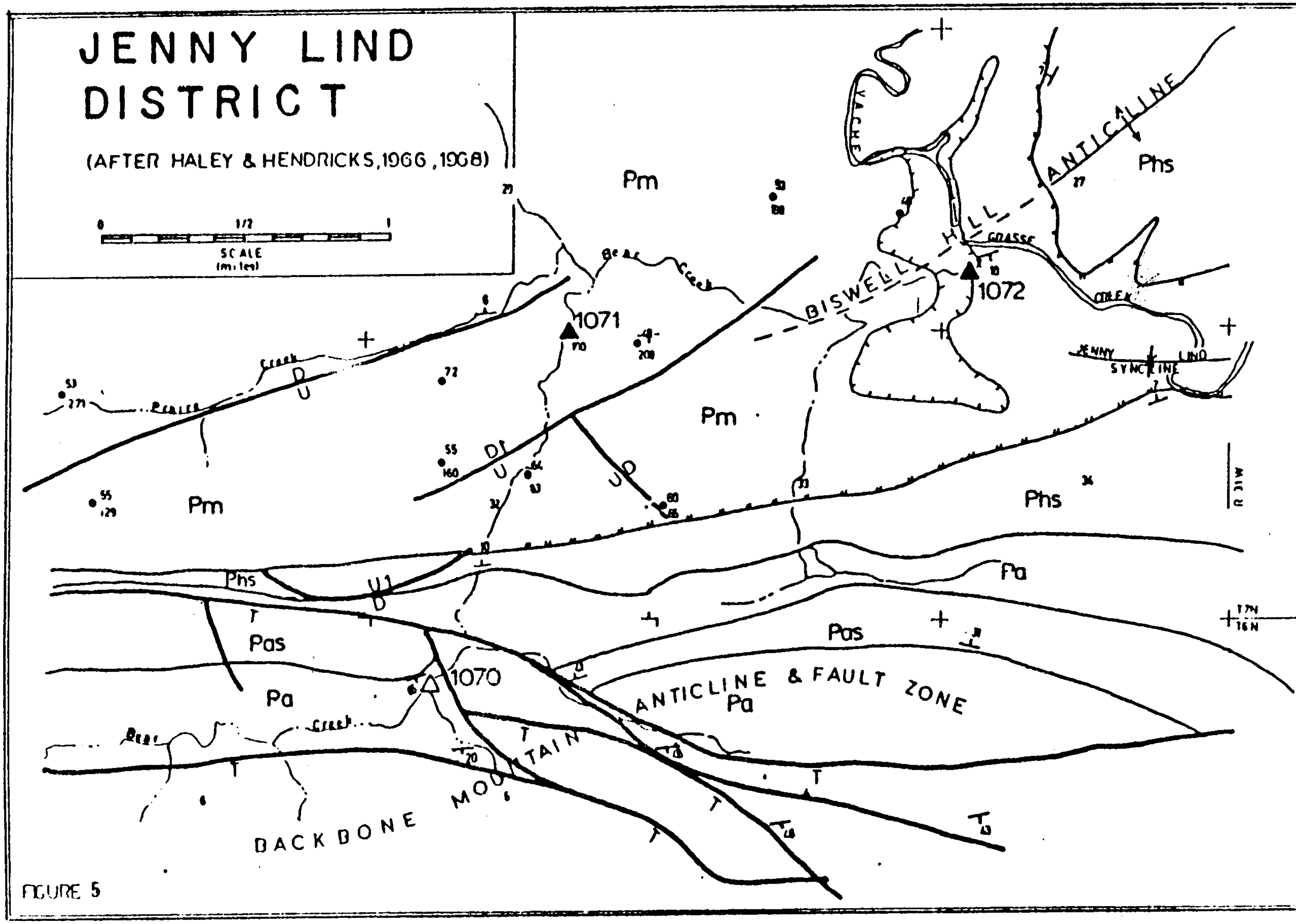

JENNY LIND
DISTRICT
(AFTER HALEY & HENDRICKS, 1966, 1968)
SCALE (miles)
0
1/2
1
Pm
Phs
Pa
Pas
1070
1071
1072
BISWELL HILL ANTICLINE
JENNY LIND SYNCLINE
ANTICLINE & FAULT ZONE
BACKBONE MOUNTAIN
Bear Creek
VACHE GRASSE CREEK
T7N
T6N
D
U

FIGURE 5

bounded to the north by the Central syncline and to the south by the Jenny Lind syncline. The structure is slightly asymmetrical with dips on the north flank (6-14 degrees) greater than those on the south limb (less than 6 degrees) (Croneis, 1930).

The Backbone anticline extends across the southern part of the study area and is expressed topographically as Long Ridge and Backbone Mountain. Strata on the north limb have the steepest dips and are locally overturned. On the south limb, rocks dip between 8 and 65 degrees (Hendricks and Parks, 1950). The Backbone anticline has been broken by reverse and thrust faults throughout most of its extent. Haley and Hendricks (1968) have identified a zone consisting of 2 to 5 faults and having a width of 300 to 4,000 feet. Fault planes of the major faults dip south at angles near vertical to 15 degrees in the subsurface and have northward moving thrust plates. Haley and Hendricks (1968) estimate the combined amount of movement along all faults, as projected on the base of the Hartshorne Formation, to exceed 12,800 feet near the Arkansas-Oklahoma state boundary. The plane of a north dipping reverse fault cutting a channel sequence in the upper Atoka Formation is exposed in a road cut on the north side of Highway 71 in SW¼, SW¼, Sec. 32, T7N, R31W. Haley and Hendricks (1968) report the dip along the fault to be between 5 and 15 degrees and movement along the fault plane to be small.

Excelsior-Greenwood District

Surface Sampling Sites: 1083, 1084, 1085 and 1086

Monitoring Wells: 1080 and 1082

The study area is located in west-central Sebastian County in Township 6 North and Ranges 31 and 32 West. Monitoring stations 1083 and 1084 are surface sampling sites, which are located on Big Branch and Hackett Creek near the town of Hackett. Hackett Creek is a tributary to Big Branch which flows southwest and empties into the James Fork of the Poteau River. Station 1084 is an up gradient site and is located in the SW¼, SE¼, Sec. 16, T6N, R32W. Station 1083 is the down gradient site and is located in the NW¼, SE¼, Sec. 21, T6N, R32W. Three miles south of Hackett, in the NW¼, NE¼, Sec. 6, T5N, R32W (not shown on geologic map, Figure 6), there is a 65 foot monitoring well, 1082. In the eastern portion of the study area, there are two surface sampling sites and one monitoring well. Sites 1085 (down gradient) and 1086 (up gradient) are located on Vache Creek in the SW¼, SE¼, Sec. 31, T7N, R31W and SW¼, SW¼, Sec. 5, T6N, R31W, respectively. Site 1080 is a down gradient monitoring well in SE¼, NE¼, Sec. 17, T6N, R31W. The depth of this well is unknown, but it is cased to 50 feet.

Lithology. Hackett Creek and Big Branch flow through alluvium overlying rocks belonging to the Atoka, Hartshorne and McAlester Formations. The contact of the upper Atoka Formation and the Hartshorne Sandstone is exposed in the Highway 45 road cut adjacent to site 1084. Here, the Atoka Formation is a black, micaceous, slightly fissile shale. The section includes 40 feet of a medium gray, very fine to fine grained, massive sandstone and fine shale lenses belonging to the Hartshorne Formation. The Hartshorne is the ridge forming sandstone in the Hackett area. The McAlester is exposed in the strip mine north of 1083. It consists of a dark gray to gray black, slightly silty, blocky shale. Most of the Lower Hartshorne coal has been removed from the mine. Water flows from unsealed up-dip slope openings into the mine. Most of the water drained from the mine empties into Big Branch, downstream of site 1083. Monitoring well 1082 is in a sandy lense of the McAlester Formation. It was not possible to determine the thickness of the sandstone, and subsurface information was not available for this location. According to structure contours of the area, the well should be situated stratigraphically well above the upper and lower Hartshorne coals (Hendricks and Parks, 1939).

In the eastern part of the study area near Greenwood, the unconformable Atoka-Hartshorne contact is well exposed in the NE¼, SE¼, Sec. 16, T6N, R30W. The Atoka is a series of gray-green, fine to medium grained, micaceous, sandstone beds overlain by very light to light gray, very fine sandstone belonging to the Hartshorne Formation. Here, and as exposed at the 1085 site, the sandstones are interbedded with dark gray, shaley siltstone. Outcrops of the McAlester were difficult to find because of the thick cover of alluvium composed of clay, silt, sand and pebbles of silt and sand. At the strip mine north of 1086, the alluvial cover was three to four feet thick. The shale in the strip pit is dark gray, micaceous and slightly silty. Lenticular beds of sandstone also occur in the area. The sandstone, where exposed in the creek bed at 1086, is a light gray, very fine to fine grained and thickly bedded. The Lower Hartshorne coal is the only coal bed known to occur in the area (Haley, 1966). It is estimated to occur at a depth of 210 feet below site 1086 and approximately 93 feet below site 1080 (Figure 6).

Structure. The Greenwood Syncline is the primary structure in the study area. Its axial trace extends from a point 3 miles southeast of Hackett following an arcuate route 15 miles to the northeast. The syncline is slightly asymmetrical with dips on the south side as much as 90 degrees to locally overturned and dips on the north limb generally less than 75 degrees.

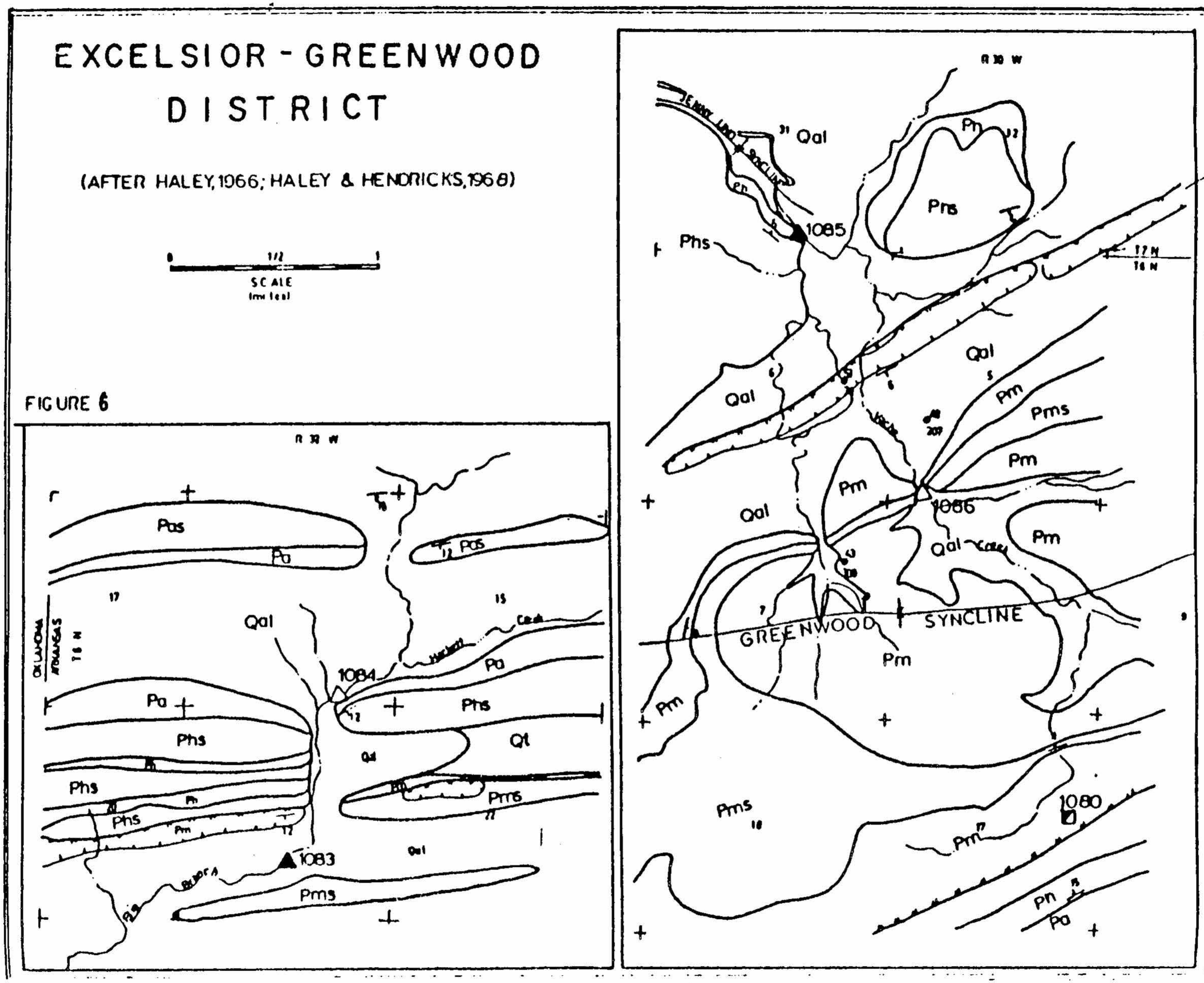
Huntington District

Surface Sampling Sites: 1093 and 1094

Monitoring Wells: 1090 and 1091

Monitoring Shaft: 1092

The study area is in southern Sebastian County in Township 5 North and Range 31 West. Surface sampling sites 1093 and 1094 are located on the James Fork of the Poteau River, which flows north through the study area. Site 1093 is an up gradient site, which is located in the SW¼, SW¼, NW¼, Sec. 6, T4N, R31W. Site



EXCELSIOR - GREENWOOD DISTRICT
(AFTER HALEY, 1966; HALEY & HENDRICKS, 1968)
SCALE
FIGURE 6
1083
1084
1085
1086
1080
GREENWOOD SYNCLINE
Qal
Pas
Pa
Phs
Pms
Pm
Pn

1094 is a down gradient site in the NW corner, NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 32, T5N, R31W. Monitoring point 1092 is the old Number 6 mine shaft, which is located in the NE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 33, T5N, R31W. The shaft reaches the workings of the Lower Hartshorne coal. It is not sealed and flows under artesian pressure. The other two sites, 1090 and 1091, are monitoring wells. Site 1090 is 60 feet deep and stops above the mine workings, the other is 490 feet deep and is cased through the workings. Both are down gradient sites located in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec. 28, T5N, R31W. Well 1091 is an up gradient site in the SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 21, T5N, R31W.

Lithology. The Atoka Formation is exposed in a road cut along the base of a ridge adjacent to 1093. It consists of approximately 60 feet of black, fissile shale interbedded with bluish-gray, fine grained sandstone. An 18 inch Atoka coal seam was penetrated by an exploratory well at a depth of approximately 67 feet one-half mile southwest of the site.

The Hartshorne Sandstone is exposed where the James Fork River cuts across the northeast trending ridge in the southern part of the study area (Figure 7). The formation consists of approximately 128 feet of pinkish-gray, fine to medium grained, massive sandstone.

The shale, sandstone and Lower Hartshorne coal of the McAlester Formation are exposed in this same cut and in the strip mine in the northeast part of the study area. Along the river, 48 feet of dark gray shale overlies the Hartshorne Sandstone.

