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Depositional Environment, Stratigraphy, and Vertical Hydraulic Conductivity of the St. Francois Confining Unit in the Fristoe Unit of the Mark Twain National Forest, Missouri

Water-Resources Investigations Report 00–4037

Prepared in cooperation with the
U.S. Department of Agriculture, Forest Service,
U.S. Department of the Interior, Bureau of Land Management,
U.S. Environmental Protection Agency, and
Missouri Department of Conservation

U.S. Department of the Interior
U.S. Geological Survey

Cover Photograph: Carbonate and shale rock core samples from exploration holes in the Fristoe Unit of The Mark Twain National Forest

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By Michael J. Kleeschulte[1] and Cheryl M. Seeger[2]

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Rolla, Missouri
2000

[1]U.S. Geological Survey
[2]Missouri Department of Natural Resources

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
1400 Independence Road
Mail Stop 100
Rolla, MO 65401

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

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Abstract

The confining ability of the St. Francois confining unit was assessed in six townships (T25-27N and R03-04W) of the Fristoe Unit of the Mark Twain National Forest in Oregon and Shannon Counties of southeastern Missouri. This was accomplished by describing the depositional environment and stratigraphy of the confining unit, and quantifying the vertical hydraulic conductivity of rock core samples from the confining unit using laboratory techniques. Stratigraphic data for this study were obtained by analysis of 238 exploration borehole core logs and rock core from exploration boreholes that typically described a 600- to 800-foot interval from near the bottom of the Potosi Dolomite into the Lamotte Sandstone or Precambrian basement rock.

Faulting created a Precambrian highland area (St. Francois Mountains) and basins; erosion gave the Precambrian igneous knobs an irregular shape. This erosion and a marine transgression with continued deposition of clastic material led to the accumulation of sediments that formed the Lamotte Sandstone. Transgression caused shelf drowning and gradual development of a large intrashelf basin with a narrow, discontinuous rim (lowermost Bonneterre Formation) which allowed the carbonate-dominant facies to form. The transition from shaley deposits with a limited stromatolite zone to carbonate with more frequent stromatolites suggest a general shallowing of the sequence as the Bonneterre Formation was deposited.

The Bonneterre Formation-Davis Formation contact denotes abrupt intrashelf basin development that was filled during cycles of transgression and shallowing. The intrashelf basin likely had a wide, continuous shelf rim producing the shale-dominant Davis Formation. The Derby-Doerun Dolomite was formed during a pair of carbonate depositional cycles. The basal shaley sequence represents a transition with the Davis Formation.

Thirty-three exploration holes penetrated Precambrian knobs that appear to intercept two linear structures or ridges that trend northwest-southeast. These knobs generally protrude less than 200 feet above the surrounding Precambrian basement rock; however, some knobs along both of these ridges extend more than 500 feet above the surrounding basement rock.

The greatest thicknesses of the Lamotte Sandstone are 50 to 60 feet and it is present throughout the study area, except where it pinches out against some Precambrian knobs. The depth from land surface to the top of the Lamotte Sandstone, where present, ranges from 1,552 to 2,450 feet with an altitude ranging from a high of 502 feet below sea level to a low of 1,600 feet below sea level. Both of the Precambrian ridges can be

[1]U.S. Geological Survey
[2]Missouri Department of Natural Resources

identified as prominent structural high features or domes.

Algal reef zones in the upper part of the lower Bonneterre Formation are common and are well-defined digitate stromatolites; reef zones reach thicknesses of 100 feet. The depth from land surface to the top of the Bonneterre Formation ranges from 1,358 to 2,002 feet, and the altitude of the top of the formation ranges from 278 below sea level to 1,152 feet below sea level. The formation generally dips to the south or southeast. Evidence for the two Precambrian ridges in the study area can again be observed as domed features.

The Davis Formation is composed of interbedded shales and carbonate, with both shale- and carbonate-dominant sequences and ranges from less than 50 to more than 300 feet thick. The Davis Formation carbonates primarily are limestone, with dolostone at the top and base of the formation. The shales restricted the flow of dolomitizing fluids from reaching most Davis Formation limestones. The depth from land surface to the top of the Davis Formation ranges from 1,171 to 1,692 feet and the altitude of the top of the formation ranges from 200 to 878 feet below sea level. The structure map is similar to that of the top of the Bonneterre Formation, with the presence of the two linear highs in the study area and the dip of the formation to the south.

The Derby-Doerun Dolomite is composed of mudstones, grainstones, and mudstone-matrix boundstones. Thin shales are present throughout but shale content and bed thickness increases near the contact with the Davis Formation. The depth from land surface to the top of the Derby-Doerun Dolomite ranges from 970 to 1,598 feet, and the altitude of the top of the formation ranges from 18 feet above sea level to 788 feet below sea level. The Derby-Doerun Dolomite structure map is similar to that of the Davis Formation with the two structural highs in the study area and the general slope of the formation to the south.

The thickness of the St. Francois confining unit generally ranges from 250 to 375 feet in the study area. The net shale thickness of the St. Francois confining unit ranges from less than 50 feet in the northeast part of the study area to more than 150 feet in the southwest.

Laboratory vertical hydraulic conductivity and porosity analysis were performed on 88 core samples primarily representing the various rock types present in the St. Francois confining unit of the Fristoe Unit and the Viburnum Trend. Vertical hydraulic conductivity ranged from 8.70×10^{-8} foot per second for one sample to less than 3.17×10^{-14} foot per second (the reporting limit) for 39 samples. The porosity values ranged from a high of 17.47 percent to a low of 0.36 percent. There did not appear to be a strong correlation between the vertical hydraulic conductivity and porosity.

There is no significant difference (p-value = 0.375) between the ranked vertical hydraulic conductivity of samples collected from the Derby-Doerun Dolomite and Davis Formation in the Fristoe Unit. The interquartile range of vertical hydraulic conductivity shown for the Derby-Doerun Dolomite samples has more than an order of magnitude greater span than the interquartile range shown for the Davis Formation samples.

In the Viburnum Trend, there is a statistically significant difference (p-value = 0.006) between the ranked vertical hydraulic conductivity of the Derby-Doerun Dolomite and Davis Formation. Although the vertical hydraulic conductivity of both formations is small, the median vertical hydraulic conductivity of the Derby-Doerun Dolomite is more than an order of magnitude greater than the median vertical hydraulic conductivity for the Davis Formation.

There is no statistically significant vertical hydraulic conductivity difference (p-value = 0.790) in ranked samples from the Fristoe Unit containing carbonate or shale or both rock types. This is also true when comparing ranked samples containing carbonate or shale or both rock types from the Viburnum Trend (p-value = 0.412), even though carbonate rocks have more than an order of magnitude greater median vertical hydraulic conductivity than shales.

The net shale thickness is not the single controlling factor that determines the effectiveness of the confining unit. Because the vertical hydraulic conductivity of the carbonate rocks and shales in the confining unit are similar, the entire carbonate-shale thickness is important in determining the effectiveness of the confining unit.

The estimated range of effective vertical hydraulic conductivity for the St. Francois confining unit in the study area was calculated to be a maximum of 1×10^{-12} foot per second and a minimum of 3.0×10^{-14} foot per second. These vertical hydraulic conductivity values are small allowing the St. Francois confining unit to effectively impede the flow of ground water between the Ozark aquifer and the St. Francois aquifer, unless preferred-path secondary permeability has developed along faults and fractures.

INTRODUCTION

Lead and zinc exploration in the Fristoe Unit of the Doniphan/Eleven Point Ranger District of the Mark Twain National Forest (hereinafter referred to as the Fristoe Unit) in southeastern Missouri has been ongoing since the 1960s. In the late 1970s and early 1980s, the search intensified, resulting in several hundred exploration holes being drilled in the Fristoe Unit. This exploration focused on a possible southern extension of the Viburnum Trend (fig. 1) ore deposits located about 20 miles to the north.

In 1983, as a result of the exploratory drilling, two Preference Right Leases were submitted for areas in the Fristoe Unit. After the Preference Right Leases were submitted, the U.S. Department of Agriculture, Forest Service (Forest Service) and the U.S. Department of the Interior, Bureau of Land Management (BLM) made the decision to prepare an Environmental Impact Statement (EIS). The EIS study area was enlarged to include 119,000 acres of the Fristoe Unit that had reasonable potential for mineral leasing proposals (U.S. Department of Agriculture, Forest Service and U.S. Department of Interior, Bureau of Land Management, 1988).

After the EIS was completed, mining companies focused their attention on a smaller area of the Fristoe Unit (prospecting area; fig. 1), south of Winona. The prospecting area lies within a larger region of well-developed karst terrain with an extensive network of solution-enlarged fractures ranging from small channels to large conduits. The two largest springs in Missouri are in this area--Big Spring, which has an annual mean discharge of 447 cubic feet per second [(ft^3/s); Hauck and others, 1997], and Greer Spring which has an annual mean discharge of 346 ft^3/s (Hauck and others, 1999). Discharge from these springs helps sustain flow in two nationally designated streams; Big Spring flows into the Current River (Ozark National Scenic Riverway) and Greer Spring flows into the Eleven Point River (Eleven Point National Scenic River). The potential for lead-zinc mining in this environmentally sensitive karst area has concerned the Forest Service and BLM in regard to possible impacts that mining may have on the water resources of the area. The concerns include but are not limited to the effects that mine dewatering may have upon shallow water resources.