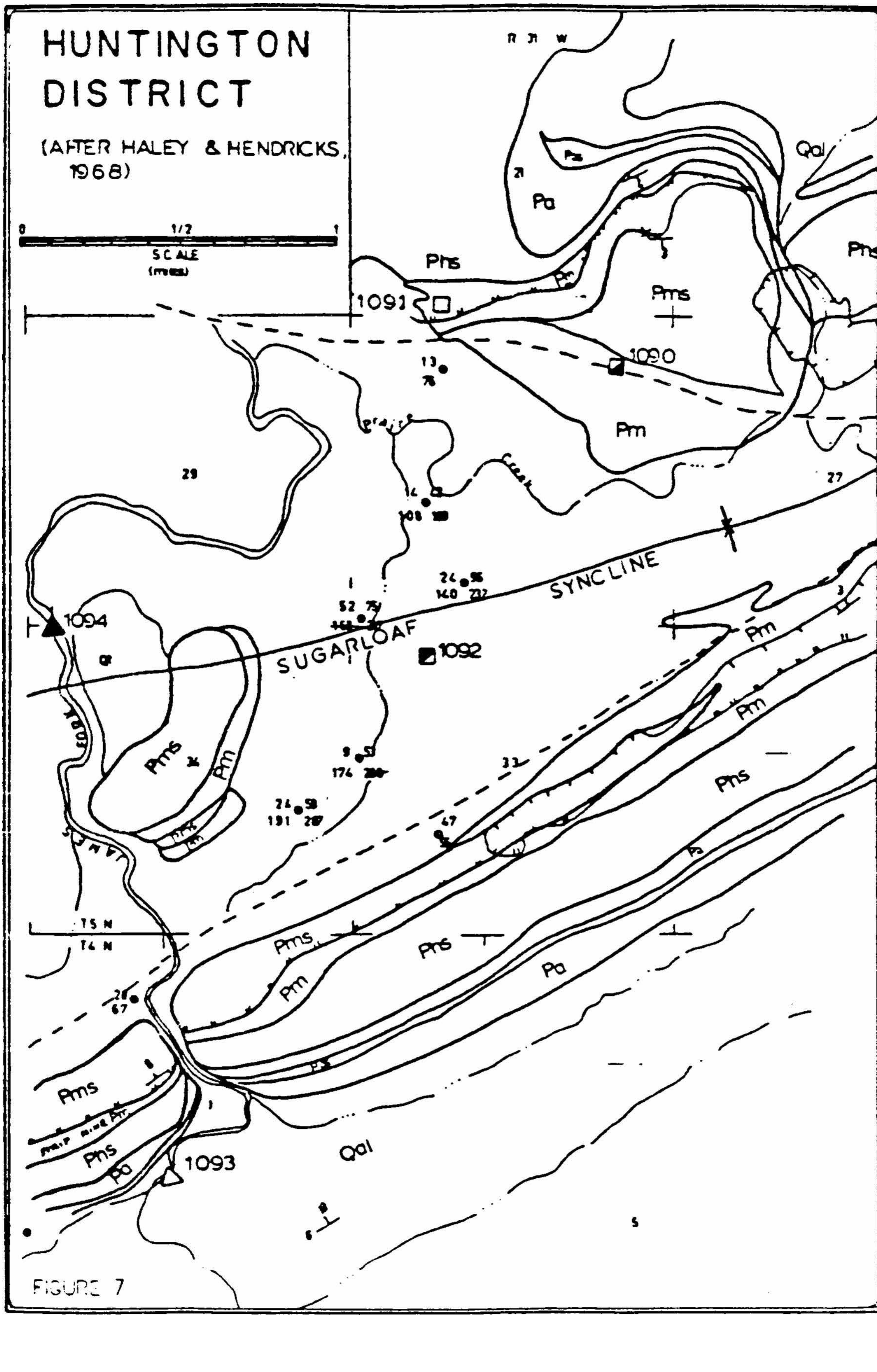

HUNTINGTON
DISTRICT
(AFTER HALEY & HENDRICKS, 1968)
SCALE
SUGARLOAF
SYNCLINE
1091
1090
1092
1093
1094
Pa
Phs
Pms
Pm
Qal
T5 N
T4 N

FIGURE 7

The Lower Hartshorne coal, which has mostly been removed by strip and slope mining, occurs above the shale and at the base of a lenticular bed of light to medium gray, medium to coarse grained, massive sandstone belonging to the McAlester Formation. This same relationship occurs in the strip mine, where 18 feet of this sandstone overlies a five-foot thick seam of Lower Hartshorne coal (SE¼, Sec. 21, T7N, R31W).

In exploratory boreholes (Figure 7), the Lower Hartshorne coal is actually a zone of 1 to 7 beds and ranges in thickness from 42 to 96 inches. A lenticular sandstone, 31 to 62 feet thick, also overlies the Lower Hartshorne coal in these shallow holes. The Upper Hartshorne coal occurs 60 to 90 feet above the Lower Hartshorne coal in the area.

Strip mining has occurred 400 feet southeast of monitoring well 1091. According to Haley and Hendrick's geologic map of the area (1968), this well penetrates the Lower Hartshorne at a depth of 22 to 27 feet. Field work indicates that this seam is traced further to the southeast of the well and dips away from the site, thus maintaining the well's integrity as an up gradient site. The trace of the Upper Hartshorne coal passes south of monitoring well 1090; hence, it is not penetrated by this well.

Reddish-yellow water, which is referred to as "yellow boy" by coal miners and is characteristic of acid mine drainage, was noted to issue from the mine shaft at 1092. Water was also observed to flow from an unsealed slope mine into the James Fork River at a point downstream from 1093. The water was clear in color, but the rocks over which it flowed were iron stained.

Structure. The Sugarloaf Syncline is the primary structure which extends through the central portion of the study area. The syncline is fairly symmetrical with low dips (3 degrees) along its axis and dips not exceeding 30 degrees on its limbs. It is bordered 2½ miles to the north by the Midland Anticline and 3 miles to the south by the Hartford Anticline. Haley and Hendricks (1968) have designated this structure the Cavanal Syncline. The difference in nomenclature appears to be a disparity in the trace of the synclinal axis to the west of the study area.

Bates District

Surface Sampling Site: 1100

Monitoring Well: 1101

The study area is located in western Scott County in Township 3 North and Range 22 West. The sampling sites are at the northeast end of a line of strip mines that extend 3 miles into Oklahoma. Surface sampling site 1100 is a down gradient site located on Shadley Creek in Sw¼, NE¼, Sec. 21, T3N, R31W. Shadley Creek drains the area and flows south, where it empties into the Poteau River. Site 1101 is an 80-foot deep, down gradient well in the SW¼, SW¼, Sec. 15, T3N, R31W.

Lithology. The Atoka Formation occurs in the southern part of the study area (Figure 8). At outcrops along the ridges, it is a light gray, fine to medium grained sandstone. Site 1100 is in alluvium which presumably overlies upper shales of the Atoka.

Strata belonging to the Atoka, Hartshorne and McAlester Formations can be traced east into Arkansas, from where they have been mapped and described for the Howe-Wilburton District in Oklahoma by Hendricks (1939). A problem with the stratigraphic nomenclature of the Hartshorne Formation has been noted. The lower most sandstone unit in the McAlester is in the same stratigraphic position as the Hartshorne Sandstone in Oklahoma and shows the same relationships that were observed in the Huntington District. This sandstone unit appears to occur as a lenticular bed in the southwest part of the Arkansas coal fields only. A section measured along Shadley Creek through the Hartshorne and lower McAlester Formation is given in Figure 9.

North of the mined area, the McAlester occurs predominantly as shale. The Upper Hartshorne coal can be traced from the Oklahoma coal field eastward into the study area in the northwest portion of Sec. 17 and 16.

Structure. The study area is located on the south flank of the Poteau Syncline. The axial trace of the syncline undulates along the crest of Poteau Mountain. It is a broad, shallow fold with higher dips on the south flank (Collier, 1907), and it is bordered two miles to the south of the study area by the Choctaw Anticline and Fault.

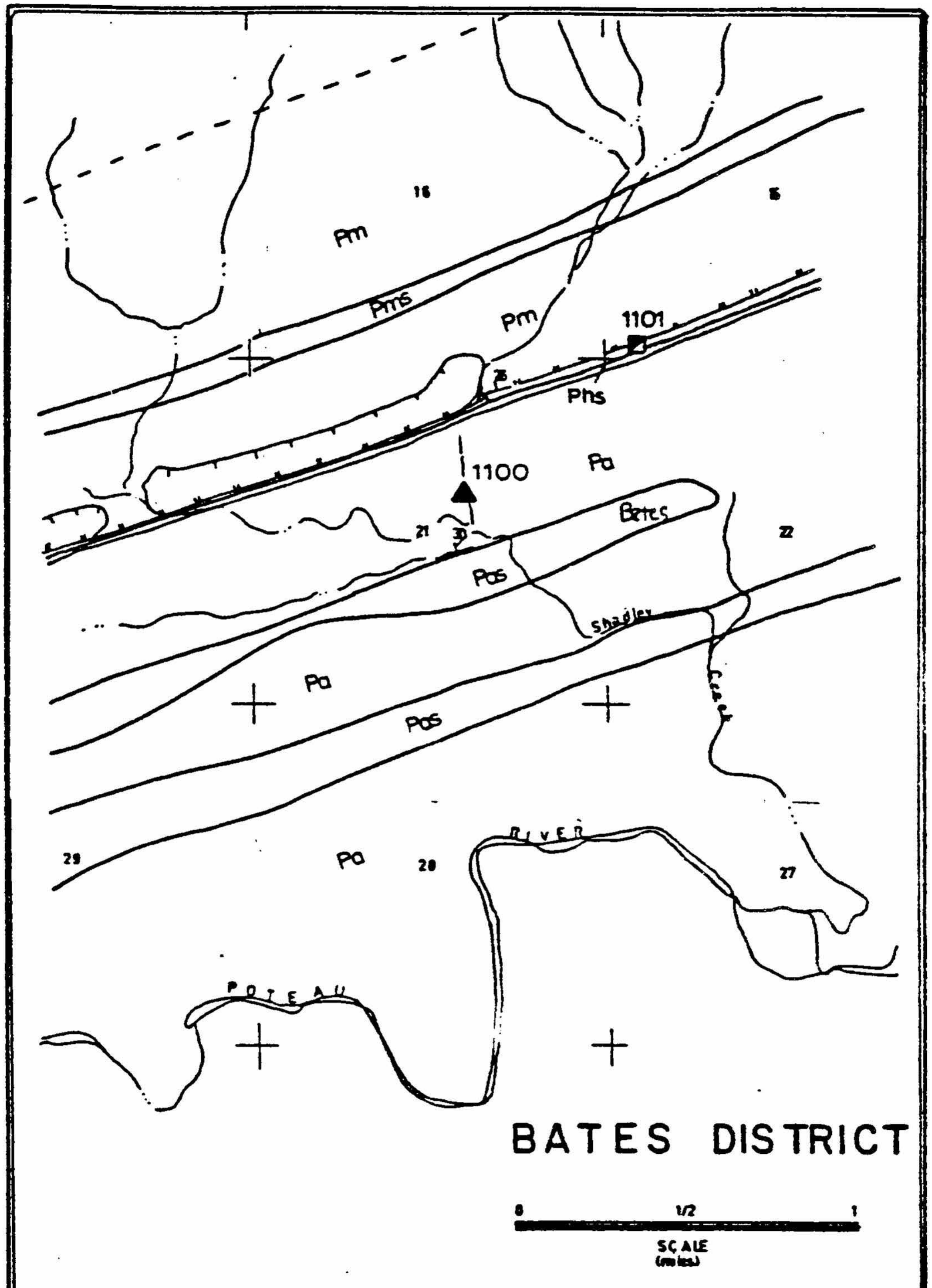

16
15
Pm
Pms
Pm
1101
Phs
1100
Pa
Bates
21
22
Pas
Pa
Pas
29
Pa
28
River
27
POTEAU
BATES DISTRICT
0
1/2
1
SCALE
(miles)

FIGURE 8

	LITHOLOGY	FEET
Sandstone	light gray, fine to medium grained, massive	65.6
Shale	dark gray, fissile	2.0
Sandstone	light gray, medium bedded to massive, micaceous	20.0
Shale	dark gray to black, fissile, contains plant stems, iron concentrations	26.3
Coal	Lower Hartshorne Coal	4.0
Shale	black & fissile at base grading to dark gray, thinly laminated	15.7
Coal		1.0
Shale	gray, clayey	5.9
Sandstone	gray, thin bedded, weathers reddish to buff, with gray shale partings	45.5
	TOTAL	186.0

Figure 9. Section measured in Shadley Creek cut in NW¼, Sec. 21, T3N, R23W.

Charleston District

Surface Sampling Sites: 1062 and 1063

Monitoring Wells: 1060 and 1061

The study area is located in southern Franklin County and western Logan County in portions of Townships 6 and 7 North and Ranges 27, 28 and 29 West. Two monitoring points, 1062 and 1063, are located on Six Mile Creek. Site 1062 is an up gradient site which is located .15 mile north of Chismville in the SE¼, NE¼, Sec. 2, T6N, R28W. Site 1063 is a down gradient site which is located 3.5 miles southeast of Branch in the SE¼, SE¼, Sec. 18, T7N, R27W. The remaining sites are monitoring wells. Site 1061 is an up gradient well located 2.5 miles northwest of Charleston in the NE¼, SE¼, Sec. 3, T7N, R29W. Well 1060 is a down gradient site which is located 3.5 miles southeast of Charleston and 3 miles southwest of Branch in the NE¼, NW¼, Sec. 21, T7N, R28W.

Lithology. Six Mile Creek flows northward from Backbone Mountain across sandstones, siltstones and shales of the Atoka Formation to sampling site 1062. The ridges to the east and west of 1062 are composed of 50 feet of light gray, fine to medium grained, medium bedded sandstone of the Hartshorne Formation. It is overlain by the dark gray shale of the McAlester Formation. Where the shale is exposed in the road cut west of 1062, it is foliated and has closely spaced (4") joints. The Lower Hartshorne coal is traced 300 feet north of the site beneath the alluvium.

From 1062, Six Mile Creek flows through sandstones, siltstones and shales of the Savanna Formation. The Savanna Formation is estimated to be 950 feet thick in the study area (Haley and Hendricks, 1972). The shale is dark gray, non-silty and fissile for the most part. Iron concentrations are common, and some pyrite occurs in the shale. The siltstone is light to medium gray, micaceous and finely sandy. The sandstone is light to medium gray, very fine grained and silty. The channeloid character of some of the sandstone in the Savanna Formation is exemplified in the SE¼, Sec. 13, T7N, R29W and in the adjoining corners of Sec. 19, 20, 29 and 30. Figure 10 is a composite section of the Savanna Formation measured south of Charleston.

	Ft.	In.
1. Sandstone, buff, in thick even beds, medium-grained, and micaceous; uppermost unit of the Savanna sandstone	20	0
2. Shale, gray, sandy	6	0
3. Sandstone, buff, shaly	5	0
4. Shale, gray	5	0
5. Limestone, sandy, with abundant fresh-water fossils	1	0
6. Shale, black, calcareous	2	0
7. Limestone, dark gray, very fossiliferous, hard, silicified	1	0
8. Coal	---	6
9. Shale, gray, sandy	6	0
10. Sandstone, brown, to shaly, thin-bedded	8	0
10a. Shale, gray and black, sandy in part	27	0
10b. Sandstone, marine fossils	2	0
11. Shale, gray in upper part; grades downward into black shale that contains abundant plant fossils	30	0
12. Coal	1	6
13. Shale, gray and black, with abundant plant fossils in lower part	110	0
14. Coal	---	2
15. Shale, black and gray, with some plant fossils in upper part	70	0
16. Sandstone, brown, fine-grained, and shaly	7	0
17. Shale, sandy, gray and black	90	0
18. Sandstone, medium-grained, soft, brown, thin-bedded	5	0
19. Coal	------	4
20. Shale, gray	100	0
21. Coal	------	4
22. Sandstone, gray, hard, fine-grained, even-bedded in beds 1 inch to 8 inches thick; used locally for structural stone	20	0
23. Shale, gray and black, and some sandy shale	200	0
24. Sandstone, gray, brown, shaly, even-bedded	8	0
25. Shale, gray and black, and some sandy shale	80	0
26. Sandstone	10	0
27. Shale, gray and black, and some sandy shale	50	0
28. Sandstone	10	0
29. Coal	------	11
30. Shale, gray and black, and some sandy shale; contains two lenticular sandstone beds	100	0
31. Sandstone, brown, even-bedded, shaly, lower 1 to 2 feet very hard	10	0
32. Shale, sandy, brown, micaceous	15	0
33. Coal	------	6
34. Shale, sandy, banded in gray and black, in quarter-inch to half-inch beds resembling varves; contains plant fossils, especially in lower part	70	0
35. Coal	1	6
36. Sandstone, gray to buff, medium-grained to shaly	10	0
37. Shale, gray, and some brown sandy shale	200	0
38. Sandstone, brown, fine-grained, thin-bedded, hard; breaks into long, narrow, rectangular fragments; basal units of the davanna sandstone	15	0
	1,359	9

Figure 10. Composite section of Savanna Sandstone south of Charleston, T7N, Rs. 28 and 29 W (Hendricks and Parks, 1950).

The McAlester Shale was not exposed at Sites 1061 and 1063 because of the thick alluvial cover. However, 1061 is drilled 65 feet into the upper 300 feet of the formation where no significant coal beds are known to occur (see Haley and Hendricks, 1972).

The Charleston coal is extensively mined in Sec.'s 30, 31 and 32, T8N, R28W. Eighteen inches of this coal is exposed in a strip mine 1/10 mile north of monitoring well 1060. The well is 65 feet deep and may not penetrate the Charleston coal which is estimated to be at a depth of 65 feet at this location. Another weathered coal bed, which is stratigraphically above the Charleston coal, is exposed in a road cut in the SW¼, SE¼, Sec. 24, T7N, R28W.

Structure. Structural features are outlined on the geologic maps for the Charleston District (Figure 11). Monitoring wells 1060 and 1061 are located on the south limb of the Game Hill Anticline. Its axial trace extends from the SE corner, Sec. 11, T7N, R27W westward to the SE corner, Sec. 3, T7N, R29W. The axis probably continues beneath the alluvium here and ends against the south dipping normal fault which passes through the area to the north. The anticline is bounded to the north by the Paris syncline and to the south by the Bloomer syncline. Dips on both limbs tend to be between 3 and 5 degrees.

Surface sampling sites 1062 and 1063 are situated on the south limb of the Bloomer syncline. Strata dip from 2 to 10

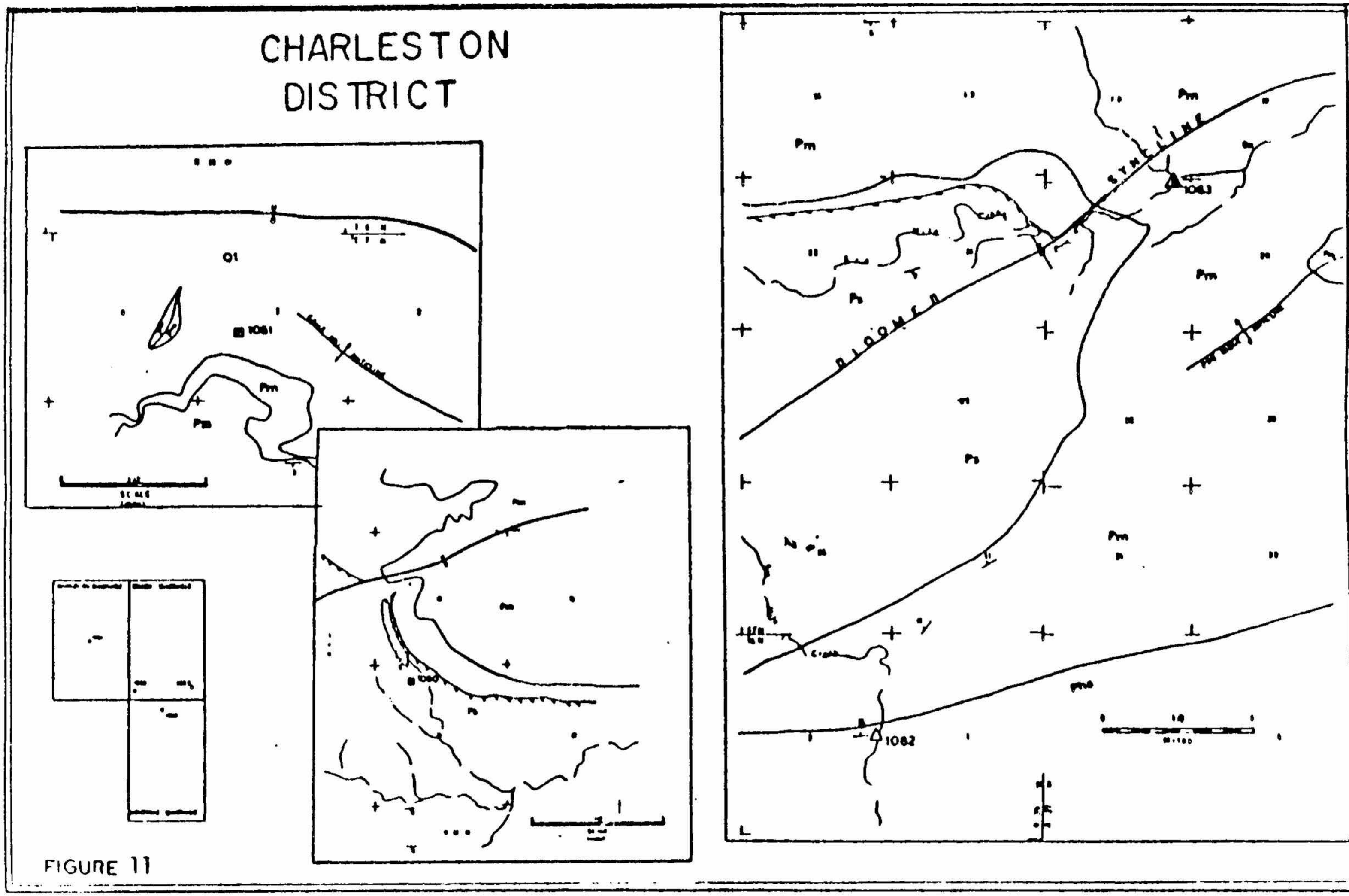


FIGURE 11

degrees along the limbs, except in the middle part of the south flank where dips increase to as much as 35 degrees.

Paris District

Surface Sampling Site: 1052

Monitoring Wells: 1050 and 1051

The study area is located in northwest Logan County in Townships 7 and 8 North and Ranges 26 and 27 West. Site 1050 is a 100-foot deep, down gradient well in the E$\frac{1}{2}$, SE$\frac{1}{4}$, Sec. 2, T7N, R27W. Site 1051 is a 30-foot deep up gradient well in the SW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 14, T7N, R27W. Surface sampling site 1052 is located on Six Mile Creek in the SE$\frac{1}{4}$, Sec. 30, T8N, R26W. It is a down gradient site.

Lithology. Monitoring point 1051 is a shallow well (30 feet) in alluvium and shales of the upper Atoka Formation. A black, fissile shale is exposed in the creek bed in the center of Sec. 14, T7N, R27W.

Approximately 100 feet of sandstone belonging to the Hartshorne Formation is exposed as steeply inclined beds in the NE$\frac{1}{4}$, Sec. 14, T7N, R27W. The McAlester Formation and the Lower Hartshorne coal are exposed here as well.

An east-west trending thrust fault, which extends through the southern part of the study area (Figure 12), brings upper beds of the Savanna Formation into contact with the McAlester Formation. The Savanna Formation is approximately 600 feet thick and includes a shale unit originally mapped as Boggy Formation in

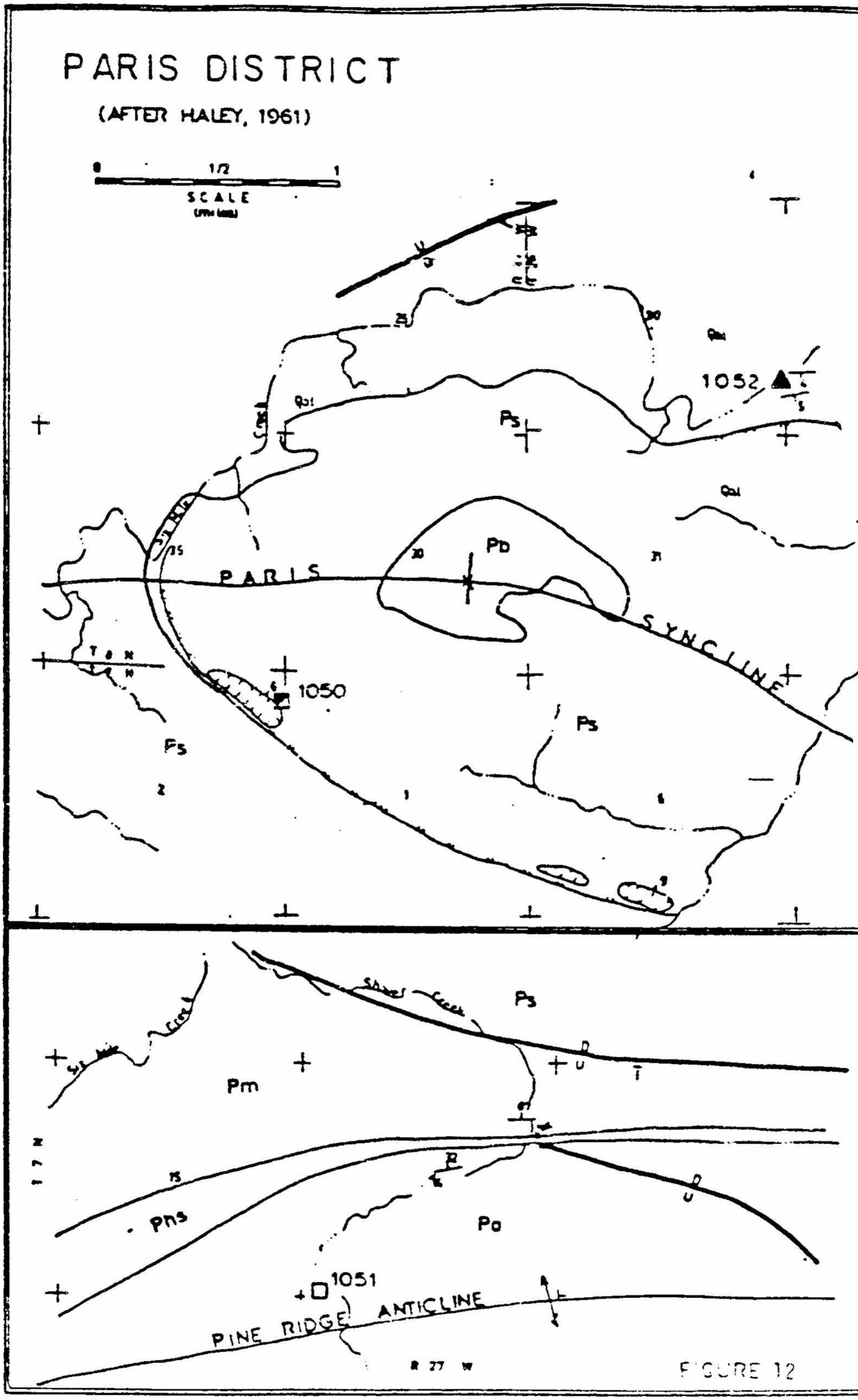

PARIS DISTRICT
(AFTER HALEY, 1961)
SCALE
1052
Ps
Pb
PARIS
SYNCLINE
1050
Fs
Pm
Pns
Po
1051
PINE RIDGE ANTICLINE
R 27 W

FIGURE 12

the Fort Smith district by Hendricks and Parks (1950). Exposures of the Savanna Formation were limited to the headwall of the strip mines. In the SE¼, SW¼, Sec. 6, T7N, R26W, it consists of dark gray, silty shale having iron concretions and interbedded with a medium gray, very fine to fine grained, thin, irregularly bedded sandstone. As exposed in the strip mine in the NE¼, Sec. 2, T8N, R27W, it is a very fine to fine grained, medium gray, silty, thinly bedded, fossiliferous sandstone. The silty layers are slightly carbonaceous. Well 1050 is located just north of this mine. Depth to the coal bed at this location is estimated to be 71.5 feet. The coal seam passes slightly to the southwest of Site 1052. Dark gray, fossiliferous shale and medium gray siltstone are exposed in the river bank, but no outcrops of coal were observed. The Paris coal has been extensively worked in several small strip pits and underground mines in the area and is reported to be 18 to 32 inches thick (Hendricks and Parks, 1939).

Horseshoe Mountain is capped by 200 feet of sandstone belonging to the Boggy Formation. It is described as a light gray, very fine to medium grained, silty, micaceous sandstone that is cross bedded, ripple marked and contains thin beds and lenses of light to medium gray siltstone and medium dark gray shale (Haley, 1961).

Structure. Monitoring well 1051 is on the north limb of the Pine Ridge Anticline. This dominant structure is a large asymmetrical anticline that has been ruptured on its north flank in part by an unnamed thrust fault. Dips on the north flank are very high to locally overturned. The Pine Ridge structure is a breached anticline.

Sampling sites 1050 and 1052 are on the flanks of the Paris Syncline. The syncline is topographically expressed as Horseshoe and Short Mountains. The Paris Syncline is a broad, gently dipping fold that is slightly asymmetrical. It is bounded to the north by the Prairie View Anticline and to the south by the Pine Ridge Anticline.

Scranton District

Monitoring Wells: 1040 and 1041

The study area is located in northern Logan County in Township 8 North and Range 24 West. The area is sampled by two monitoring wells. Well 1040 is a 30-foot, up gradient well which is located in the SE¼, SW¼, Sec. 26, T8N, R24W, 2.8 miles southeast of Scranton. Well 1041 is a 96-foot deep down gradient site which is located 1.5 miles southwest of Scranton in the SW¼, SW¼, Sec. 22, T8N, R24W.

Lithology. Haley (1968) reports that 6,100 feet of the Atoka Formation was penetrated by a well in Sec. 23, T8N, R24W, and he estimates that 1,210 feet have been removed from the section by two normal faults. Outcrops of the Atoka within the study area are limited to creek beds in Sec.'s 25, 26 and 27, T8N, R24W, where it is represented by dark gray to black, silty, micaceous shale in beds 1/16 to ½ inches thick. Underlying the shale is a medium grained, irregular bedded, lenticular sandstone that outcrops on the south flank of the Prairie View Anticline in section 24 (Figure 13).

Coal beds in the Atoka Formation are exposed to the south of the study area in Sec.'s 2, 10 and 11, T6N, R26W, Sec. 19, T7N, R26W (Reinold, 1953), and they have been penetrated by drill holes to the north of the study area (Collier, 1907) and at depths greater than 800 feet in Sec. 23 and 25, T8N, R24W (Haley, 1968). Most of the coal beds are thin and not continuous for any great distance.

The Hartshorne Formation is composed of alternating layers of thin bedded, fine grained sandstone and thick bedded to massive, medium grained sandstone. Haley (1968) reports thicknesses of 20 feet (SW¼, SW¼, Sec. 23, T8N, R24W) to 220 feet in Sec. 13, T7N, R23W. Where the formation is thin, it is light gray to gray, irregular and thin bedded, very silty, fine grained and well indurated sandstone. Such sandstone is exposed in the strip mine in Sec. 23, T8N, R24W, where it is 20 feet thick, and in the exposure south of 1041 in the S½, Sec. 22 and N½, Sec. 27, T8N, R24W, where it is 80 feet thick. Where the formation is thicker south of the study area, it is a thickly bedded to massive, medium to coarse grained sandstone. Haley (1968) maintains that most of the sandstone in the formation is of the type deposited in stream channels and is characterized by sharp upper and lower boundaries.