Predominantly carbonate rock sequences of the Lower Ordovician and Upper Cambrian Series (Jefferson City Dolomite to the base of the Lamotte Sandstone) overlie the igneous granites and rhyolites of the Precambrian basement rock in the study area (fig. 2). The formations from the Jefferson City Dolomite to the Eminence Dolomite are predominant at land surface; these rocks, together with the Potosi Dolomite, form the Ozark aquifer, which is a primary source of water for private and public-water supplies and major springs (Imes and Emmett, 1994). The St. Francois confining unit lies beneath the Ozark aquifer and consists of the Derby-Doerun Dolomite and the Davis Formation. This confining unit impedes the circulation of water between the overlying Ozark aquifer and the underlying St. Francois aquifer, which consists of the Bonneterre Formation (the potential host formation for lead-zinc deposits; Wharton, 1975) and the Lamotte Sandstone. Little is known about the hydrology of the St. Francois aquifer because the shallower Ozark aquifer is a reliable source of ground water for the area. The geologic names used in this report follow the nomenclature used by the Missouri Department of Natural Resources, Division of Geology and Land Survey (DGLS).

The Bonneterre Formation is the potential host formation for lead-zinc deposits in the prospecting area. This formation is part of the St. Francois aquifer and the top of this formation is at depths greater than 1,300 feet in the prospecting area. Before potential lead-zinc deposits can be extracted, the mine area will have to be dewatered. If the overlying St. Francois confining unit is leaky, mine dewatering could result in lowering water levels in the shallow Ozark aquifer. Because the prospecting area is a possible extension of the Viburnum Tend, where lead-zinc mining is currently (2000) active, the geology and depositional environment in these two areas during Late Cambrian time when these formations were deposited may be similar.

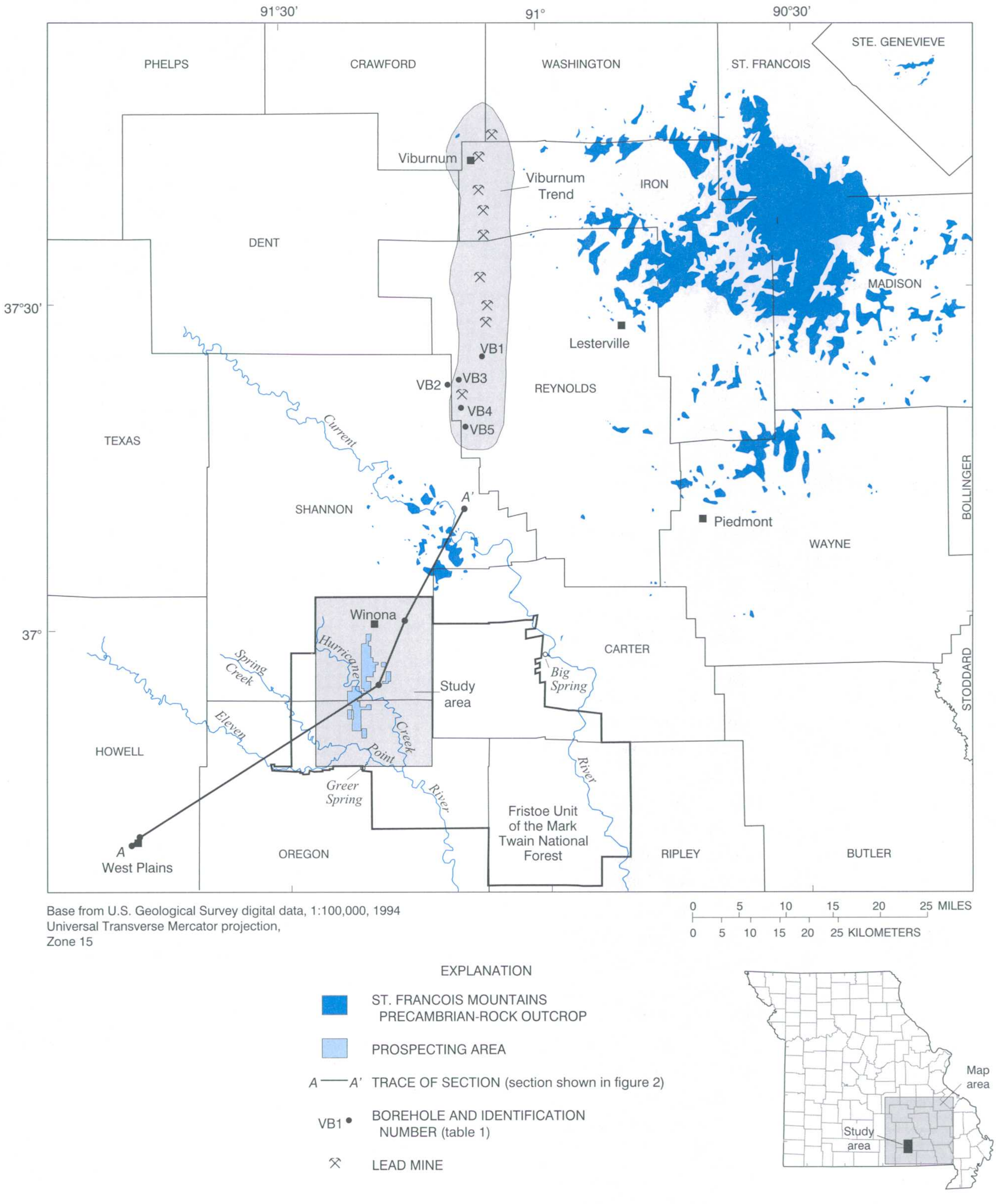


Figure 1. Location of study area, Viburnum Trend, Precambrian-rock outcrops in the St. Francois Mountains, and the prospecting area.

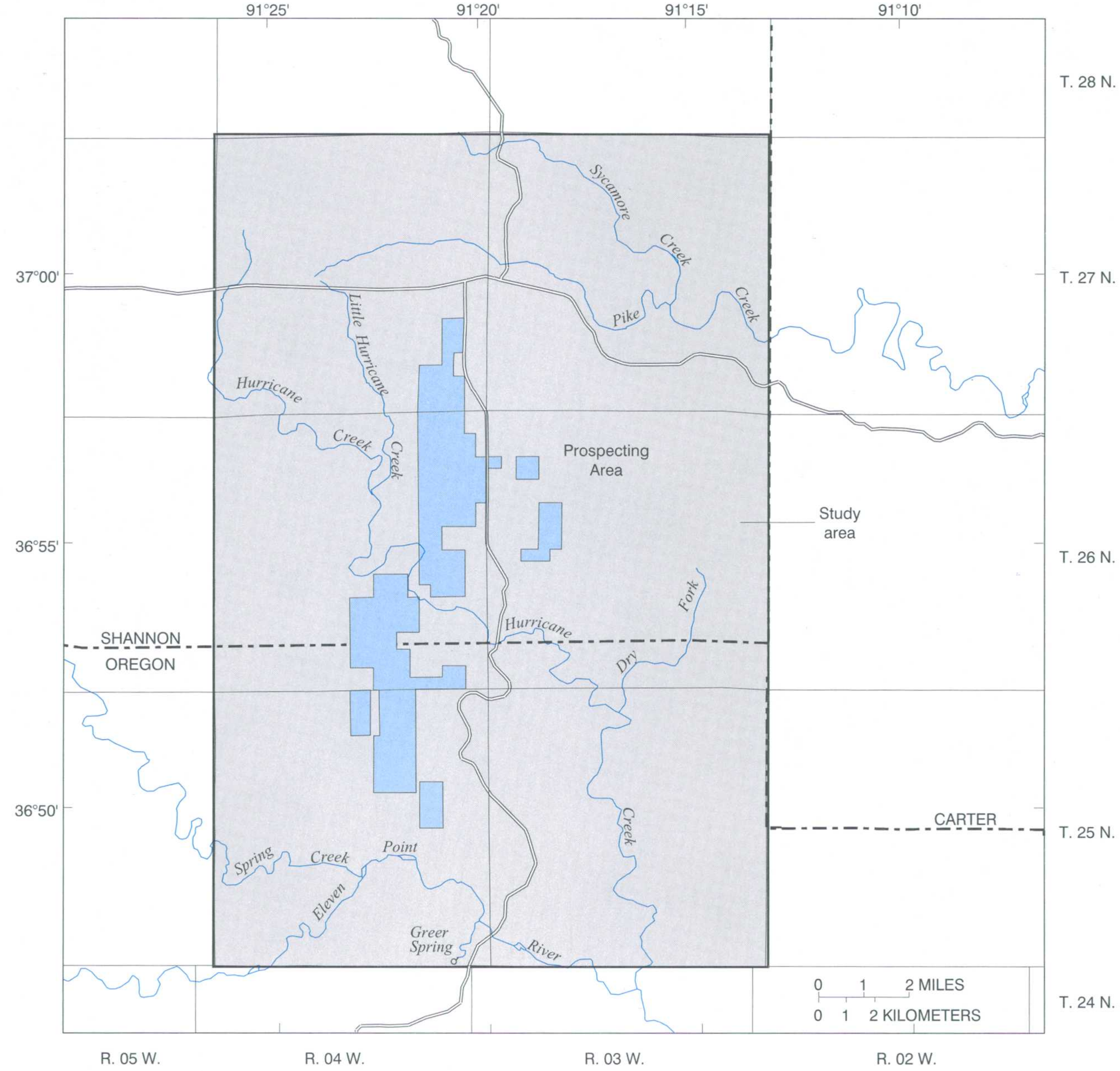


Figure 1. Location of study area, Viburnum Trend, Precambrian-rock outcrops in the St. Francois Mountains, and the prospecting area—Continued.