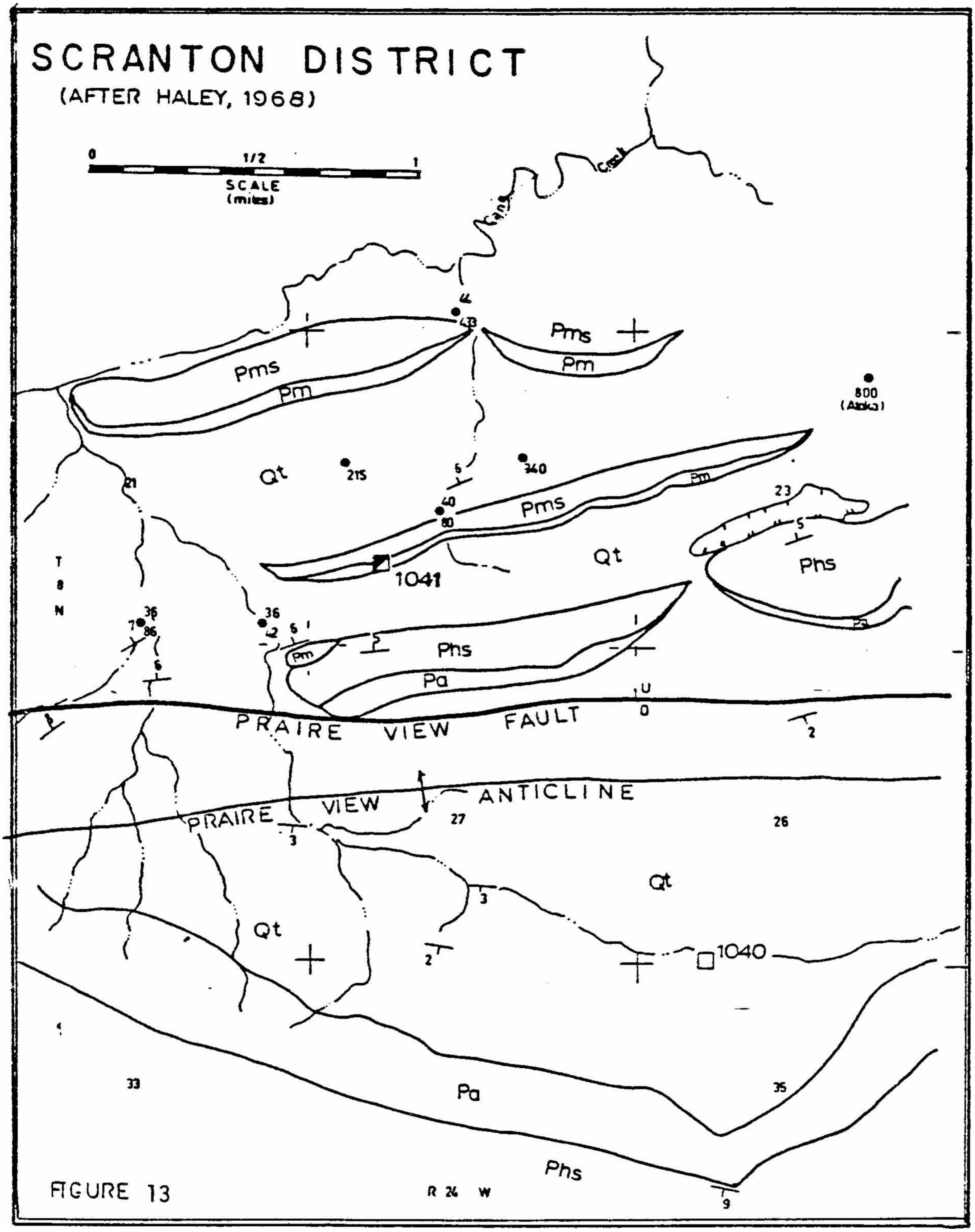

SCRANTON DISTRICT
(AFTER HALEY, 1968)
0
1/2
1
SCALE
(miles)
Pms
Pm
Qt
PRAIRE VIEW FAULT
PRAIRE VIEW ANTICLINE
1041
1040
Phs
Pa
800
T
8
N
R 24 W

FIGURE 13

The McAlester Formation is predominantly a dark gray to black, slighty silty, micaceous, fissile to thinly laminated shale, locally containing iron concretions. It is lithologically similar to the upper Atoka Formation but tends to be less silty and darker in color. The formation is reported to be between 250 and 1200 feet thick in the Scranton District (Reinold, 1953; Eby, 1952; Haley, 1968). Sandstone lenses are present and are local in extent. The sandstone is a light gray, very fine grained, silty, micaceous, thin to irregular bedded, ripple marked and cross bedded.

The Lower Hartshorne coal underlies the greater part of the district and extends north passing under the Arkansas River and into the Spadra District. Haley (1968) reports two additional unnamed coal beds within the district. One is 45 feet above the Lower Hartshorne coal, the other is 150 feet above the base of the formation. These beds were penetrated by drill holes in the SW¼, SE¼, Sec. 9, T7N, R24W and the NW¼, NW¼, Sec. 20, T8N, R32W (see Collier, 1907). Well 1041 is probably completed in a 40-inch thick bed of the Lower Hartshorne coal, the base of which is estimated to be at a depth of 96 feet below the site.

Well 1040 is in unconsolidated terrace deposits which overlies the Atoka Formation. Though Atoka shale outcrops in several locations in the vicinity of the well, its exact stratigraphic position could not be determined, hence, depth to the top of the Atoka Formation could not be calculated. However, Cordova (1964) has indicated that depths of wells in alluvial material are generally determined by depth to bedrock or to a basal gravel zone. Hence, it is likely that the Atoka Formation occurs at a depth of 30 feet (the depth of the well) at this site.

Structure. Rocks in the Scranton District have been folded into east-west trending anticlines and synclines and have been broken by east trending, southward and northward dipping normal faults. Wells 1041 and 1040 are located .7 miles north and .6 miles south of the axis of the Prairie View Anticline, respectively. The axial trace of the Prairie View Anticline extends across the center of the study area and it lies between the Scranton Syncline to the north and the Paris Syncline to the south (Croneis, 1930). In the study area the anticline is slightly asymmetrical with steeper dips on the north limb (6 to 12 degrees).

The Prairie View Anticline is broken by a north dipping fault, the trace of which strikes along the axial trace of the Prairie View Anticline. Earlier investigations described the Prairie View fault as a thrust fault with its upthrown side on the south (Collier, 1907). Subsequent subsurface information shows that the fault is a northward dipping normal type fault with maximum displacement of 350 feet in Sec. 28, T8N, R24W (Haley, 1968). The fault is covered by alluvium in the study area, but it is evidenced topographically by the abrupt termination of a sandstone ridge in Sec. 29, T8N, R24W.

Philpott District

Surface Sampling Sites: 1022, 1023 and 1024

Monitoring Wells: 1020 and 1021

The study area is located in west-central Johnson County in the northern half of Townships 10 and 11 North, Ranges 24, 25 and 26 West. Horsehead Creek and its tributaries delineate the major surface drainage features in the area. Monitoring points 1023, an up gradient site, and 1024, a down gradient site, are located on Cole Creek in the NW¼, SE¼, Sec. 1, T10N, R25W and the NW¼, SW¼, Sec. 31, T11N, R24W, respectively. Surface sampling site 1022 is a down gradient site located on Dirty Creek in the NE¼, SE¼, Sec. 28, T10N, R25W. Dirty Creek issues directly from the Utah Strip Mine to the northwest of the site. Monitoring well 1020 is 65 feet deep and is located at the western end of the Utah Strip Mine in the NE¼, NW¼, NE¼, Sec. 24, T10N, R26W. Site 1021 is 64 feet deep and is one of six monitoring wells constructed by Peabody Coal Company. It is located in a reclaimed area that extends east-west of Highway 164 at Hunt in the NW¼, SE¼, Sec. 16, T10N, R25W.

Lithology. The upper 4500 feet of the Atoka Formation are exposed adjacent to the study area. Where the formation is exposed at sampling site 1022, it is a light to medium gray, fine to medium grained, thin bedded (3/4" to 1"), micaceous sandstone. It is interbedded with shalier units in this vicinity, and at its contact with the Hartshorne Formation in the SE¼, NW¼, Sec.

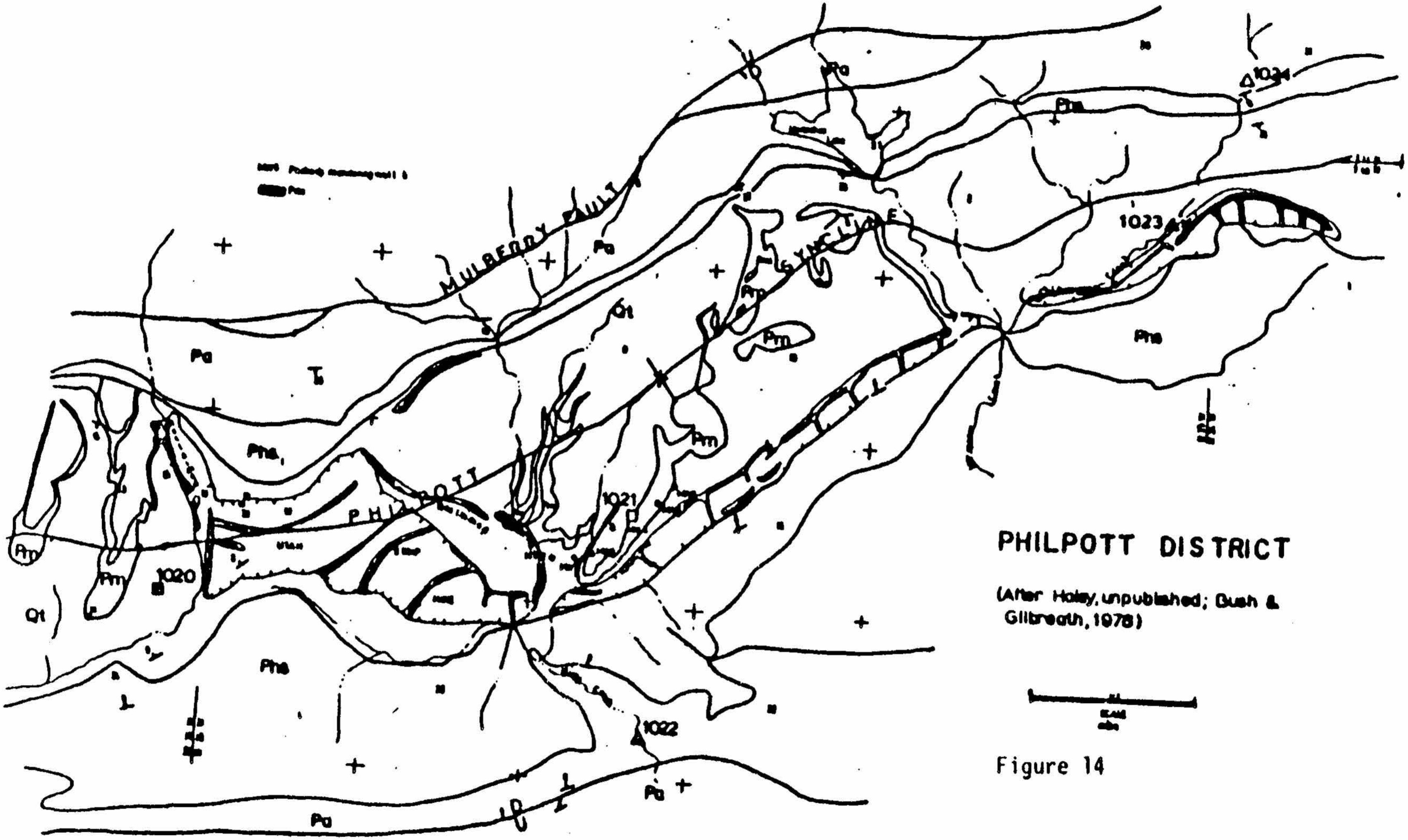
21, T10N, R25W, it is a black, fissile, micaceous shale. This black fissile shale also occurs at sampling site 1024. Approximately 300 feet downstream from site 1024, the Hartshorne Formation forms an east-west trending ridge and occurs as a medium gray, weathered pinkish-gray, medium to coarse grained, massive, cross bedded sandstone and is approximately 76 feet thick.

The McAlester Formation overlies the Hartshorne Sandstone and occurs predominantly as shale throughout the entire basin. The Lower Hartshorne coal occurs near the base of the formation. Collier (1907) had correlated this coal, which was then designated the Philpott coal, with the Charleston coal of the Savanna Formation. Subsequent investigations show the Savanna Formation as the youngest unit in the area (McRae, 1950; Haley, 1960). The correct relationship of these formations, however, was recognized by Haley (1976) while he prepared the State geologic map.

The McAlester Formation is exposed in the strip mines lying to the south of sites 1024 and 1023, respectively. In the pit near site 1024, it occurs as a dark gray to black fissile shale which is overlain by a thin (2") to medium (16") bedded, buff-colored sandstone. In the pit adjacent to site 1023 the formation occurs as 2 feet of black shale and 10 feet of interbedded shale and siltstone which are separated by a 7" coal seam. Though there is no coal present, this same relationship was observed in the strip pit north of site 1020.

Most stripping operations have been confined along the southern outcrop of the Lower Hartshorne coal because steep dips on the north carry the coal too deep for stripping. Depth of the overburden along the central part of the basin is approximately 150 feet (Stroud, 1969). Depth of the Lower Hartshorne coal in the vicinity of Peabody Monitoring Wells 1-6 before it was mined was 60 to 100 feet. The coal here averaged 18 inches in thickness. A second coal bed, averaging 8" in thickness, occurs 30 feet above the Lower Hartshorne coal in the drilling logs for these monitoring wells. The two coals are separated by a persistent sandstone bed that is 26 to 30 feet thick. At site 1021, (Peabody Monitoring Well 4) this upper coal (Upper Hartshorne coal?) and the Lower Hartshorne coal occurred at 31.4 and 60.3 feet, respectively. The Lower Hartshorne coal is estimated to occur at a depth of 30 feet in monitoring well 1020.

Structure. The Philpott District lies within an east-west trending synclinal basin that is ¼ to 1¼ miles wide and 12 miles long. The Philpott Syncline is asymmetrical with dips on the north flank (averaging 25 degrees) greater than those on the south flank (6 to 12 degrees) (Croneis, 1930). The basin is bounded to the north by the Mulberry Fault, which is a south dipping normal growth fault. Displacement along this fault is 2500 feet (Bush and others, 1977). The basin is bounded to the south by an unnamed, north dipping, normal growth fault that is estimated to have 800 feet of displacement in the sursurface (Haley, per comm).



PHILPOTT DISTRICT

(After Haley, unpublished; Bush & Gilbreath, 1978)

Figure 14

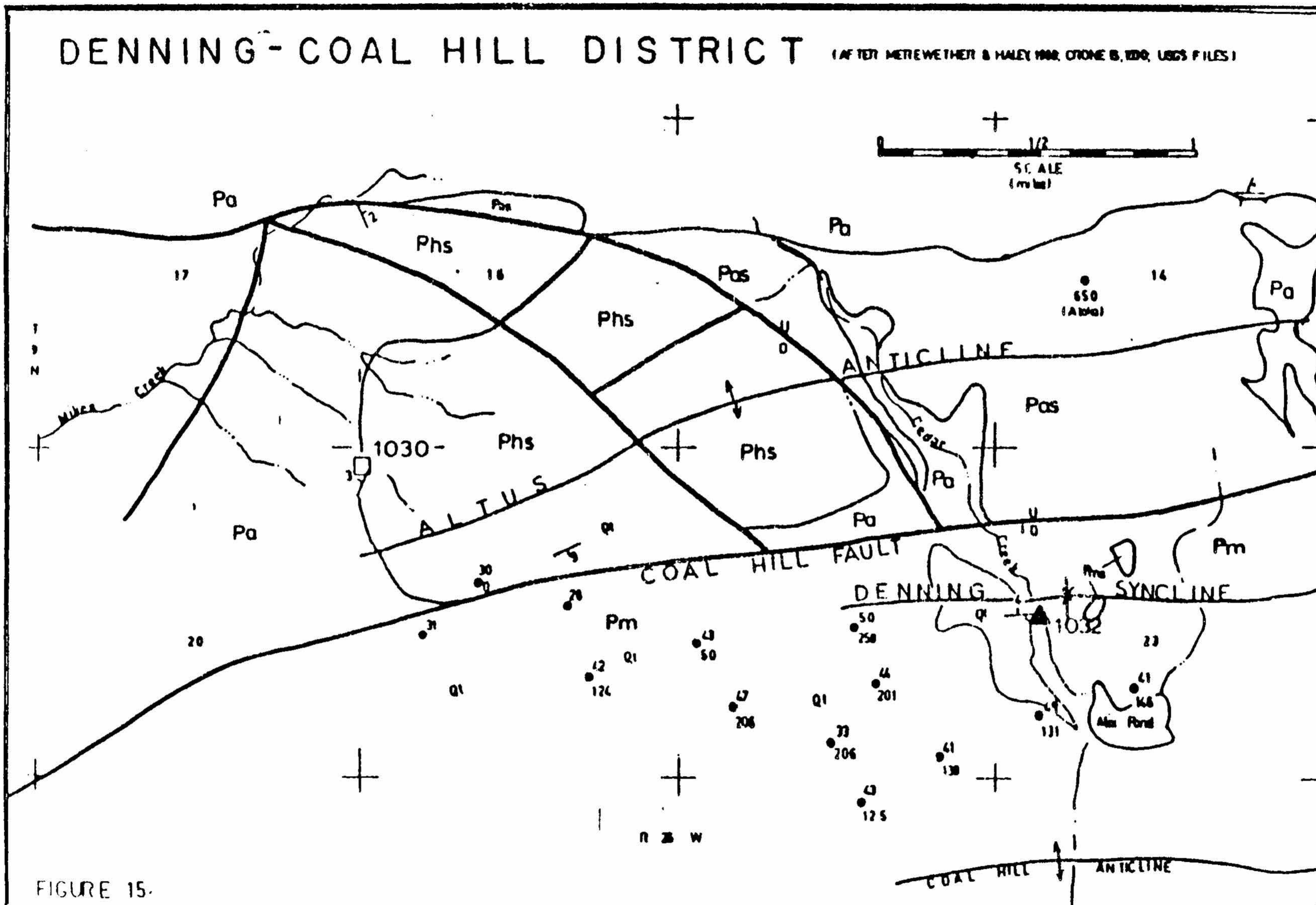
Denning-Coal Hill District

Surface Sampling Site: 1032

Monitoring Well: 1030

The study area lies in southeast Franklin County in Township 9 North and Range 26 West. Site 1030 is a 120-foot up gradient well in the NW¼, NW¼, Sec. 21, T9N, R26W. Surface sampling site 1032 is a down gradient site located on Cedar Creek in the NW¼, SW¼, Sec. 23, T9N, R26W. Cedar Creek drains the eastern part of the study area and empties into the Arkansas River to the southeast.

Lithology. Exposures of the Atoka Formation are limited to the upper part of the formation (Figure 15). According to Merewether and Haley (1969), the stratigraphic units within the Atoka are consistent in neither lithology nor thickness. The sandstones are mostly light to medium gray, very fine to fine grained, silty, micaceous and well indurated. Bedding is thin to massive, regular to irregular and may even be lenticular. Most beds have ripple marked surfaces. Sandstones may be in units 70 feet thick. The siltstone is light to dark gray, argillaceous to quartzose, micaceous, well indurated, with bedding 1 to 6 inches thick. The siltstone may occur in units 20 feet thick. Northeast of site 1032, the Atoka Formation occurs as a medium gray to gray black shale that is silty and micaceous. Just north of the Coal Hill fault, it is approximately 400 feet thick. The contact of the Atoka and Hartshorne Formations is exposed in


DENNING-COAL HILL DISTRICT
SCALE
(miles)
0
1/2
1
Pa
Phs
Pas
Pm
Qt
17
16
14
20
23
T 9 N
R 26 W
Mikes Creek
Cedar Creek
1030
1032
ALTUS ANTICLINE
COAL HILL FAULT
DENNING SYNCLINE
COAL HILL ANTICLINE
650
(Abbie)
Alix Pond
U
D
FIGURE 15.

a road cut near site 1030. The well is estimated to penetrate the top 120 feet of the Atoka.

Atoka coals are thought to form thin, lenticular beds and are confined to the upper part of the formation. No such coal beds were exposed in the area; however, they were penetrated by gas wells in the NW¼, Sec. 14 and center of Sec. 25, T9N, R26W at depths of 650 and 1,200 feet, respectively (Merewether and Haley, 1969).

The Hartshorne Formation caps the hills south of Altus. It is predominantly a sandstone, but may be interlayered with scattered thin beds of shale. In a few places it consists mainly of siltstone. In a road cut near 1032, the formation is a light to medium gray, fine to medium grained, silty and very micaceous sandstone. Bedding is ¼ to 3/4 inches thick, and the unit is estimated to be 58 feet thick. At the road cut in the SW¼, NE¼, Sec. 21, the formation is a light gray, fine to medium grained quartz sandstone that is slightly micaceous and well indurated. It is thinly bedded (3/4") and has well developed ripple marks.

The McAlester Formation occurs south of the Coal Hill fault. Exposures of the formation are poor in the area. The formation is predominantly a shale, but in the road cut near 1032, it is a light to medium gray, thinly bedded (¼") siltstone. It is overlain here by surficial deposits of cobbles and pebbles of sandstone and quartz which grade upward into silt and clay.

The Lower Hartshorne coal is 32 to 63 inches thick and occurs in two benches separated by 4 to 11 inches of bone and shale (Stroud, 1969). It occurs at a depth of approximately 200 feet beneath 1032. The coal has been extensively mined using underground methods (Bush and Gilbreath, 1978). The position of the southern limit of the coal bed has not been determined, but it probably extends southward beneath the Arkansas River.

Structure. The structure of the rocks in the area consists of generally east trending discontinuous folds and normal faults. Surface traces of these features have gently, irregular curved axes. Site 1032 is just south of the axis of the Denning syncline which is a broad, symmetrical fold having dips not exceeding 4 degrees. It is bounded approximately 3/4 miles to the south by the Coal Hill Anticline, which is also a broad, symmetrical fold characterized by low dips on its flanks. The Denning Syncline abuts the Coal Hill fault 1½ miles to the north (Figure 15). Site 1030 is on the north flank of the Altus anticline, which extends from the NE¼, Sec. 26, T9N, R27W to the NE¼, Sec. 13, T9N, R26W. The anticline is asymmetrical with dips on the south limb (3 to 9 degrees) slightly greater than dips on the north limb (2 to 7 degrees) (Croneis, 1930).

Normal faults, downthrown to the south, are common in the area. The most prominent is the Coal Hill fault, which extends across the southern part of the study area. The greatest displacement at the surface is 675 feet in the N½, Sec. 24, T9N, R26W

(Merewether and Haley, 1969). North of the fault, rocks of the Atoka and Hartshorne formations are exposed. The McAlester Formation has been downthrown to the south, hence, all of the workable coals in the area are south of the fault. The Coal Hill fault is joined by lesser faults which can be traced south of Altus.

Spadra District

Surface Sampling Sites: 1043 and 1044

The study area is located in south Johnson County in Township 10 North and Range 23 West. Both sampling sites are located north of Clarksville on Spadra Creek, which with its tributaries drains the study area and empties into the Arkansas River to the south. Site 1044 is an up gradient site and is located in the E½, SW¼, Sec. 21, T10N, R23W. Site 1043 is the down gradient site which is located in the SW¼, NW¼, Sec. 33, T10N, R23W.

Lithology. Sampling site 1044 is situated on an upthrown block of the Atoka Formation (Figure 16). Here, the formation consists of gray, fine to medium grained, very micaceous sandstone which exhibits massive bedding, irregular in part, convoluted in part and forms the bluffs along Spadra Creek. It is approximately 300 feet thick. The black, splintery shale, which is more typical of the upper Atoka, was observed 400 feet east of the site near the base of the Hartshorne Formation.

The Hartshorne Formation is reported to be 80 to 200 feet thick in the area (Hille, 1951). South of the fault, in the SW¼,

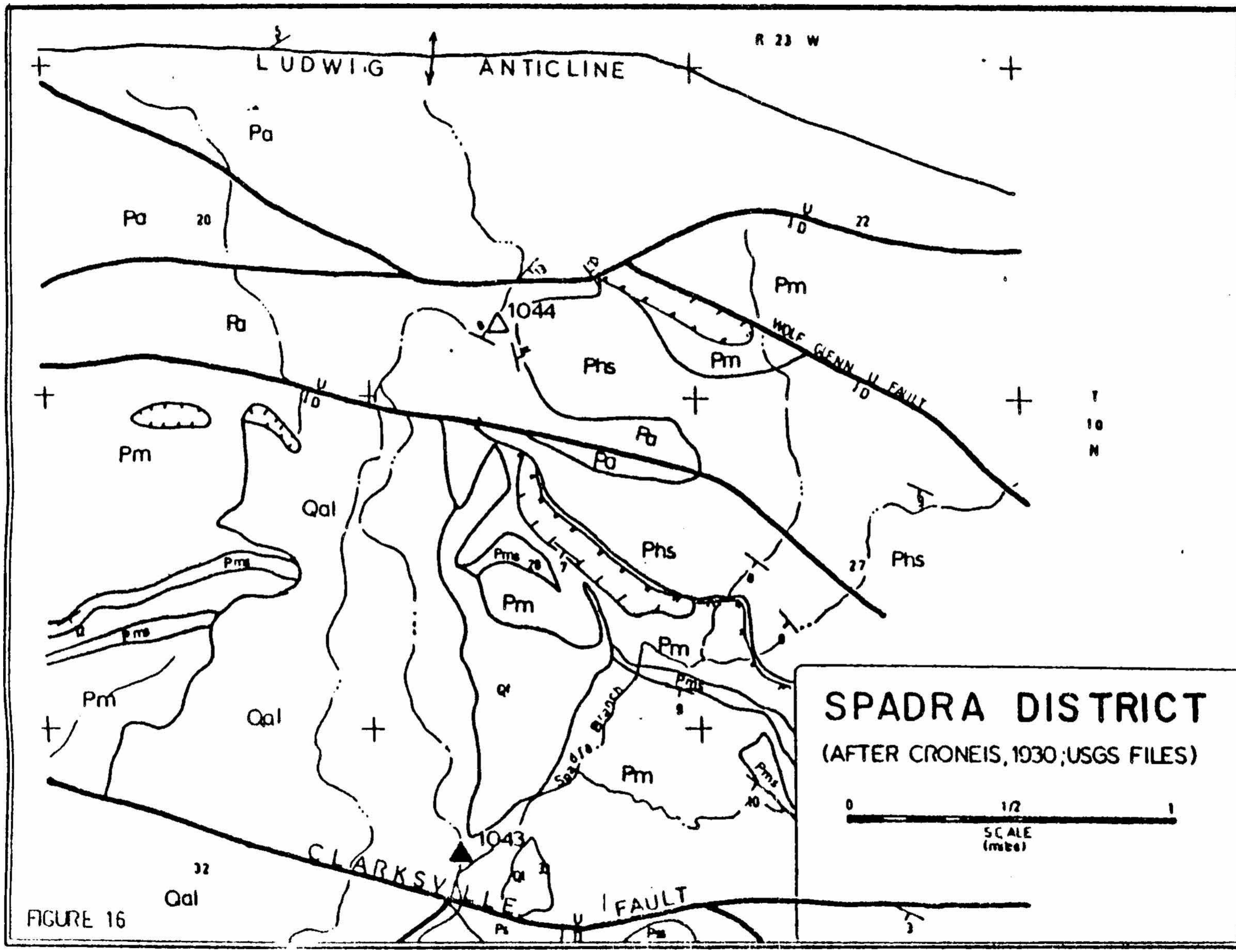

SPADRA DISTRICT
(AFTER CRONEIS, 1930; USGS FILES)
SCALE
(miles)
0
1/2
1
LUDWIG ANTICLINE
WOLF GLENN FAULT
CLARKSVILLE FAULT
R 23 W
T 10 N
1044
1043
Spadra Branch
Pa
Pm
Phs
Pms
Qal

FIGURE 16

NE$\frac{1}{4}$, Sec. 14, T10N, R23W of the Hartshorne, is an ashy gray, coarse grained, well cemented, cross bedded sandstone. Exposures of the McAlester Formation are limited by the extent of the surficial deposits in the area. The thickness of the formation is reported to be between 250 and 500 feet in the area (Hille, 1951). The formation exposed in local strip mines is a black, splintery shale.

The continuity of the Lower Hartshorne coal is broken by normal faulting in the area. Eighteen inches of the coal bed outcrops in the Carter strip pit in Sec. 28. Collier (1907) estimates the depth of the coal to be 500 feet below the city of Clarksville.

Structure. The sampling sites are located on the south flank of the Ludwig Anticline (Croneis, 1930). The anticline is slightly asymmetrical with dips averaging 7 degrees on the north flank and 5 degrees on the south flank. The structure has no pronounced topographic expression.

Normal faulting is pervasive in the area. The only named normal fault is the Clarksville Fault which lies on the north flank of the Clarksville Syncline and is 1/10 mile south of site 1045. The faults in the area are downthrown to the south.

CONCLUSIONS

This investigation provides geologic information in the vicinity of 19 surface and 19 ground water monitoring sites in order to better define the water chemistry where little information is presently available. Further research should be conducted on the mineralogy of the rock strata associated with coal beds in the various mining districts and should include detailed petrology of the individual coal seams. In areas where the quality of water does not meet standards recommended by the American Public Health Association, additional research should be directed towards the nature of movement of ground water in unsaturated zones and in the fractured sedimentary rocks and associated coal beds.

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APPENDIX B WATER ANALYSES AND EVALUATION

Sampling Sites and Locations

The area under investigation has been historically divided into twelve coal producing districts, each district basically confined to a specific geologic structure containing the sought after coal seam or seams. The specific names of these different districts are listed in the appendix dealing with geology and their location is as shown on the accompanying map.

An effort was made to establish at least one surface site and one groundwater site within each coal mining district. This was accomplished in all but three districts: Ouita and Shinn, which only had one groundwater site each, and Bonanza-Jenny Lind, which had only surface water sites. Also, the Spadra and Scranton districts were combined as one basin. These exceptions were due to the fact that no other suitable sites for sampling could be found. Sites were initially selected based upon the perceived probability of a continuous supply of water throughout the year; however, some streams were known to be only intermittent and were chosen for lack of better sites elsewhere within the district. All but three of the groundwater sites were domestic water wells. Of the three, two were old mine shafts with flowing water and the other was a well drilled by a mining company specifically for groundwater monitoring. In total, there were nineteen (19) surface sampling sites and nineteen (19) groundwater sampling sites for a total of thirty eight (38) sampling sites.

In locating the individual sampling sites, it was attempted to place both surface and groundwater sites up and down gradient from the crop line of the major coal seams in the particular district under investigation. This would entail a minimum of four sample sites for each district. In some particular instances, these categories (up and down gradient) were further subdivided if the water flowed through an area of surface mining (past or present) prior to reaching the sample site. Only four of the districts exhibit a complete set of sample sites due to various difficulties. Some of the districts had more than four sample sites, based on a desire for some redundancy for additional data gathering purposes, and the subdividing into areas of mining or near mining. The list of sample sites in the appendix indicates the relationship of each sample site to the coal and mining activity within each district.