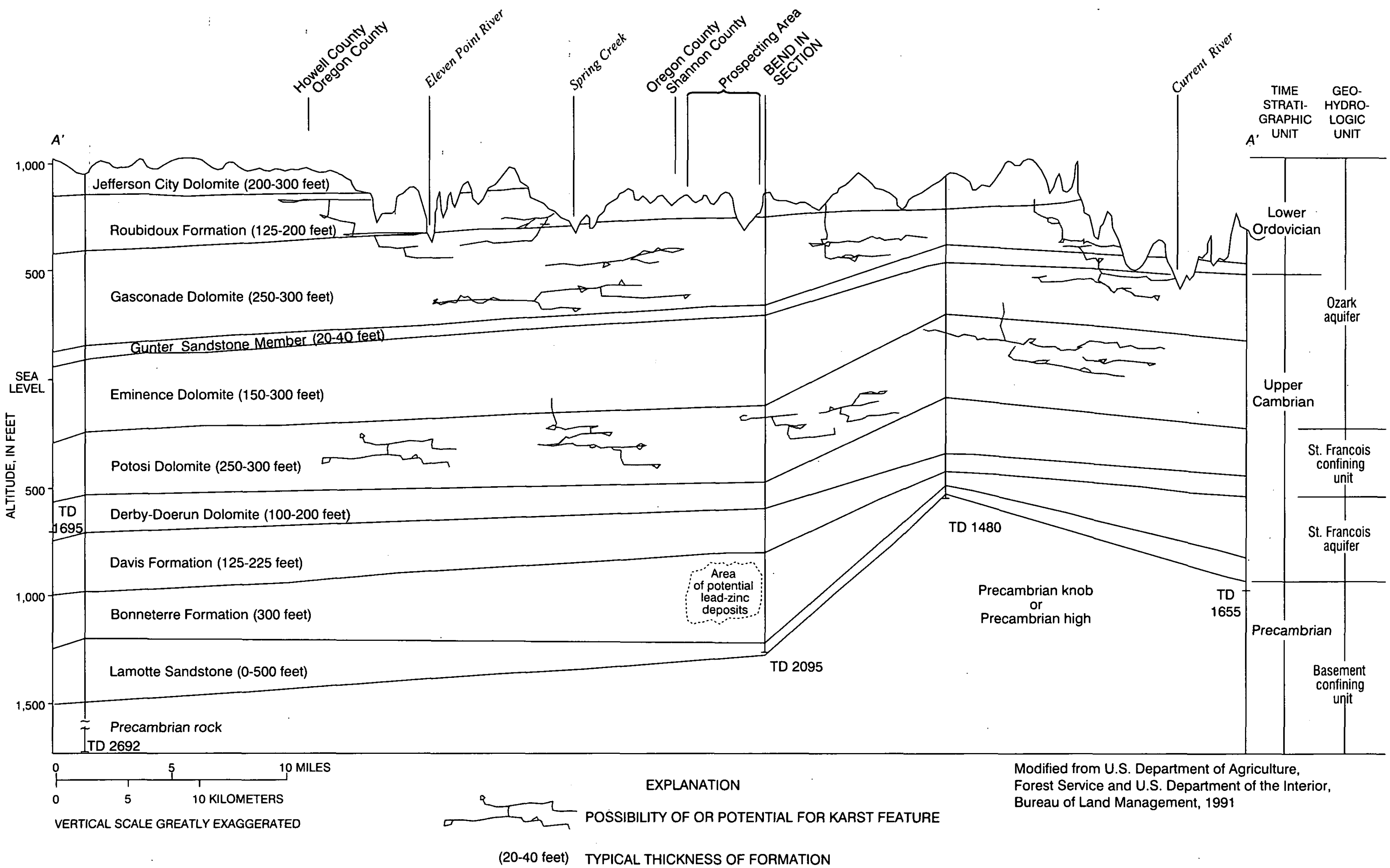


Figure 2. Generalized geohydrologic section from western Howell County to eastern Shannon County across the prospecting area (trace of section is shown in figure 1).

Extensive studies performed in the Viburnum Trend by Palmer (1991) and Thacker and Anderson (1979) indicate the environment that existed when the St. Francois confining unit was deposited affects the mud content of deposited sediments, which in turn affects the confining ability of the formations.

In 1990, the first of several consecutive geohydrologic studies was started in and adjacent to the Fristoe Unit. As a result of these studies, baseline hydrologic information was collected (Kleeschulte and Sutley, 1995) to help understand the natural flow rates of streams, water quality in surface and ground water, ground-water level fluctuations, and ground-water flow in the aquifers. Ground-water-level mapping and dye-trace studies have shown the presence of a ground-water trough between Hurricane Creek, which is adjacent to the prospecting area, and Big Spring. This indicates the possible presence of a large-permeability conduit system in the area that supplies water to Big Spring from the Hurricane Creek Basin (Imes and Kleeschulte, 1995).

In 1995, the U.S. Geological Survey (USGS) and the DGLS began a study in the prospecting area that supplements the geohydrologic studies that have already been completed in the Fristoe Unit. This study was preformed in cooperation with the Forest Service, BLM, U.S. Environmental Protection Agency, and the Missouri Department of Conservation.

The purpose of this study was to determine the depositional environment, stratigraphy, and vertical hydraulic conductivity of the St. Francois confining unit to assess the confining ability of the confining unit in an area centered on the prospecting area. However, the scope of the project was expanded to include the formations of the St. Francois aquifer. The Bonneterre Formation (part of the St. Francois aquifer) has a transitional contact with the overlying Davis Formation of the St. Francois confining unit. By including a description of the formations of the St. Francois aquifer, the entire interval from the Precambrian basement rock to the Davis Formation was considered. A better understanding of the effectiveness of the confining unit in the area was obtained by also analyzing the vertical hydraulic conductivity of rock core from five boreholes (VB1-VB5; fig. 1) in the Viburnum Trend. The results of these analysis were used for comparison purposes with the results of the core analysis from the study area.

The overall confining ability of the confining unit could have been obtained by performing aquifer tests. However, because of the expected small hydraulic conductivity of the confining unit, the excessive depth of the confining unit, and the resulting installation costs for pumping and observation wells, this was economically prohibitive. Therefore, the alternative laboratory hydraulic conductivity analysis method was selected. It is understood that there are inherent restrictions associated with the results of the laboratory hydraulic conductivity analysis, such as the inability to account for the effects of secondary permeability features (faults and fractures) that may be present in the subsurface of the study area.

Purpose and Scope

This report assesses the confining ability of the St. Francois confining unit in six townships (T25-27N and R03-04W) of the Fristoe Unit of the Mark Twain National Forest in Oregon and Shannon Counties of southeastern Missouri. The first objective of this report was to describe the depositional environment of the St. Francois confining unit. This information was interpreted from descriptions on mining company borehole and water well logs, and from detailed logging of five borehole cores from the study area on file at the DGLS McCracken Core Facility in Rolla, Missouri. This discussion was expanded to include the St. Francois aquifer.

The second objective of the report was to describe the stratigraphy of the St. Francois confining unit. This not only included describing physical rock characteristics but also geologic structure and formation thickness. After the stratigraphic data were compiled, structure maps were prepared depicting the altitude of the top of formations in the St. Francois aquifer and confining unit. Other maps show the thickness of the St. Francois confining unit and the areal distribution of cumulative shale thicknesses (net shale thickness) in the confining unit.

The third objective of this report was to quantify the vertical hydraulic conductivity of rock core samples from the St. Francois confining unit in the study area. This was achieved by performing laboratory vertical permeability analyses on rock cores from exploration holes. Ground water obtained from the Bonneterre Formation was used as the transmitting fluid during the analysis, allowing the vertical permeability to be converted to vertical hydraulic conductivity.

Study Area

Data for this report were collected from a four-county area of southeastern Missouri. However, the area of intense data collection (study area) for the core log and laboratory vertical hydraulic conductivity analysis consists of six townships (T25-27N and R03-04W) in the Fristoe Unit of Shannon and Oregon Counties. Core log data also were collected beyond the study area perimeter to aid in contouring formation structure; this expanded area included part of western Carter County (fig. 1). For comparison purposes, laboratory vertical hydraulic conductivity analysis also were performed on rock core samples from boreholes in the Viburnum Trend area in Shannon and Reynolds Counties.

Exploration Borehole Data

Several hundred exploration holes have been drilled by numerous mining companies during the decades of exploration for lead-zinc ore in and near the Fristoe Unit. Two hundred thirty eight exploration borehole core logs from in and near the study area were made available for study (table 1, at the back of this report) by the BLM, DGLS, and the Doe Run Company. The BLM receives copies of core logs from all exploration holes drilled on Federal lands, DGLS was donated copies of logs from several mining companies, and currently the Doe Run Company owns and operates all of the active mines in the Viburnum Trend. These sources have obtained copies of many of the exploration core logs from the various mining companies that have performed exploratory drilling in the study area. These logs provide general information such as location of the borehole, land surface altitudes at the borehole, depths to formation tops, and total depth of the hole. In some cases, the logs also provide detailed lithologic descriptions of the formations encountered from near the bottom of the Potosi Dolomite into the Lamotte Sandstone or Precambrian basement, typically an interval of 600 to 800 feet. These core logs along with a detailed study of core samples from five Amax Exploration, Inc. boreholes drilled in the study area (801-002, 801-009, 801-010, 801-016, and 801-031; table 1) provided the primary source of the detailed stratigraphic data contained in this report. Considerable interpretation was necessary in defining stratigraphy in some of the logs because of transitional lithologies and variable stratigraphic nomenclature that has been applied in the area.

In this report, the location of exploration boreholes is shown as the local well number (table 1) and follows the General Land Office coordinate system (fig. 3). According to this system, the first three sets of numbers of a hole location designate township, range, and section. The letters that follow indicate quarter section, quarter-quarter section, and quarter-quarter-quarter section. The quarter sections are represented by letters A, B, C, and D, in counterclockwise order, starting in the northeastern quadrant. Two or more exploration holes in the same division are numbered serially in the order they were inventoried.

Rock Classification According to Depositional Texture

Carbonate mud constitutes the bulk of many carbonate rock sequences. Sediment type and depositional environment (sediment deposited in calm water versus sediment deposited in agitated water) are two factors that influence the confining ability of rocks that are formed from these sediments. According to Larsen (1975), one way of classifying depositional environments is to focus on fine material that remained at the deposition site. In calm water, mud (particle size less than 20 microns) settles to the bottom and remains there, so mud-rich rocks are categorized differently than mud-free rocks, regardless of the amount and size of coarse-grained material in the rock.

Dunham (1962) defined five textural classes of carbonate rocks (fig. 4). These classes distinguish between mud-support, grain-support, and components that were bound together during deposition of the carbonate rock. These classes include:

Mudstone—Mud-supported carbonate rocks primarily composed of fine-grained carbonate mud and containing less than 10 percent grain-sized particles (quantity at which the grains become noticeable). The significance of mudstone is that it implies a calm-water or low-energy environment.

Wackestone—Mud-supported carbonate rocks in which grain-size particles are in excess of 10 percent, but are not so abundant as to support one another.

Packstone—Mud-rich carbonate rocks with grains so abundant they support one another (generally more than 65 percent grain-size particles). Grain support generally is a property of rocks deposited in an agitated-water or high-energy environment. Rocks exhibiting properties of both high- and low-energy depositional environments are peculiar. The unusual

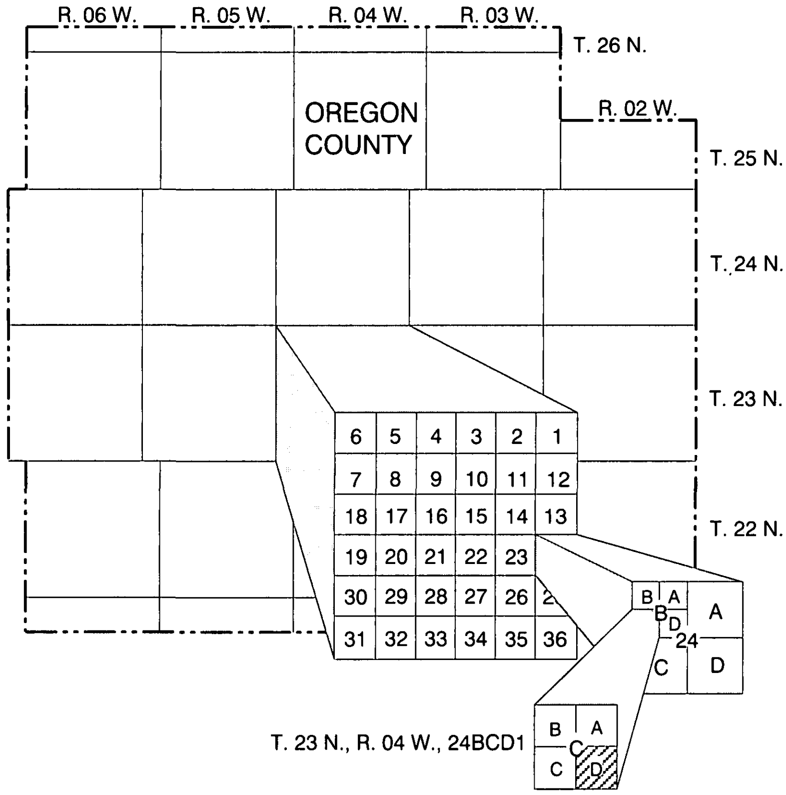


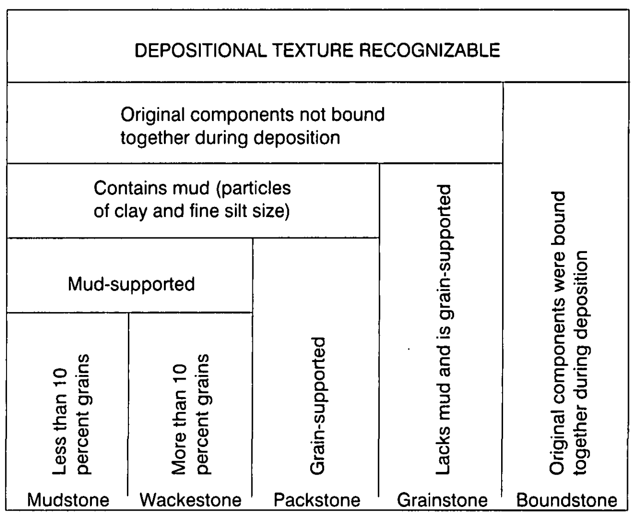
Figure 3. Well-numbering system.

properties may simply be a result of compaction of wackestone (especially where interstices are completely filled with mud), may indicate the introduction of mud-rich sediments into an area occupied by previously mud-free sediment, or may indicate the abundant production of grains in calm water.

Grainstone—Mud-free carbonate rocks that are grain-supported. Some grainstones are current laid, some are the result of mud being bypassed while locally produced grains accumulate, and some are the result of mud being winnowed from previously deposited mud-rich sediment. The class name merely denotes the absence of mud and that the grains are supported by each other.

Boundstone—Carbonate rocks that exhibit signs that the original components were bound together during deposition. These components exhibit intergrown skeletal matter (corals), lamination contrary to gravity (laminations of algal stromatolites), and cavities present on sediment floors that are too large to be interstices.

"Whiterock" is an additional term used in the lithologic descriptions and facies discussions in this report. The term originated during lead mining in southeastern Missouri and denotes back-reef (area between barrier reef structure and the exposed land mass) facies composed of planar algal stromatolites interbedded with burrowed carbonate sands and muds, with localized soft green clay (Howe, 1968). Both algal stromatolites and carbonates are bleached, dolomitized, and recrystallized to varying degrees. The back-reef facies is interpreted as representing a low-energy zone above wave base in shallow water with restricted tides and circulation (Lyle, 1977). Whiterock horizons are present in much of the Upper Cambrian Series (Eminence Dolomite through the Lamotte Sandstone) of southern Missouri.



(Dunham, 1962)

Figure 4. Dunham rock classification.

Geohydrologic Units

Delineation of geohydrologic units is based on hydraulic properties and the hydrologic relation of each unit to adjacent geohydrologic units at a regional scale. The terms aquifer and confining unit, as defined regionally, may not adequately describe the hydraulic properties of a sequence of rocks locally because of the variation in water-yielding capability of the same sequence from one area to another.

The lowermost geohydrologic unit is the Basement confining unit which is dominantly granite and rhyolite. Imes (1989) states that this confining unit is virtually impermeable. In areas where extensive faulting and fracturing has occurred Imes reports the basement confining unit can yield small quantities of water. In areas where the unit crops out, well yields are less than 10 gallons per minute.

The St. Francois aquifer (Imes, 1990c) overlies the Basement confining unit and consists of the Bonneterre Formation and the Lamotte Sandstone. In areas of southeastern Missouri near the St. Francois Mountains where this aquifer is close to land surface, it yields adequate supplies of water for domestic and small capacity public-supply wells. The thickness of the St. Francois aquifer can vary considerably because of the rugged surface of the underlying Precambrian basement rocks.

The Derby-Doerun Dolomite and the Davis Formation form the St. Francois confining unit (Imes, 1990b) that overlies the St. Francois aquifer. Imes and Emmett (1994) state in their regional study of the Ozark Plateaus aquifer system that substantial secondary porosity and permeability have not developed regionally in the St. Francois confining unit. The fine-grained nature of the formations indicates they have minimal permeability, even in areas containing little or no shale. The physical and hydraulic characteristics of the unit generally impede the circulation of ground water between the overlying Ozark aquifer and the underlying St. Francois aquifer (Imes and Emmett, 1994).

Common indicators of the effectiveness of a confining unit are the thickness and the shale content (usually a minimally permeable material) of the unit. Whereas these normally are good measures of the confining ability of a unit, other physical properties of the unit may alter the confining ability, including the degree of cementation of the rock and secondary permeability features that development in the rock such as solution channels, fractures, and faults (Imes, 1990b). Because of the depths at which these units are found in the study area, the presence of the secondary permeability features in the units could not be assessed.

Although the characterization of the Ozark aquifer is not within the scope of this report, a general description of the unit is provided to show the significance of the unit in regard to the underlying confining unit. Being the uppermost geohydrologic unit in the study area, the Ozark aquifer (Imes, 1990a) consists of rocks from the top of the Jefferson City Dolomite to the base of the Potosi Dolomite (fig. 2). This predominantly carbonate aquifer is made up of dolostone and limestone with some sandstone and is the most widely used aquifer in southern Missouri. Ground water in the aquifer generally occurs under water-table conditions, which means the upper surface of the aquifer is at atmospheric pressure, and the water is not confined by less permeable rocks.

Lead-Zinc Deposit Exploratory History

The Bonneterre Formation is the prominent host formation for the major lead-zinc deposits located in southeastern Missouri. During the prospecting and mining of lead in eastern Missouri, the close correlation that exists between the ore deposits and stratigraphic traps, structural highs, and "reef" structures was discovered (Wharton, 1975). This relation provided the rationale used during the exploration for new ore bodies in the Viburnum Trend. As the ore deposits in the Viburnum Trend were being discovered and mined, the data gathered from extensive drilling and mapping provided new information about the depositional history and regional facies relation of the formations. Exploration in the Fristoe Unit in Shannon and Oregon Counties was directed at a potential extension of the Viburnum Trend (fig. 1). Much of the extensive geologic information that has been collected in the Viburnum Trend probably is transferable to the Fristoe Unit, especially information concerning the general description of the regional geologic setting and the depositional environment of the formations. A basic understanding of these factors gives insight as to the hydrologic characteristics of subsurface structural features and facies, which influence the confining ability of geohydrologic units.

Acknowledgments

A special acknowledgment of gratitude is extended to Glenn Adams of the Doe Run Company for his assistance in obtaining rock core samples and for access to the core logs on file at the Doe Run Company. Much of the data in this report could not have been obtained without his cooperation.