Sample Collections and Field Analysis

Samples were collected on a quarterly basis (every three months) beginning December/January of the 1985 fiscal year. It took approximately seven days to make a complete circuit of the area under study to collect all samples. The same procedure for storing and treating of samples was used regardless of how or where the sample was taken. This consisted of placing water which was filtered in the field through a 45 micron filter and treated with approximately two milliliters of nitric acid for preservation of metal ions into a one liter plastic bottle which was then labeled "A". A second plastic bottle was filled with unfiltered water, labeled "C" and placed in an ice chest for cold storage to preserve various anions. A third sample was placed, unfiltered, into a one pint glass mason jar, treated with two milliliters of sulfuric acid for preservation of phenols and labeled "D".

In addition to the collecting of samples which were taken back for laboratory analyses, four simple observations and tests were undertaken in the field at each site: temperature, pH, conductivity and alkalinity. These were all recorded in a field notebook, along with any pertinent observations concerning the site conditions. The results of each field observation/test for each sample have been presented along with the subsequent laboratory analyses in this appendix. All sampling and laboratory analyses were done following the guidelines established for water and wastewater by the American Public Health Association as published in their Standard Methods manual.

Surface water samples were obtained with a two and one half gallon plastic bucket attached to a fifty-foot nylon rope. The bucket was lowered over the side of the bridge and rinsed with the water to be sampled prior to taking the actual water for analysis. Groundwater samples from domestic wells were obtained through faucets which did not have the water passing through the household filtering system. This meant occasionally going directly to the pump house in order to bypass any water conditioning/filtering arrangements.

Laboratory Analysis

After the samples had been returned to the laboratory, a series of tests were conducted to determine the amount of various constituents each sample contained. These were done through the use of Hach standard reagent test kits, a Bausch and Lomb Spectronic 20 spectrophotometer and an IL 157 atomic absorption spectrophotometer (AAS) which entailed the use of both atomic absorption and atomic emission techniques. In addition, total dissolved solids were determined for each sample by oven drying a 100 ml. portion. All metallic ions (i.e. cations) were determined through the use of the AAS and have been reported in terms of milligrams per liter, which is the same as parts per million. Due to the variation in sensitivity of the different AAS cathode tubes, it was possible to determine some elements to the nearest 0.01 ppm while others only to the nearest 0.1 ppm. All the anions, as well as phenols and dissolved solids, were done with the wet chemistry methods using the Hach reagent kits.

Some sample values that are missing are due to site locations having dried up, as in the case of several streams during the summer. One water well went dry while another one had the pump break down during the sampling period. The first quarter samples were not run for silicon and aluminum because of an inability to obtain the necessary N_2O oxidant in time to run the tests before the samples became too old.

Evaluation of Analyses

The accumulated data for the duration of this study have been tabulated and are presented in the accompanying tables. In all, there were twenty-five measured parameters for each of thirty-eight different samples which were tested four times each, with a few exceptions, during the course of the year. These measurements have indicated that waters from the study area are typical of waters from other similar areas and are, with only a few exceptions, what might be expected from natural, non-polluted waters in a non-carbonate geologic environment. The exceptions just mentioned are associated with some old mine workings, mostly underground, which have contributed to slightly higher concentrations of dissolved solids and lower pH values than would be normally expected. However, even these relatively higher amounts are well below those typically found in coal mine areas of the eastern United States.

On the whole, the surface waters in this area reflect the conditions of a rapid runoff rate following rainfall events. The streams are flashy and there is little opportunity for the water to pick up soluble material in this area, and there are little, if any, pollutants generated from the small amount of local industry.

The groundwater in this area appears to be indicative of an environment in which the host material is relatively insoluble and therefore, does not contribute much in the way of dissolved solids. What little was found is apparently resulting from mineralization associated with the coal beds in this region, and indeed, much higher (relatively) values of certain ions were found to be present in and around old coal mine workings. It would appear that the predominant compounds in this water are calcium, magnesium and sodium sulfate. In two instances, a consistently larger amount of iron was detected as compared to all the other sample sites and again this appeared in conjunction with old coal mine areas. It is easy to understand the relative abundance of sulfate when considering the high pyrite (sulfur) content of the coal occurring nearby.

Sample Site Descriptives

Numbers refer to both coal district and the sample site number within that district. For example, number 32 refers to coal district 30, sample site number 2.

Coal District	Reference Number
Shinn	1010
Philpott	1020
Denning - Coal Hill	1030
Scranton - Spadra	1040
Paris	1050
Charleston	1060
Bonanza - Jenny Lind	1070
Excelsior - Greenwood	1080

Huntington - Hartford	1090
Bates	1100
Ouita	1200

Sample Site Number	Legal Description/Owner
1010	SW¼, NW¼, Sec 23, T7N, R20W Ira Shinn - domestic water well Route 1, Box 265, Russellville, Ark.
1020	NW¼, NE¼, Sec 24, T10N, R25W Roy Green - domestic water well
1022	NW¼, SE¼, Sec 21, T10N, R25W Dirty Creek at bridge
1023	NE¼, SW¼, Sec 1, T10N, R25W Cole Creek at bridge
1024	NW¼, SW¼, Sec 31, T11N, R24W Cole Creek at bridge
1030	SW¼, NW¼, Sec 21, T9N, R26W J.B. McLeroy - domestic water well P. O. Box 774, Ozark, Ark.
1031	NW¼, SW¼, Sec 21, T9N, R25W Johnny Jones - domestic water well P. O. Box 308, Coal Hill, Ark.
1032	Center, W½, Sec 23, T9N, R26W Cedar Creek at bridge
1040	SW¼, SW¼, Sec 26, T8N, R24W John Schwartz - domestic water well Route 1, Box 151, Subiaco, Ark.
1041	NW¼, SW¼, Sec 22, T8N, R24W Dwayne Sumners - domestic water well P. O. Box 42, Scranton, Ark.
1042	SW¼, NE¼, Sec 6, T9N, R22W R & S Coal Co. monitoring well - permit #318
1044	NE¼, SW¼, Sec 21, T10N, R23W Spadra Creek - farm lane crossing (private road)

1045	Center, $NW\frac{1}{4}$, Sec 33, T10N, R23W Spadra Creek - farm lane crossing (private road) George Morgan, Route 2, Clarksville, Ark.
1050	$SE\frac{1}{4}$, $SE\frac{1}{4}$, Sec 35, T8N, R27W Tom Black - domestic water well Route 2, Box 244D, Paris, Ark.
1051	$SW\frac{1}{4}$, $SW\frac{1}{4}$, Sec 14, T7N, R27W J.V. Roberson - domestic water well Route 2, Box 199, Paris, Ark.
1052	Along section line between sections 29 and 30 Sixmile Creek at bridge
1060	$N\frac{1}{2}$, $NW\frac{1}{4}$, Sec 21, T7N, R28W Norbert Adams - domestic water well Route 3, Box P56, Charleston, Ark.
1061	$NE\frac{1}{4}$, $SW\frac{1}{4}$, Sec 3, T7N, R29W Robert Corley - domestic water well Route 3, Box 73A, Charleston, Ark.
1062	$SE\frac{1}{4}$, $NE\frac{1}{4}$, Sec 2, T6N, R28W Sixmile Creek at bridge
1063	$SE\frac{1}{4}$, $SE\frac{1}{4}$, Sec 18, T7N, R27W Sixmile Creek at bridge
1070	$NW\frac{1}{4}$, $NW\frac{1}{4}$, Sec 5, T6N, R31W Bear Creek at bridge
1071	$SW\frac{1}{4}$, $SE\frac{1}{4}$, Sec 29, T7N, R31W Bear Creek at bridge
1072	Center of western section line of the $SW\frac{1}{4}$, Sec 27, T7N, R31W Bear Creek at bridge
1080	$SE\frac{1}{4}$, $NE\frac{1}{4}$, Sec 17, T6N, R30W Edward Pillar - domestic water well Route 2, Box L E 12, Greenwood, Ark.
1081	Center, $W\frac{1}{2}$, Sec 27, T5N, R31W Mid-State Mining Co. - vertical shaft being pumped
1082	$NW\frac{1}{4}$, $NE\frac{1}{4}$, Sec 3, T5N, R32W Eugene Branum - domestic water well Route 1, Box 849, Hackett, Ark.

1083	NE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec 21, T6N, R32W Big Branch, alongside county road
1084	SW$\frac{1}{4}$, SE$\frac{1}{2}$, Sec 16, T6N, R32W Big Branch at bridge
1085	Center, S$\frac{1}{2}$, Sec 31, T7N, R30W Vache Grasse Creek at bridge, inside Ft. Chaffee
1086	SW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec 5, T6N, R30W Vache Grasse Creek at bridge
1090	NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec 28, T5N, R31W George Kitchens - domestic water well Route 1, Box 539, Huntington, Ark.
1091	SE$\frac{1}{4}$, SW$\frac{1}{4}$, Sec 21, T5N, R31W William Holstein - domestic water well Route 1, Box 537, Huntington, Ark.
1092	N$\frac{1}{2}$, NW$\frac{1}{4}$, Sec 33, T5N, R31W No. 6 Mine vertical shaft (abandoned)
1093	SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec 6, T4N, R31W James Fork River at bridge
1094	NW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec 32, T5N, R31W James Fork River at bridge
1100	SW$\frac{1}{4}$, NE$\frac{1}{4}$, Sec 21, T3N, R32W Shadley Creek at ford
1101	SW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec 15, T3N, R32W Harvey Parker - domestic water well Route 1, Box 326, Waldron, Ark.
1201	NE$\frac{1}{4}$, NE$\frac{1}{4}$, Sec 22, T8N, R21W Martin Jacob - domestic water well Route 3, Box 212, Russellville, Ark.

Sample Site Number	Site Type
1010	down gradient well
1020	down gradient well - mined area
1022	down gradient stream - mined area
1023	down gradient stream
1024	up gradient stream
1030	up gradient well
1031	down gradient well - mined area
1032	down gradient stream
1040	up gradient well
1041	down gradient well
1042	down gradient well - mined area
1044	down gradient stream
1045	up gradient stream
1050	down gradient well
1051	up gradient well
1052	down gradient stream
1060	down gradient well
1061	up gradient well
1062	up gradient stream
1063	down gradient stream
1070	up gradient stream
1071	down gradient stream
1072	down gradient stream - mined area
1080	down gradient well
1081	down gradient shaft - mined area
1082	up gradient well
1083	down gradient stream
1084	up gradient stream
1085	down gradient stream - mined area
1086	up gradient stream
1090	down gradient well
1091	up gradient well
1092	down gradient shaft - mined area
1093	up gradient stream
1094	down gradient stream
1100	down gradient stream - mined area
1101	down gradient well
1201	down gradient well

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Hach Company, Procedures for Water and Wastewater Analysis, 2nd ed., Loveland, 1984.

ANALYSES OF WATER SAMPLES

	pH				TEMPERATURE °C.			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	7.5	5.9	6.2	6.2	12.0	20.0	20.0	17.0
20	6.7	6.0	6.6	6.5	4.0	18.0	18.0	18.0
22	6.9	6.4	6.9	6.4	11.0	15.0	24.0	15.0
23	6.3	5.2	-	-	9.5	17.0	-	-
24	5.9	5.0	-	-	8.0	16.0	-	-
30	8.4	-	-	-	12.0	-	-	-
31	6.9	5.7	6.8	6.3	15.0	6.0	17.0	18.0
32	7.4	5.9	5.2	5.9	14.0	18.0	28.0	-
40	5.5	5.0	6.5	6.6	16.0	16.0	17.0	18.0
41	6.1	6.5	6.9	7.1	10.0	19.0	21.0	20.0
42	4.5	-	6.6	6.1	13.0	-	17.0	18.0
44	7.4	5.8	6.8	7.6	4.0	18.0	22.0	25.0
45	7.1	6.3	6.8	8.2	5.0	19.0	25.0	22.0
50	6.5	6.6	6.4	6.8	18.0	19.0	18.0	18.0
51	7.0	6.4	6.0	6.3	13.0	16.0	17.0	19.0
52	6.6	6.2	6.8	6.9	11.0	23.0	26.0	24.0
60	7.5	7.3	6.9	6.9	17.0	17.0	18.0	18.5
61	7.2	6.7	6.7	6.7	21.0	17.0	17.0	19.0
62	7.4	5.9	6.5	-	10.0	19.0	21.0	-
63	8.3	5.9	6.5	7.0	10.0	19.0	23.0	23.0
70	5.9	6.5	6.0	6.5	1.0	23.0	23.0	21.5
71	5.7	7.2	7.2	7.6	6.0	17.0	18.0	19.0
72	5.7	6.8	6.7	6.5	5.0	17.0	23.0	20.0
80	6.4	6.8	6.6	7.2	7.0	17.0	21.0	22.0
81	7.5	6.0	5.5	5.6	10.0	16.0	17.0	16.0
82	7.5	7.0	6.3	6.8	17.0	18.0	17.0	17.0
83	6.3	8.2	6.4	6.6	6.0	23.0	22.0	14.0
84	7.5	8.8	6.4	6.5	8.0	24.0	25.0	11.0
85	7.0	6.2	6.2	6.8	9.0	19.0	22.0	20.5
86	8.0	6.5	6.4	6.8	10.0	18.0	25.0	20.0
90	6.4	5.0	5.1	-	15.0	16.0	17.0	-
91	6.7	5.9	5.5	6.2	15.0	17.0	17.0	17.0
92	4.5	5.0	5.1	4.2	15.0	17.0	17.0	17.0
93	8.1	6.0	6.3	6.7	6.0	17.0	25.0	14.0
94	7.0	6.0	5.9	6.4	7.0	19.0	25.0	15.5
100	5.5	6.6	5.7	6.5	11.0	18.0	24.0	20.0
101	6.6	7.4	6.0	7.1	11.0	19.0	24.0	18.5
201	7.2	8.3	8.1	-	9.0	17.0	23.0	-

	SPEC. COND. (UMHOS)				ALKALINITY (mg/L)			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	-	280	280	340	-	137.0	171.2	154.0
20	2700	510	450	400	-	205.0	308.1	240.0
22	-	300	420	370	-	68.5	154.1	110.0
23	-	37	-	-	-	13.7	-	-
24	-	21	-	-	-	13.7	-	-
30	-	-	-	-	-	-	-	-
31	1600	260	260	190	-	154.0	171.2	151.0
32	-	80	90	64	-	20.5	34.2	27.0
40	170	130	200	260	30	34.2	102.7	120.0
41	2600	490	480	460	-	257.0	273.9	240.0
42	140	-	84	130	-	-	54.8	68.0
44	-	38	48	60	-	13.7	51.4	17.0
45	-	53	48	110	-	13.7	20.5	17.0
50	1200	1100	1100	820	130	445.0	547.8	445.0
51	960	670	1100	1000.	160	120.0	171.2	154.0
52	140	100	220	200	30	-	68.5	86.0
60	950	100	860	810	150	394.0	393.7	291.0
61	2200	1900	1800	1800	90	428.0	393.7	394.0
62	86	75	140	-	30	27.4	47.9	-
63	110	82	170	60	0	34.2	68.5	51.0
70	140	210	180	860	-	47.9	61.6	51.0
71	470	560	75	620	-	164.0	287.6	325.0
72	2700	430	520	350	-	110.0	171.2	17.0
80	2600	430	420	310	-	291.0	70.0	223.0
81	280	300	480	600	70	85.6	102.7	154.0
82	450	390	370	390	130	239.7	222.5	223.0
83	85	150	140	400	0	47.9	68.5	137.0
84	79	120	110	90	30	27.4	41.1	51.0
85	110	91	145	220	40	41.1	110.0	120.0
86	115	65	145	220	90	27.4	90.0	120.0
90	63	38	50	-	-	13.7	51.4	-
91	440	470	400	360	100	75.3	119.8	86.0
92	900	850	680	620	-	27.4	51.4	26.0
93	115	78	110	190	-	20.5	34.2	68.0
94	150	190	180	460	-	34.2	34.2	43.0
100	50	175	280	1000	0	34.2	34.2	27.0
101	225	890	820	900	80	393.7	410.8	419.0
201	2200	650	600	-	-	376.6	325.2	-

SAMPLE #	CHLORIDE (mg/L) QUARTER 1	2	3	4	CYANIDE (μg/L) QUARTER 1	2	3	4
10	6.0	0	16.0	61.5	0	3.8	.2	1.0
20	24.0	21.0	13.0	16.0	0	0	1.1	0
22	2.5	2.0	2.5	11.0	0	2.1	.3	0
23	2.0	6.0	-	-	0	3.2	-	-
24	3.0	2.0	-	-	0	1.9	-	-
30	34.5	-	-	-	30.0	-	-	-
31	12.0	12.5	10.5	12.5	0	4.2	.4	0
32	6.0	5.5	7.0	5.5	2.0	8.1	0	6.2
40	17.0	11.0	17.5	21.0	0	14.9	0	0
41	8.0	8.0	7.5	11.0	0	9.0	0	1.4
42	2.0	-	3.0	3.5	0	-	0	0.7
44	2.5	3.6	3.5	5.0	0	3.8	3.6	2.4
45	2.5	4.0	3.5	4.0	0	1.9	3.1	6.1
50	6.5	29.5	2.5	11.0	0	7.2	0	0.5
51	35.0	2.5	42.5	10.5	0	6.7	5.7	0
52	5.5	3.0	6.5	12.0	0	7.7	5.9	2.6
60	22.0	12.5	11.0	11.0	0	0	0	0
61	43.5	45.0	47.5	52.0	9.0	0	1.5	0
62	4.5	3.5	5.0	-	0	10.7	0	-
63	6.0	3.5	7.0	1.0	38.0	9.8	0	0
70	7.5	11.0	13.0	31.4	0	4.2	3.5	5.5
71	12.0	11.5	11.5	2.0	0	4.2	13.6	2.2
72	11.0	10.0	11.5	7.5	4.3	3.0	.7	1.4
80	11.0	15.5	6.5	9.5	0	3.2	.3	0
81	4.0	4.0	2.5	8.0	0	0	3.0	0
82	7.0	8.0	7.0	9.5	0	3.2	.5	0
83	4.5	6.0	6.5	26.5	0	4.2	1.4	0
84	3.5	5.0	5.0	8.5	0	4.2	0	0
85	5.5	3.5	5.5	14.0	9.0	3.2	3.5	2.6
86	8.0	4.0	7.0	18.5	0	3.2	28.7	8.6
90	5.0	2.5	2.5	-	0	0	1.9	-
91	3.5	5.5	5.0	7.0	0	0	50.5	20.1
92	2.5	2.5	2.5	4.5	0	0	63.5	14.6
93	1.5	1.5	4.5	5.0	0	0	4.1	0
94	3.0	3.5	4.0	6.0	0	0	13.6	2.4
100	4.8	4.0	7.5	18.0	4.0	0	2.1	0
101	20.8	51.0	53.0	20.5	4.0	0	.5	0
201	2.5	10.0	7.5	-	0	3.8	6.5	-

	FLUORIDE (mg/L)				NITRATE (mg/L)			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	.33	.33	.36	.24	3.08	1.93	.61	.03
20	.58	.29	.35	.26	2.64	1.07	0	.05
22	.27	.21	.50	1.17	6.82	.88	0	.07
23	.12	0	-	-	6.16	.90	-	-
24	0	.11	-	-	3.52	.77	-	-
30	1.09	-	-	-	.20	-	-	-
31	.63	.16	.26	1.32	0	.31	0	.03
32	.27	.06	.49	.20	9.46	3.19	.27	.38
40	.38	.16	.22	.30	19.40	2.38	.70	.03
41	.63	.37	.36	.34	.40	0	.97	.07
42	.42	-	.24	1.29	1.16	-	0	.09
44	.22	.06	.13	.40	6.16	.94	.25	.09
45	.22	0	.12	.15	.83	.78	.20	.12
50	.61	.30	.52	.79	0	.15	14.30	.06
51	.68	.55	.45	.75	.17	0	.31	.06
52	.22	.16	.19	.21	1.05	.96	.93	.10
60	.48	.27	.41	.92	12.80	1.26	.74	.11
61	.73	.57	.72	.92	22.00	23.58	43.12	3.40
62	.22	.06	.16	-	-	.47	.90	-
63	.43	.11	.38	.16	.11	.53	1.05	.03
70	.33	.15	.19	.15	.42	.10	.50	.09
71	.48	.38	.62	.49	.33	.71	1.40	.12
72	.53	.27	.45	.48	.46	.63	.40	.09
80	.43	.24	.28	.18	.53	1.23	2.00	.40
81	.48	.23	.19	1.52	.52	.87	.90	.03
82	.48	.24	.45	.21	.08	0	.36	.05
83	.35	.27	.25	.14	.60	.21	.40	.04
84	.30	0	.21	.28	.70	.76	.73	.24
85	.17	.08	.22	.29	.43	1.06	1.04	.03
86	.22	.03	.20	.23	.20	1.03	.67	.05
90	.33	0	.16	-	25.17	2.55	12.90	-
91	.48	.93	.18	.33	.04	0	.64	.07
92	.73	.45	.19	.87	.04	.16	0	.01
93	.43	.02	.16	.17	.28	.75	.24	.05
94	.35	.08	.16	.33	.26	3.83	1.03	.04
100	.63	.02	.17	1.15	.45	0	.55	.02
101	.63	.78	.23	1.56	1.00	0	1.04	.06
201	.63	.35	.42	-	.32	.47	.92	-

SAMPLE #	PHENOL (µg/L) QUARTER 1	2	3	4	SULFATE (mg/L) QUARTER 1	2	3	4
10	20.0	1.5	4.2	171.0	16.4	10.3	15.7	10.4
20	0	0	13.7	0	24.8	24.8	21.8	11.2
22	30.0	1.8	9.7	0	124.4	21.8	110.1	109.0
23	8.0	2.4	-	-	7.5	9.2	-	-
24	0	3.2	-	-	4.3	9.2	-	-
30	2.0	-	-	-	4.4	-	-	-
31	0	1.6	10.6	0	0	6.0	6.9	7.5
32	2.0	2.3	8.6	34.0	6.8	11.8	11.1	11.2
40	10.0	3.1	8.3	81.0	16.4	21.4	11.2	8.0
41	0	1.6	0	204.0	4.3	3.4	7.1	7.5
42	0	-	9.7	0	7.5	-	15.1	12.7
44	20.0	12.9	0	55.0	8.5	8.4	8.4	8.4
45	2.0	1.5	4.0	67.0	6.2	8.2	7.8	4.9
50	10.0	4.7	0	169.0	123.5	117.3	86.6	73.6
51	10.0	3.6	2.9	122.0	154.0	66.6	270.4	236.0
52	30.0	9.3	4.0	42.0	24.5	19.7	24.5	30.9
60	4.0	3.6	0	2.0	82.0	95.9	80.9	106.0
61	10.0	9.1	11.6	0	250.4	317.3	344.7	451.0
62	30.0	2.9	13.2	-	12.0	16.8	22.4	-
63	30.0	2.0	9.7	52.0	23.6	16.0	18.8	12.6
70	0	6.8	8.3	11.0	18.2	23.6	20.0	39.3
71	9.1	4.5	0	3.0	42.4	52.8	79.7	94.6
72	13.6	13.7	0	91.0	54.1	62.7	71.9	221.0
80	4.5	0	4.0	8.0	5.3	9.2	6.1	6.4
81	2.2	1.8	13.7	5.0	47.0	76.1	167.3	166.0
82	4.5	-	0	7.0	5.3	5.4	4.1	4.3
83	6.8	4.0	2.9	6.0	12.7	15.7	13.5	31.1
84	14.1	.4	11.6	107.0	12.0	14.2	3.2	15.3
85	20.0	4.7	13.7	94.0	23.6	12.6	14.9	21.9
86	20.0	3.6	13.2	12.0	15.8	12.3	14.0	13.7
90	4.5	16.6	9.7	-	6.2	10.5	9.1	-
91	9.1	10.0	8.6	11.0	115.5	123.5	100.0	89.0
92	11.4	.9	10.6	5.0	256.4	229.0	253.8	267.0
93	9.5	5.4	9.7	15.0	23.9	16.9	24.1	36.9
94	1.1	18.7	27.0	8.0	30.3	42.0	38.2	208.0
100	10.0	26.8	0	13.0	5.5	37.8	112.8	414.0
101	10.0	129.0	0	5.0	2.7	4.1	7.7	6.2
201	0	0	0	-	6.2	7.9	14.0	-

SAMPLE #	TOTAL DISSOLVED SOLIDS (mg/L) QUARTER 1	2	3	4	SODIUM (mg/L) QUARTER 1	2	3	4
10	212	180	185	372	22.0	21.9	32.8	23.8
20	272	277	310	286	37.9	41.5	92.8	46.2
22	300	219	299	245	15.2	11.7	22.9	28.0
23	22	28	-	-	1.2	1.7	-	-
24	22	20	-	-	1.8	3.8	-	-
30	452	-	-	-	185.1	-	-	-
31	208	209	203	189	42.4	42.3	62.1	52.2
32	73	56	55	368	7.9	5.6	0	4.0
40	477	111	142	126	14.6	13.3	34.6	30.0
41	293	292	299	288	110.0	108.8	86.0	99.6
42	50	-	181	86	5.9	-	31.6	16.0
44	35	30	26	29	1.9	2.1	4.0	5.0
45	37	28	24	39	2.2	2.1	5.0	4.0
50	924	423	609	557	106.1	52.8	76.0	138.1
51	942	547	704	533	65.4	39.4	47.2	80.7
52	520	90	107	136	8.3	6.0	15.6	23.5
60	1124	529	541	439	193.7	208.4	69.0	163.1
61	1393	989	1019	980	244.2	247.4	83.6	223.4
62	638	73	79	-	6.1	5.6	10.7	-
63	500	70	109	46	6.9	5.7	29.4	9.3
70	88	119	118	783	10.0	16.2	22.8	88.8
71	240	257	417	559	55.6	106.8	66.0	175.8
72	262	281	301	437	58.6	61.4	52.4	27.5
80	238	234	261	302	78.4	77.5	53.2	190.5
81	163	195	349	395	7.2	8.7	31.2	25.7
82	262	234	243	244	40.1	38.4	21.6	43.2
83	149	16	82	266	5.6	9.5	23.3	56.7
84	73	69	60	69	5.9	8.7	12.5	6.3
85	744	65	83	230	8.8	6.8	14.7	30.0
86	410	52	91	227	8.5	6.3	13.4	26.2
90	49	54	25	-	3.0	2.4	10.4	-
91	290	322	272	278	8.1	9.4	17.5	8.4
92	612	573	515	512	16.2	18.8	24.6	15.2
93	109	62	82	124	5.5	5.0	10.1	11.0
94	123	110	109	157	6.5	8.5	13.7	24.4
100	35	95	225	721	3.5	11.8	43.4	194.7
101	107	474	469	495	30.1	162.7	80.0	168.5
201	345	357	375	-	139.2	145.5	75.0	-

SAMPLE #	POTASSIUM (mg/L) QUARTER 1	2	3	4	CALCIUM (mg/L) QUARTER 1	2	3	4
10	1.32	.98	.81	.85	9.16	7.82	1.20	12.60
20	3.80	4.31	4.70	3.58	2.03	30.21	2.10	19.80
22	1.38	1.38	2.50	1.55	3.02	25.50	3.00	35.60
23	.62	.71	-	-	.24	.24	-	-
24	.67	.70	-	-	.29	.33	-	-
30	.68	-	-	-	2.27	-	-	-
31	.68	.57	.92	.63	1.09	2.88	.90	8.70
32	1.97	1.80	-	5.92	1.35	1.15	-	8.00
40	5.14	4.08	2.80	2.72	1.33	.79	.80	15.90
41	.51	.36	.79	.47	1.25	.94	.30	5.10
42	.34	-	.55	.89	.22	-	.30	2.60
44	.83	.67	1.07	1.49	.77	.48	.30	2.10
45	.85	.69	1.07	1.40	.75	.48	.30	2.20
50	3.52	1.89	3.50	3.11	3.30	30.42	5.80	52.80
51	1.65	3.51	3.20	1.42	3.24	49.46	5.00	39.60
52	1.58	1.90	3.20	.02	4.03	2.60	.90	9.00
60	1.07	.76	.94	.71	2.00	1.01	.40	2.30
61	1.87	2.34	5.00	1.13	2.98	29.52	3.10	25.20
62	1.25	1.49	1.82	-	1.63	1.45	.70	-
63	1.63	1.43	.21	2.21	2.64	1.53	.90	63.00
70	.99	1.93	2.80	18.08	1.67	3.34	.70	72.00
71	1.52	2.23	2.50	2.48	2.34	18.30	2.40	28.20
72	1.52	2.28	2.50	2.64	2.38	12.74	1.90	21.60
80	1.21	1.45	1.74	1.36	1.39	9.15	1.30	12.60
81	1.78	2.38	2.00	2.85	12.60	17.79	2.80	37.80
82	.84	.83	.90	.76	28.88	28.59	2.60	34.70
83	1.54	2.02	5.00	4.52	1.40	5.54	.70	23.70
84	1.51	1.95	2.90	3.21	2.76	4.36	.60	8.10
85	1.30	1.34	.80	5.08	2.47	1.88	.70	16.10
86	1.14	1.15	1.70	2.86	1.83	1.54	.70	18.20
90	1.54	1.04	1.33	-	.51	.34	.10	-
91	1.19	1.40	1.29	1.00	2.62	6.43	1.80	13.10
92	2.76	3.25	2.10	2.23	2.69	23.28	2.70	22.10
93	1.09	1.35	2.10	2.65	2.15	1.10	.50	8.10
94	1.20	1.66	1.30	2.76	4.61	3.13	.80	24.60
100	1.19	1.62	1.00	3.44	.64	2.34	1.30	27.70
101	1.92	1.79	2.00	1.54	2.57	6.14	1.10	12.80
201	.41	.15	1.97	-	.24	.09	.02	-

	SILICON (mg/L)				MAGNESIUM (mg/L)			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	N/A	9.4	4.9	8.9	16.6	2.6	10.2	13.1
20		10.1	7.4	9.3	22.6	3.6	12.2	16.9
22		3.6	2.9	2.2	28.8	3.3	20.0	26.2
23		3.4	-	-	.6	.3	-	-
24		4.2	-	-	.7	.4	-	-
30		-	-	-	.9	-	-	-
31		20.0	21.2	12.7	2.5	2.8	10.4	4.7
32		4.7	-	0	2.9	2.4	-	3.5
40		5.8	6.9	7.9	3.8	2.1	4.3	9.7
41		13.2	1.8	9.0	1.2	.5	7.6	4.2
42		-	6.6	6.3	.8	-	8.5	4.2
44		3.7	0	3.1	1.7	1.1	4.1	2.4
45		4.8	1.9	2.4	1.6	1.1	4.0	2.1
50		9.7	1.5	5.3	26.0	4.6	18.0	16.4
51		6.2	9.3	4.3	35.5	3.5	26.0	47.4
52		4.0	1.3	3.1	5.8	3.7	3.8	9.4
60		9.3	3.8	5.8	3.5	1.0	8.5	1.2
61		8.0	1.0	3.9	58.6	7.8	33.1	40.2
62		4.0	2.3	-	3.8	2.8	10.3	-
63		4.0	2.9	1.7	3.7	2.8	3.8	2.3
70		4.6	1.9	0	4.7	5.3	7.9	39.4
71		3.4	3.5	3.6	12.6	10.4	10.3	16.4
72		3.9	4.7	3.6	12.1	9.9	16.2	19.7
80		9.2	6.5	7.4	7.9	6.2	18.9	4.1
81		4.1	4.0	3.3	17.3	3.3	26.4	42.2
82		15.5	11.6	11.4	11.8	8.0	3.5	11.3
83		0.8	1.0	2.3	3.0	4.2	15.4	16.4
84		2.0	2.9	2.1	3.1	3.8	9.5	4.1
85		2.5	0	10.2	4.1	2.9	16.0	10.4
86		7.3	2.1	12.3	.3	2.4	13.8	14.7
90		6.3	1.0	-	2.4	1.1	9.0	-
91		13.8	6.3	10.3	25.0	3.9	24.8	22.5
92		13.5	7.9	7.9	37.8	5.3	29.6	32.4
93		7.5	2.2	1.0	5.9	2.8	14.9	9.5
94		2.8	3.7	3.6	7.4	6.6	5.3	31.8
100		3.7	3.9	3.3	1.6	5.2	17.0	34.0
101		8.9	5.6	4.1	5.3	7.9	10.9	8.3
201		4.3	2.7	-	.1	0	.2	-