DEPOSITIONAL ENVIRONMENT

The Late Cambrian depositional environments can be described only in general because of the extreme variability in the core descriptions and unequal core distribution (fewer data are available for the western one-third of the study area). For example, descriptions of the Bonneterre Formation (the target formation for mineral exploration) by different core loggers vary from brief one line descriptions to detailed descriptions several pages in length. Formations other than the Bonneterre Formation are typically described by no more than a few lines per formation. Also, various carbonate-rock classification systems such as Dunham (1962) and Folk (1959) were used. Classification of carbonates as either packstone or grainstone often is difficult without extensive petrographic work in even slightly altered limestones. Often the limestone and dolostone were not differentiated within individual cores because these data were not necessary for the mining geologist. Relogging of cores with consistent terminology would be required for a thorough characterization of depositional environments and confirmation of the interpretations provided herein.

Faulting created a Precambrian highland area (St. Francois Mountains; fig. 1) and basins, and parts of this terrane underwent extreme erosion before deposition of Upper Cambrian alluvial and marine sediments. This erosion gave the more resistant Precambrian igneous knobs an irregular shape. They typically have steep sides, but are separated by broad flat valleys and where these Precambrian knobs are present, overlying formations can be thin or missing.

The overlying Upper Cambrian sediments are composed of alluvial and fluvial clastics that grade upward into marine sandstones and carbonates and are characteristic of intershelf basin areas. These sediments were deposited during repeated cycles of marine transgressions (spreading of the sea over land areas) and subsequent shallowing. The intershelf basin was a large basinal feature that formed on the regional shelf. The intershelf basin covered much of southeastern Missouri, including the study area and the Viburnum Trend (Palmer, 1989). The deposited rock sequence in this intershelf basin area includes the following formations (in ascending order): Lamotte Sandstone, Bonneterre Formation (including the Sullivan Siltstone and Whetstone Creek Members), Davis Formation, Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite. This sedimentation in southeastern Missouri was controlled by pre-Late Cambrian uplift and erosion of the igneous basement rock, and by faulting during the Late Cambrian Epoch. Most of southern Missouri was uplifted repeatedly throughout the Paleozoic Era, which includes the Cambrian and Ordovician Systems. This is evidenced by unconformity-bounded sequences between and within nearly every system in the Paleozoic Erathem (Palmer and Seeger, 1998).

The St. Francois Mountains (located about 45 miles to the northeast of the study area; fig. 1) and Precambrian knobs affected mineralization in the Viburnum Trend. During the Late Cambrian, the Precambrian highland area was east of the Viburnum Trend and a shallow water basin was to the north and west (fig. 5). The exposed Precambrian knobs in the basin were a major influence on the marine depositional environment in the area and affected the formation of island complexes. These island complexes were conducive for the development of algal reefs which were covered by sediments that later formed the Bonneterre Formation. A simplified schematic section of a typical buried reef structure (fig. 5) in the Viburnum Trend area, shows features that probably are common to the prospecting area.

Erosion of the Precambrian highlands and a marine transgression with continued deposition of clastic material led to the accumulation of sediments that formed the Lamotte Sandstone. The Lamotte Sandstone basal conglomerate is associated with fan deposits (alluvium deposited where streams flowed onto a lowland from the Precambrian knobs) (Houseknecht and Ethridge, 1978; Yesberger, 1982). These deposits can be divided into debris flows (sandstone matrix conglomerates) and mudflows (clay matrix conglomerates). Both types of fan deposits are described in the borehole logs. Coarseness of the alluvial deposits generally decreases with distance from the Precambrian highland area. Palmer (1991a) interpreted arkosic sections as gravel-based channel deposits, sandbars, laminated sheet-flood deposits, and overbank deposits (from bottom to top through each fining-upward

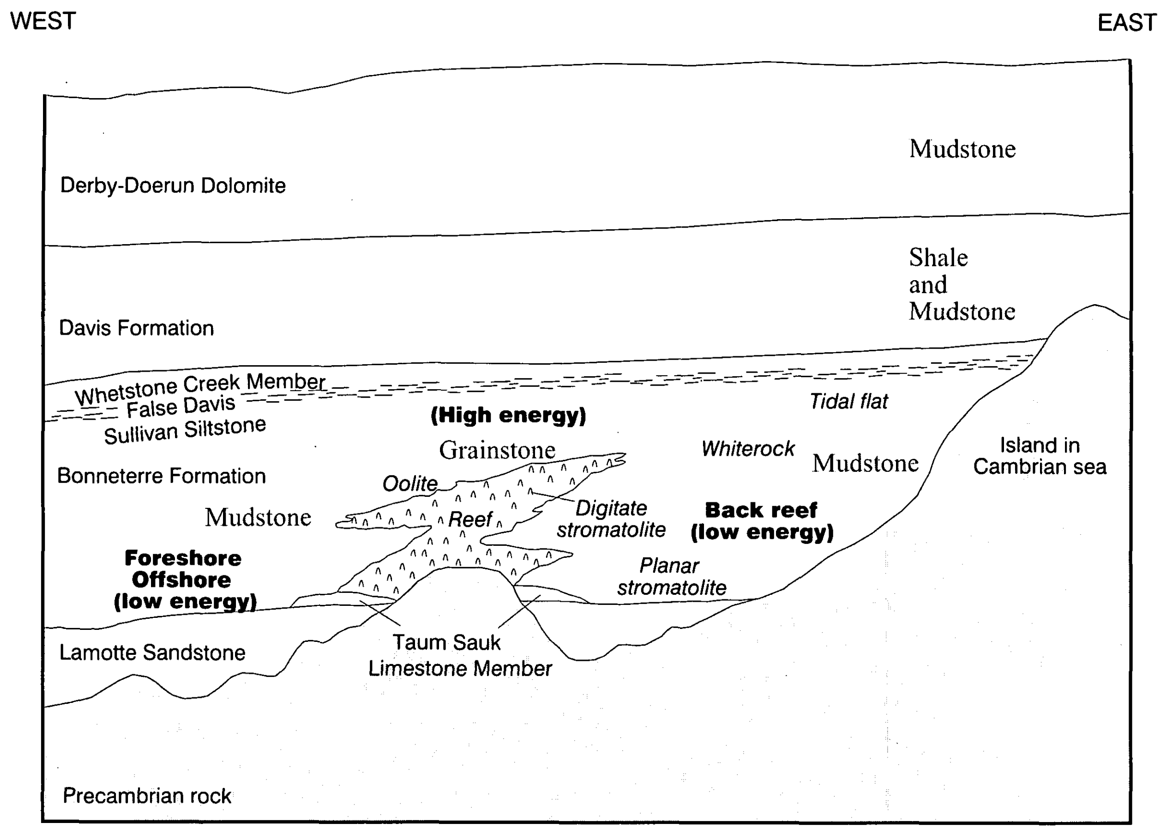


Figure 5. Schematic section of depositional conditions and lithologies showing facies development in the Viburnum Trend.

sequence). Arkosic deposits are also present near Precambrian knobs and generally these deposits thin with increased distance from knobs.

Conglomerate and arkose facies are conformably overlain by well-sorted, well-indurated (hard), fine- to medium-grained quartzose sandstone. Some cross-bedding and burrows are present in these facies. These facies are interpreted as normal marine sandstone, and may have been a near shore barrier and shallow tidal flat complex (Palmer, 1989, 1991a, 1991b).

Transgression caused shelf drowning and gradual development of a large intrashelf basin (Central Missouri Intershelf Basin) (Palmer, 1989). Interbedded sandstones and marine carbonates of the Lamotte Sandstone and Bonneterre Formation are included in sediments deposited in the transition zone where fan deltas were still active and discharged into tidal flats or shallow marine areas (Hayes and Knight, 1961; Yesberger, 1982). Differences between sandstone- and carbonate-dominated facies probably indicate distance from the clastic source (Precambrian highland area), with carbonate-dominant facies likely deposited farther from the source of the clastic material.

The lowermost shaley carbonate sequence of the Bonneterre Formation also suggests intrashelf basin deposition, when the basin margin was likely a narrow, discontinuous rim, allowing the carbonate-dominant facies to form. Interbedded shales are indicative of increased clastics coming into the basin, which periodically suppressed algal stromatolite growth. Stromatolitic zones indicate periods of limited clastic deposition and possible limited sedimentation. Between the lower shale-rich carbonates and the upper coarse crystalline dolostones, Bonneterre Formation rocks are mostly non-argillaceous (lacking clays and shales) and oolitic. The texture and alterations to the rock make identifying algal constituents in this sequence difficult and the rock is described as cryptalgal "reef" dolostones and grainstones. The transition from shaley deposits with a limited stromatolite zone to carbonate with more frequent stromatolites suggests a general shallowing of the sequence, with possible channel development. Oolitic horizons (indicative of near-shore, high-energy wave-action environment) with possible shoaling.

Arkosic zones (up to 4 feet thick) may be interpreted in several ways. If the zones are interbedded with whiterock (indicative of shallow or subaerially exposed rock) or oolitic rocks, they may be a near shore facies and suggest proximity to a Precambrian knob. Alternately, if interbedded with only white- rock, the environment may have been alluvial channels. Finally, if they are interbedded with dark-colored mud-rich dolostones, they are more likely to be grain flows (small debris flows that moved farther offshore during storm events). Most core descriptions are not in sufficient detail to determine which depositional environment was present.

Several rock sequences show a cyclic pattern of deepening, then becoming shallow with whiterock present at the top of the shallowing-upward cycles. The whiterock thins toward the basin area. Reddened hematitic (iron oxide) patches remain in many whiterock sequences and grade outward to pale olive-green clay-rich coarse-crystalline dolostone, suggesting that reddened limestones were the precursor to whiterock dolostone (Palmer, 1991a). Dissolution of the precursor limestones suggests that these areas were subaerially exposed. The Sullivan Siltstone Member is a transgressive clastic-dominated facies that occurs where the shelf surface was inclined at steeper angles. This may have been accompanied by southeastward-directed shelf subsidence that was filled with sediments that lessened the steeper angle shelf area (Larsen, 1977; Palmer, 1991a). Intraclast refers to sediments that were "torn up" by erosion, reworked, and then redeposited in the same basin to form a new sediment. Intraclast conglomerate beds are interpreted as possible storm-generated debris flow deposits that moved down slopes of only a few degrees (Palmer, 1991a). One core description in the northern part of the study area notes siltstone intraclasts, interpreted to have been formed where they were found; carbonate clasts in cores to the south are considered to have moved down slope from the source area and deposited.

The Bonneterre Formation sequence may change to nearly all limestone or all coarse crystalline dolostone in short distances. Retention of limestone in the basal part suggests that the southern and extreme northwestern parts of the study area were deeper offshore environments because generally near-shore carbonates are dominated by vuggy coarse-crystalline dolostone.

The Bonneterre Formation-Davis Formation contact denotes abrupt intrashelf basin development. The intrashelf basin continued to be filled during cycles of transgression and shallowing. The facies is a clastic sequence deposited within a regional carbonate shelf. The intrashelf basin likely had a wide, continuous shelf rim, as is suggested by the shale-dominant Davis Formation, unlike that of the basal Bonneterre Formation basin which had a narrow, discontinuous rim and carbonate-dominant facies. Horizontal burrows in the Davis Formation are suggestive of slow periodic deposition in a marine subtidal setting, where the shelf underwent gradual drowning during a slow transgression. Intraclast conglomerate beds can be interpreted as storm-generated flow deposits that presumably moved down slopes of only a few degrees or less. Individual cores with more abundant intraclast conglomerate layers suggest that those locations are near the intrashelf basin margin and consequently nearer to the source of the conglomerate. These facies tends to thin towards the geographic center of the shale depositional basins where there was less deposition.

The Derby-Doerun Dolomite was formed during a pair of carbonate depositional cycles. The formation includes sequences of thinly layered carbonate rock of differing composition (ribbon rock) that change upslope to sequences with thinner mudstone beds and thicker grainstone or packstone beds. Intraclast conglomerate beds (storm-generated debris flow deposits) presumably moved down slopes of only a few degrees. Abundant intraclast beds in individual cores may suggest that those locations were near the basin margin. The basal shaley sequence represents a transition with the Davis Formation.

Arkosic and porphyry conglomeratic material throughout the section indicates Precambrian highlands remained exposed during the Upper Cambrian carbonate deposition. Continued exposure of the Precambrian highlands may have been caused by the original height of the highlands, or be the result of continued uplift on fault-related structures.

STRATIGRAPHY

The 238 exploration boreholes from which the stratigraphic data were obtained (fig. 6) ranged from 1,478 to 2,590 feet deep. The borehole location recorded on the core log was determined either to the nearest quarter-quarter-quarter section or in feet from the north/south and east/west section line. Land surface altitudes were determined at the time of drilling using altimeters or topographic maps. The reported altitudes were verified during this study using USGS 7.5-minute

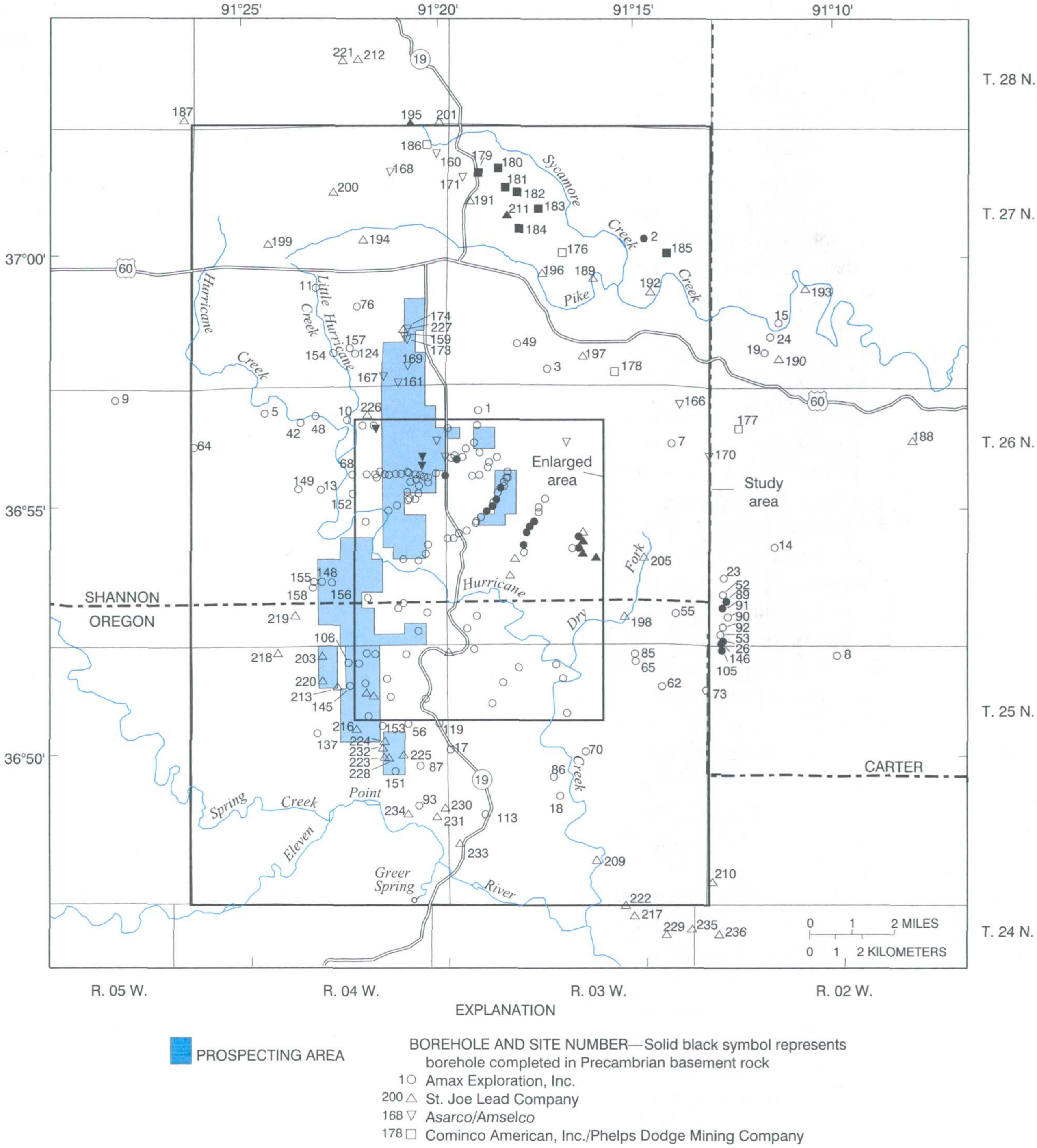


Figure 6. Location of exploration boreholes.