SAMPLE #	CADMIUM (mg/L) QUARTER 1	2	3	4	COPPER (mg/L) QUARTER 1	2	3	4
10	0	0	0	0	.03	0	0	0
20	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	0	0	0	-	0	0	-	-
24	0	0	-	-	0	0	-	-
30	0	-	-	-	0	-	-	-
31	0	0	0	0	0	0	0	0
32	0	0	-	0	0	0	-	.03
40	0	0	0	0	.35	.23	.07	.03
41	0	0	0	0	.01	0	.01	0
42	0	-	0	0	0	-	0	.02
44	0	0	0	0	.01	0	0	0
45	0	0	0	0	0	0	0	0
50	0	0	0	0	.02	0	.01	.02
51	0	0	0	0	.01	0	0	0
52	0	0	0	0	.01	0	0	.01
60	0	0	0	0	0	0	0	0
61	0	0	0	0	.02	0	.03	0
62	0	0	0	0	.01	0	.04	0
63	0	0	0	0	0	0	.02	.01
70	0	0	0	0	0	0	.01	.02
71	0	0	0	0	0	0	0	0
72	0	0	0	0	.01	0	.01	0
80	0	0	0	0	0	0	0	0
81	0	0	0	0	.02	0	.02	0
82	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	.12	0
84	0	0	0	0	0	0	.03	0
85	0	0	0	0	0	0	.04	0
86	0	0	0	0	.01	0	.12	.02
90	0	0	0	0	.02	0	.18	0
91	0	0	0	0	0	0	0	0
92	.01	0	0	0	0	0	0	0
93	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	.05	0
100	0	0	0	0	.01	0	0	0
101	0	0	0	0	.01	0	0	0
201	0	0	0	0	0	0	.05	0

	LEAD (mg/L)				MANGANESE (mg/L)			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	0	0	0	0	.41	.27	.44	.39
20	0	0	0	0	0	.02	-	.49
22	0	0	0	0	.02	.02	.07	.03
23	0	0	-	-	0	.01	-	-
24	0	0	-	-	0	.04	-	-
30	0	-	-	-	.03	-	-	-
31	0	0	0	0	0	.01	.21	.22
32	0	0	-	0	.03	.01	-	1.46
40	0	0	0	0	.01	.08	.06	.17
41	0	0	0	0	.02	.01	.04	.04
42	0	-	0	0	0	-	.06	.21
44	0	0	0	0	.01	.04	.06	.04
45	<.1	0	0	0	0	.09	.02	.30
50	0	0	0	0	.07	.83	.48	.42
51	0	0	0	0	.23	.06	2.72	1.71
52	0	0	0	0	0	.05	.01	.63
60	0	0	<.1	0	.03	.03	.08	0
61	0	0	0	0	0	.02	.16	.06
62	0	0	0	-	.04	.12	0	-
63	0	0	0	0	0	.06	.06	.12
70	0	0	0	0	.05	.13	.88	2.62
71	0	0	0	0	.10	.05	0	.17
72	0	0	0	0	0	.61	1.02	4.36
80	0	0	0	0	0	.07	0	.03
81	0	0	0	0	0	.01	1.02	1.06
82	0	0	.1	0	0	.14	.09	.10
83	0	0	0	0	0	.04	0	1.14
84	0	0	0	0	.01	.07	.04	.55
85	0	0	0	0	0	.13	.21	.78
86	0	0	0	0	.01	.12	.12	.47
90	0	0	0	0	.02	.06	.18	-
91	0	0	0	0	.22	.91	1.20	.98
92	0	0	<.1	0	0	2.23	3.37	2.67
93	0	0	0	0	0	.04	.07	.09
94	0	0	0	0	.01	.16	.18	.20
100	0	0	0	0	0	.08	.16	.12
101	0	0	0	0	.04	.03	.11	.04
201	0	0	0	0	0	.04	0	-

	NICKEL (mg/L)				SILVER (mg/L)			
	QUARTER				QUARTER			
SAMPLE #	1	2	3	4	1	2	3	4
10	0	0	0	0	0	.02	0	0
20	0	0	.08	0	0	0	0	0
22	.04	0	0	0	0	.03	0	0
23	.02	0	-	-	0	0	-	-
24	.03	0	-	-	0	0	-	-
30	0	-	-	-	0	-	-	-
31	0	0	.01	0	0	0	0	0
32	0	0	-	0	.01	0	0	0
40	.01	0	0	0	0	.01	0	0
41	.12	0	.07	0	0	.05	0	0
42	.03	-	.04	0	0	-	0	0
44	.02	0	.04	0	0	.01	0	0
45	.02	0	.04	0	0	.02	0	0
50	0	0	0	0	0	0	0	.03
51	0	0	.02	0	0	.01	0	0
52	.02	0	.04	0	0	0	0	.04
60	.01	0	.08	0	0	0	0	0
61	0	0	.04	0	0	.02	0	0
62	.02	0	0	0	0	0	0	0
63	0	0	.05	0	0	.02	0	0
70	.01	0	0	0	0	0	0	0
71	.01	0	.01	0	0	0	0	0
72	0	0	.04	0	0	.03	0	0
80	0	0	0	0	0	0	0	0
81	.01	0	.04	0	0	.01	0	0
82	0	0	0	0	0	0	0	0
83	0	0	0	0	0	0	0	0
84	.03	0	.07	0	0	.01	0	0
85	0	0	.04	0	0	0	0	0
86	.02	0	.07	0	.02	0	0	0
90	.04	0	.05	0	0	.01	0	0
91	0	0	.07	0	0	0	0	0
92	.08	.05	.09	0	0	.03	0	0
93	.02	0	.01	0	0	.02	0	0
94	0	0	.07	0	0	0	0	.03
100	0	0	.06	0	0	0	0	0
101	0	0	.07	0	0	.02	0	0
201	0	0	.06	0	0	0	0	0

SAMPLE #	ZINC (mg/L) QUARTER 1	2	3	4	IRON (mg/L) QUARTER 1	2	3	4
10	.61	0	.16	0	1.0	.3	3.3	3.4
20	.19	0	.07	.05	.1	0	.7	2.7
22	.23	0	.04	0	0	0	0	0
23	.20	0	-	-	0	.3	-	-
24	.21	0	-	-	0	.2	-	-
30	.12	-	-	-	.1	-	-	-
31	.04	0	0	0	2.3	.3	3.0	3.2
32	.05	0	-	.17	0	.2	0	.5
40	.30	.02	.11	0	0	.3	.4	.6
41	.04	0	.04	0	.8	.2	.7	0
42	.13	-	.37	0	0	-	.6	.8
44	.04	0	.06	0	0	1.3	.4	.6
45	0	0	.04	0	0	.4	.4	1.1
50	.55	0	.04	0	2.2	.1	11.0	0
51	1.05	0	.04	0	1.1	.1	12.0	12.0
52	.94	0	.04	0	.1	1.0	.4	.4
60	.93	0	.05	0	.1	0	.4	0
61	.41	0	.07	0	0	.3	.6	0
62	.24	0	.10	0	0	0	.6	-
63	.02	0	.11	0	0	0	.4	.1
70	0	0	.07	.08	.2	.2	.6	.7
71	.03	0	0	.05	.5	.2	.1	.1
72	.04	0	.04	.15	0	0	.6	1.4
80	.03	0	0	0	.1	.2	0	.6
81	.80	0	.22	0	.1	.3	.9	7.0
82	.98	0	.04	.08	.4	.9	.7	.7
83	.87	0	.14	.06	.1	0	0	1.0
84	.92	0	.10	0	0	.3	.5	.7
85	.77	0	.12	0	0	0	.4	.7
86	.76	0	.33	0	.1	.5	.6	.9
90	.90	0	.26	0	.2	.2	1.0	-
91	.75	0	.02	.63	14.6	13.9	12.0	12.0
92	.48	0	.10	0	47.1	23.4	4.0	27.0
93	.71	0	.04	0	.1	.5	.5	.5
94	.95	0	.20	0	0	.1	.5	.4
100	.60	0	.03	0	0	0	.5	.1
101	.29	0	.04	0	0	0	1.2	1.0
201	0	0	.05	0	0	0	0	-

ALUMINUM (mg/L)

SAMPLE #	QUARTER 1	2	3	4
10	N/A	.01	0	0
20		0	0	0
22		.20	0	0
23		.07	-	-
24		.58	-	-
30		-	-	-
31		0	0	0
32		.58	0	2.00
40		.04	0	2.00
41		0	0	0
42		-	.40	0
44		.35	0	0
45		.24	0	0
50		.46	0	0
51		.14	0	0
52		.77	0	0
60		.46	0	0
61		.34	0	0
62		.34	0	-
63		.83	0	0
70		.50	0	0
71		.40	0	0
72		.01	.25	2.00
80		0	0	0
81		0	0	0
82		.02	0	0
83		.55	0	0
84		.23	0	0
85		.59	0	0
86		.02	0	0
90		.41	.15	-
91		.20	0	0
92		.38	1.10	0
93		.68	.40	0
94		.05	0	0
100		.18	0	0
101		.29	0	0
201		.05	0	-

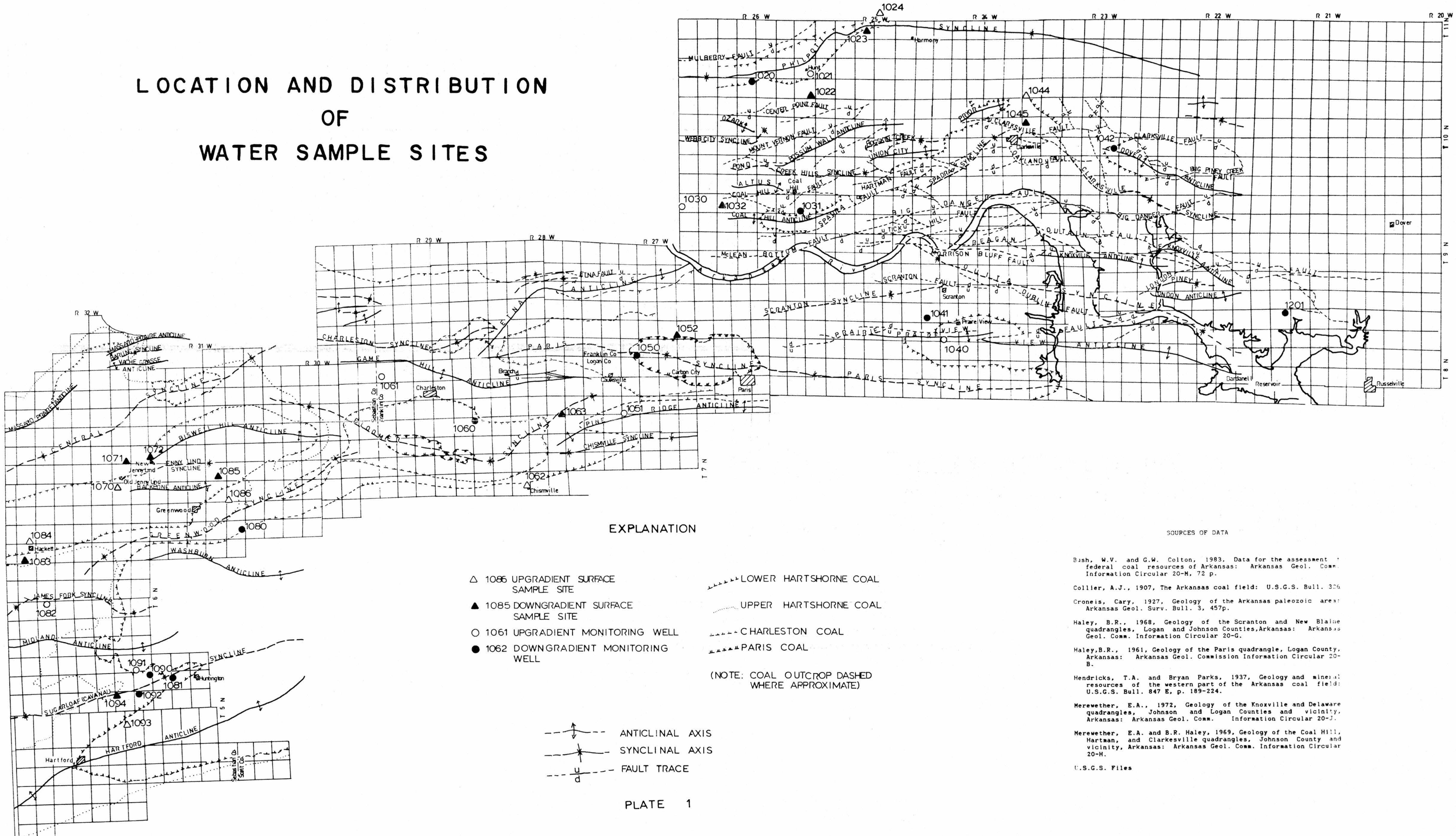
SUMMARY OF FINDINGS AND RECOMMENDATIONS

There are no pristine areas underlain by coal in the Arkansas Valley Coal Field that have not yet been inspected by either surface and/or underground mining of coal since this activity began in commercial form in about 1870. Thus, it can be stated with a degree of certainty that water, be it surface or underground or associated with the coal-bearing sub-basins, (districts), has already been affected by mining. Yet, despite extensive mining in each of the 12 districts, most of the coal originally counted as resources is still in place and, therefore, it is assumed that when economics are favorable, production of coal will continue to a greater or lesser degree.

While water samples were taken at widely dispersed sites and under varying geologic conditions, no markedly radical conditions were noted in analyses that would render the water unsuitable for some purpose, be it agriculture and industry related. On the other hand, potable water within individual sub-basins is scarce because of lack of available quantity and fairly high levels of iron, manganese, sulfate and a pH on the acid side. Thus, to make this water suitable for human consumption expensive treatment programs must be adopted. This treatment would require reduction of calcium, magnesium, sodium sulfate and iron.

It is, in finality, doubtful that additional mining will have a further deleterious effect on the water resources associated with the coal sub-basins in the Arkansas Valley Coal Field. However, stringent adherence to regulations governing water resources invoked by both State and Federal regulations must be followed on a continuing basis.

LOCATION AND DISTRIBUTION OF WATER SAMPLE SITES



EXPLANATION

- △ 1086 UPGRADIENT SURFACE SAMPLE SITE
- ▲ 1085 DOWNGRADIENT SURFACE SAMPLE SITE
- ○ 1061 UPGRADIENT MONITORING WELL
- ● 1062 DOWNGRADIENT MONITORING WELL

- LOWER HARTSHORNE COAL
- UPPER HARTSHORNE COAL
- CHARLESTON COAL
- PARIS COAL

(NOTE: COAL OUTCROP DASHED WHERE APPROXIMATE)

- ANTICLINAL AXIS
- SYNCLINAL AXIS
- u/d FAULT TRACE

PLATE 1

SOURCES OF DATA

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