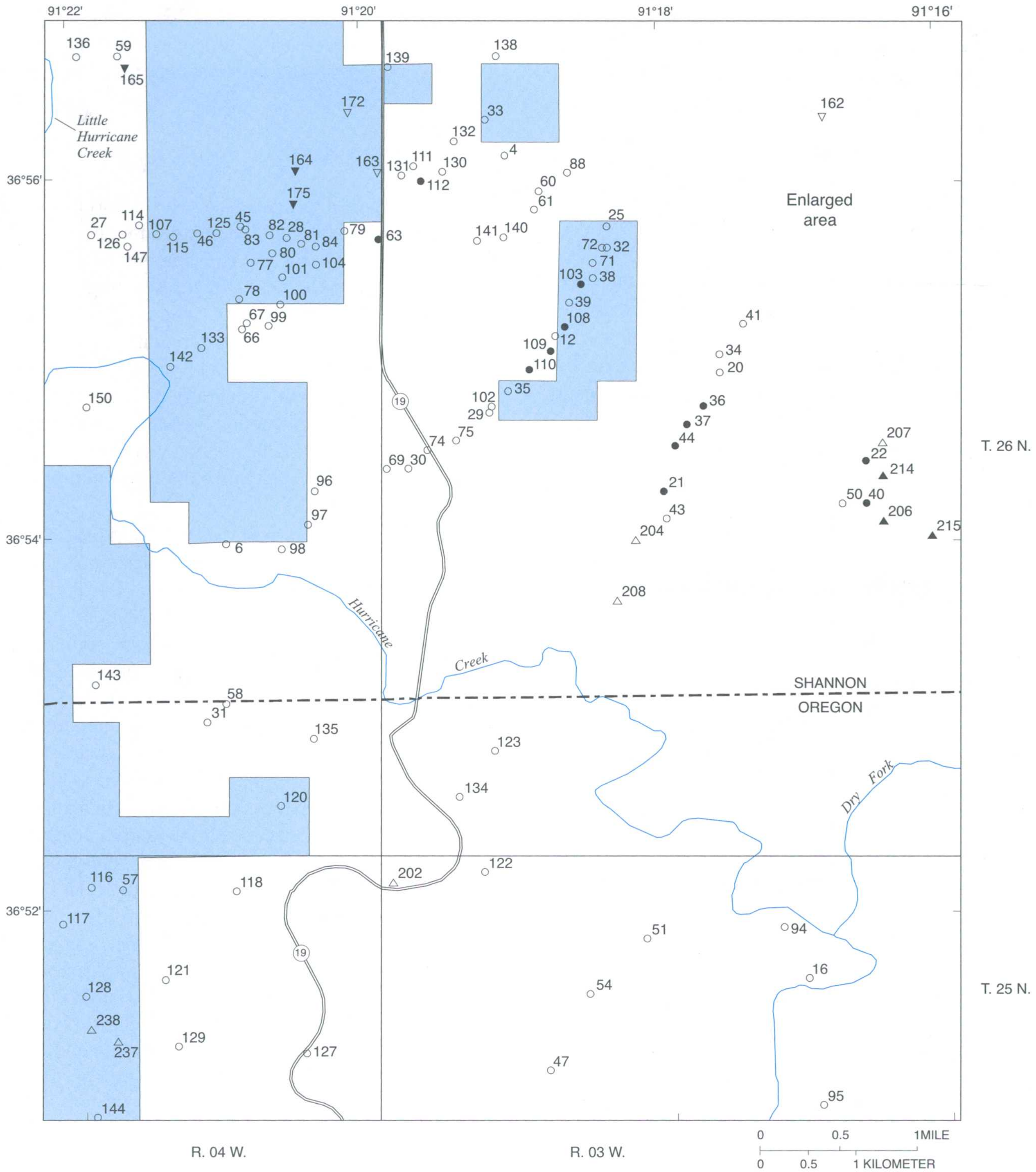


Figure 6. Location of exploration boreholes — Continued

topographic maps that generally had contour intervals of 20 feet, making the land surface altitude accurate to about 10 feet (one-half the contour interval). In a few instances, the reported land surface altitudes on the core log did not agree with the land surface altitudes shown on the topographic maps for the given location. When this situation occurred, the altitude shown on the topographic map at the borehole location was used. The altitudes used in contouring the formation tops of the Lamotte Sandstone, Bonneterre Formation, Davis Formation, and Derby-Doerun Dolomite were determined by subtracting the depth of the formation top reported on the core log from the land surface altitude. The thickness of the St. Francois confining unit also was mapped.

Because shale content usually is a good indicator of the effectiveness of a confining unit, core logs with detailed descriptions of lithologies were used to determine the net shale thickness of the Derby-Doerun Dolomite and the Davis Formation. These logs typically divided the cored section into small intervals in which the lithology had similar characteristics. The rock was described as to color, texture (mudstone, wackestone, packstone, grainstone, or boundstone), grain size, physical features present in the rock (algal stromatolites, vugs, and staining), and the percentage of each rock type (shale, dolostone, and limestone). Net shale thickness was calculated by multiplying the reported percent shale in an interval by the thickness of the described interval. The net shale thicknesses of all intervals were then summed to determine the total net shale thickness at that borehole location. Because most of the cores were not logged in sufficient detail to extract all the needed information to make a net shale thickness determination, these data are not as extensive as the data describing the altitude of the formation tops.

The Upper Cambrian sequence in the study area is a complex series of dolostones, limestones, shales, sandstones, and siltstones, with minor arkosic and conglomeratic layers. The lithologic summaries presented below are necessarily brief and focused on lithologic features that potentially affect hydraulic properties. Palmer (1989) contains a detailed discussion of the lithologic framework of the Upper Cambrian strata in southeastern Missouri. The Dunham classification system for carbonate rocks (Dunham, 1962) was used in this report where the Dunham system was applied by the core logger. Many dolostone "grainstone" may be "packstone", or should be termed "packstone-grainstone". Logs reported using other classification systems are described using Dunham classification terms.

Precambrian Rocks

Thirty-three core logs analyzed as part of this study described exploration boreholes that penetrated Precambrian knobs (fig. 6). The locations of these boreholes define two linear structures or ridges that trend northwest-southeast. One ridge is located along Sycamore Creek in the northeastern part of the study area and the other extends through the central part of the study area. The knobs generally protrude less than 200 feet above the surrounding Precambrian basement rock; however, some knobs along both of these ridges extend more than 500 feet above the surrounding basement rock.

Structural evidence of the Precambrian knobs or ridge in the central part of the study area appears to extend as high as the Roubidoux Formation. Based on altitudes of the contact between the Roubidoux Formation and Gasconade Dolomite, a structural dome was identified during geologic mapping of the area conducted in 1996 by the USGS (R.W. Harrison, U.S. Geological Survey, oral commun., 1996). In other areas where buried Precambrian knobs occur, structural domes have been mapped in overlying strata as high as 1,000 feet above the buried knobs. One explanation as to why the existence of Precambrian knobs can be indicated so far up in the geologic section is that younger horizontal sediment layers originally buried the Precambrian basement rocks in southeastern Missouri. Over time, loading on the buried sediments caused compaction and subsidence. Thick sediments deposited away from and on the flanks of the buried knobs subsided more than the much thinner sediments deposited directly over the knobs, creating the mappable structural domes (R.W. Harrison, oral commun., 1996).

Lamotte Sandstone

The Lamotte Sandstone is present throughout the study area, except where it pinches out against some Precambrian knobs. The greatest thicknesses of this formation indicated by borehole data are 50 to 60 feet. Most cores penetrated the Lamotte Sandstone (if present), but were terminated before the complete section was drilled.

The Lamotte Sandstone is a white to light tan or gray, well-sorted, well-indurated mature quartzose sandstone. It generally varies from fine- to medium-grained, but can be very coarse-grained. The sandstone has locally abundant burrows and small fossils (type not identified). Sandstones are dolomite-cemented in the upper part of the formation. Some dolostone is bleached, recrystallized, porous, and vuggy. Minor secondary calcite fracture fill and calcite- and dolomite-lined vugs are reported.

Several cores contain Lamotte Sandstone that is all or partially arkosic or conglomeratic. Clasts are detrital porphyry fragments, and are supported by poorly sorted and angular feldspathic quartzose sandstone; clast size is up to 1 foot in diameter. The thickest conglomerate section is 33 feet; the thickest arkose section is 31 feet. Some clasts are scattered in thin beds throughout the sandstone, suggesting continual shedding of moderately worked material by erosion and/or continued uplift of the Precambrian highland area.

The depth from land surface to the top of the Lamotte Sandstone, where present, ranges from 1,552 to 2,450 feet, with an altitude ranging from a high of 502 feet below sea level (borehole 212, 1.5 mile north of the study area) to a low of 1,600 below sea level (borehole 236; 0.7 mile south of the study area) (table 1, figs. 5, 6, and 7). The general dip of the formation is to the south or southeast. Both of the Precambrian ridges can be identified as prominent structural high features or domes. Along these ridges are several Precambrian knobs that protrude above the top of the surrounding Lamotte Sandstone. Superimposed on the dome structure in the central part of the study area are several local highs. A smaller structural high evident in the southeastern part of the study area (based on two boreholes) is adjacent to a structural trough that trends to the south. This trough is also a distinct feature on structural maps of overlying formations.

Lamotte Sandstone-Bonneterre Formation Transition Zone

The contact between the Lamotte Sandstone and Bonneterre Formation is marked by a transition zone. This transition zone is comprised of tan or light to medium gray medium-grained quartz sandstones with minor dolostone grainstone lenses. The sandstones exhibit some cross-bedding and mottling, have locally abundant glauconite that may be pelletal (fecal pellets), and are cemented by fine-grained brown dolostone. Several logs note scattered green to dark-green and dark-gray crepey (crinkled appearance) shale partings.

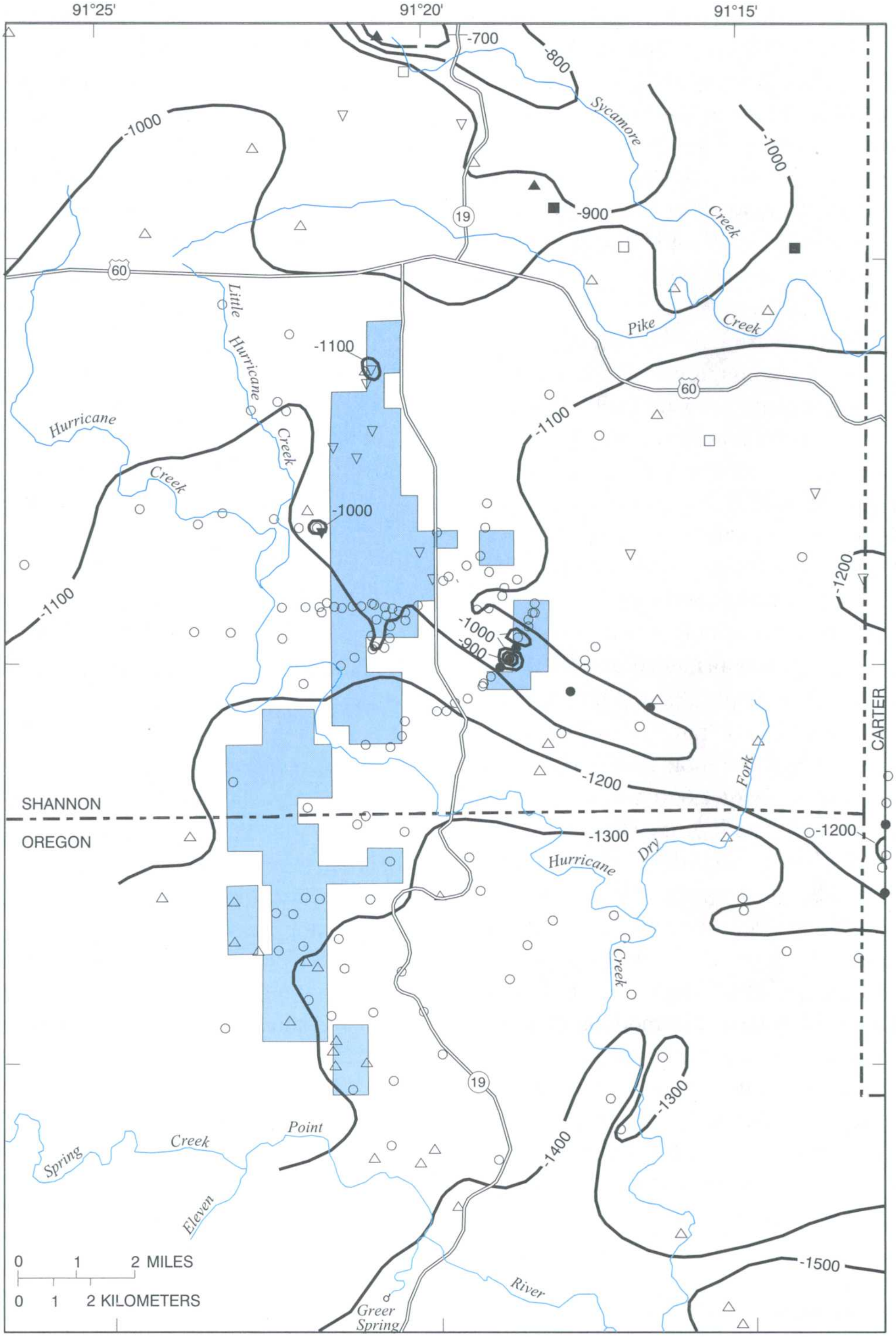
In several core intervals, the transition zone is pale to medium gray or tan to grayish-brown dolostone with localized sandstone lenses. The dolostone is shaley to sandy, fine to medium crystalline and fine- to medium-grained. Dolostones are grainstones, wackestones, and mudstones; the sequence appears to coarsen upward. Some mudstones are interbedded with grainstones, and scattered whiterock is reported. The dolostone is sometimes mottled, burrowed and bioturbated (sediment disturbed or agitated by organisms), and nodular. Secondary calcite and dolomite vug fill and calcite fracture fill is present. Irregular, wavy, dark gray-green to greenish-gray or dark gray argillaceous partings as much as 1-inch thick are present. Dolostone porosity is noted, but no description of type or degree is given. Both sandstone- and dolostone-dominant core intervals contain detrital igneous lithic fragments.

Bonneterre Formation

Because of the importance of the Bonneterre Formation as the host rock for potential ore deposits, the formation is studied and described in much more detail in logs than the other formations. The Bonneterre Formation is dominantly carbonate, with several shaley horizons and a siltstone (the Sullivan Siltstone Member). The formation is missing from several cores because it pinches out against Precambrian knobs. The lower Bonneterre Formation is subdivided into a basal part composed of carbonate with interbedded shale and an upper part composed of dolostone with occasional shale layers or partings. Several logs note a basal sequence of the Taum Sauk Limestone Member (fig. 5).

The Taum Sauk Limestone Member is a light gray-white to greenish gray-white and red-mottled limestone with some dolostone. Where noted, the unit is generally found in the vicinity of the reef structures and is 20 to 40 feet thick. It is fine- to medium-grained and moderately argillaceous with red and green shale, and is locally burrowed.

The basal part of the lower Bonneterre Formation primarily is dolostone. Limestone is preserved in the southern and extreme northwestern parts of the study area. The basal unit ranges from 30 to more than 300 feet thick. The dolostones are comprised of mudstones to grainstones with mudstone-matrix bound-



EXPLANATION

PROSPECTING AREA

—-900— STRUCTURE CONTOUR—Shows altitude of the top of the Lamotte Sandstone. Dashed where approximately located. Contour interval 100 feet. Datum is sea level

BOREHOLE—Solid black symbol represents borehole completed in the Precambrian basement
- ○ Amax Exploration, Inc.
- △ St. Joe Lead Company
- ▽ Asarco/Amselco
- □ Cominco American, Inc./Phelps Dodge Mining Company

Figure 7. Structure of the top of the Lamotte Sandstone.

stones and vary in color from gray to gray-tan, and tan. Argillaceous zones are pale green. Bleached zones suggest that parts of the section are whiterock. The dolostones are fine to medium crystalline, fine- to medium-grained, and have interbedded quartzose-rich to arkosic layers (as much as 4 feet thick), primarily near the base (transition zone). Dark greenish-gray and gray to black shale is present in beds as much as 21 feet thick, and as wispy partings. Dolostones occasionally are mottled and have common bioturbation and burrowing. Algal structures are digitate (finger-like appearance) stromatolites as much as 1 foot high, occasional crypt-algal laminates, and minor hummocky algal forms. Grains are oolites and fossil fragments (type not specified); several logs note edgewise carbonate conglomerates. Minor porphyry conglomerate layers are noted in some core intervals. Structural features include infrequent scattered subvertical fractures, locally disrupted bedding, and, in one log, a 100-foot vertical slump structure. Solution features include scattered stylolites, and vugs partially to completely occluded by calcite spar and pink dolomite. Vugs are the most common form of visible porosity and often are reported in algal zones. Noted porosity generally is 5 percent or less.

Limestone core intervals range from 100 to 260 feet thick. They are more lithologically heterogeneous than equivalent dolostones, being comprised of mudstones and grainstones, with interbedded wackestones and mudstone-matrix boundstones. They are light gray, tan and pale greenish-gray, and are fine crystalline and fine- to medium-grained. The limestones commonly are burrowed, mottled, sparsely to moderately glauconitic, and contain carbonate intraclasts, fossil fragments (type not noted), oolitic layers, and digitate stromatolite zones. They have rare vugs and pores that are partially to completely occluded by pink dolomite and calcite spar. Occasional, thin dolostone layers are reported. Dark greenish-gray thin wavy-bedded shales are interbedded with the limestone. Shale percentages are higher in the limestones than in the dolostones; the shales probably restricted the movement of dolomitizing fluids. Dolostones similar to those described above bound the top and base of the limestone core intervals, and range from 20 to 70 feet thick.

The upper part of the lower Bonneterre Formation ranges in thickness from 40 to nearly 250 feet. It is composed of interbedded dolostone grainstones, mudstones, and grainstone- and mudstone-matrix boundstones, with occasional wackestones. The top of the unit generally is a grainstone underlain by whiterock. The dolostones are fine- to medium-grained and fine through coarse crystalline. The coarse crystalline dolostones and reported bleached zones probably are whiterock. Color ranges from light to medium gray, gray-tan, pale greenish-gray, and brown. The dolostone often is mottled and is sometimes irregularly banded. Algal reef zones are common and are well-defined digitate stromatolites with infrequent hummocky algal features; reef zones reach thicknesses of 100 feet. Burrowing is also common in the unit. Clastic material includes occasional shale partings, and quartzose, arkosic, and porphyry conglomeratic layers. Solution structures include stylolites, possible solution breccias, and vugs partially to completely occluded by calcite spar and pink dolomite. Several descriptions note porosity, but are not specific as to type and nature. Scattered subvertical fractures sometimes are partially healed by calcite and/or dolomite.

The whiterock is comprised of fine- to coarse-grained dolostone with green to greenish-gray intercrystalline clay. It ranges in color from white to light gray, pale brown-gray, light tan, and light blue gray. Where clays have not entirely occluded intercrystalline pores, the dolostone appears very porous or vuggy. Matrix dolostone grains are sometimes visibly overgrown by medium-grained pink or white dolomite.

The Sullivan Siltstone Member (fig.5) is in the upper Bonneterre Formation, is 2.5 to 50 feet thick, and is composed of light to dark gray or brown, finely laminated, well indurated, fine- to medium-grained quartzose siltstone to sandstone. The unit thickens to the west and south. Siltstone is interbedded with thin dolostone lithoclast conglomerates, grainstone beds (primarily in the southern part of the study area), and scattered thin dark green to dark gray wavy shale partings. The siltstones have varying amounts of siliceous and dolomitic cement. Dolostones are tan, fine crystalline, and sometimes mottled, glauconitic, fossiliferous (type not noted), oolitic and/or porous. Solution vugs and brecciation are common in some dolostones. Brecciation is most commonly reported as soft-sediment deformation. Vugs have calcite, and contain trace sulfide mineralization which is most common in brecciated zones. Cores suggest that an incipient facies change to dolostone may be present in the north-central part of the study area.

The Whetstone Creek Member (fig. 5) ranges from 30 to 150 feet thick. The unit is dolostone with some limestone and limey dolostone, especially in the northwestern part of the study area. Color ranges from light to medium gray and grayish brown to tan, light blue gray, and greenish gray. Carbonates are fine to medium crystalline, fine- to medium-grained mudstones and grainstones, with wackestone-packstones and mudstone-matrix boundstones. Grainstones and wackestone-packstones are oolitic, fossiliferous (type not specified), and contain intraclasts. All carbonates are mottled, burrowed, and glauconitic. Mottled and finely laminated dolostones alternate. Unlike most Whetstone Creek Member sections in other areas of southeastern Missouri, these logs do not show abundant pelletal glauconite. Digitate stromatolites and crypt-algal laminates are noted; digitate stromatolites are more common to the north and laminate stromatolites to the south. Crypt-algal laminates are underlain by mottled dolostone, which is underlain by laminated dolostone. Solution features are stylolites and vugs with dolomite. Fracturing is present, but not common. Where reported, fractures generally are subvertical, with rare medium-angle fractures. Some fractures are healed by calcite. Porous zones are noted but extent and type are not described. Some whiterock is noted and reported bleached zones likely are also whiterock. Arkosic and igneous-conglomeratic layers are noted throughout the unit. Silt content is greater in the lower Whetstone Creek Member, near the contact with the Sullivan Siltstone Member.

Dark green shale partings are present throughout the Whetstone Creek Member. A prominent shale (1 to 27 feet thick) at the base of the unit is informally known as the False Davis (fig.5). Core descriptions are inadequate to determine if the False Davis is present throughout the study area. The shale is often interbedded with dolostone grainstones; the dolostones contain fossil fragments (type not identified), oolites, and occasional pyrite.

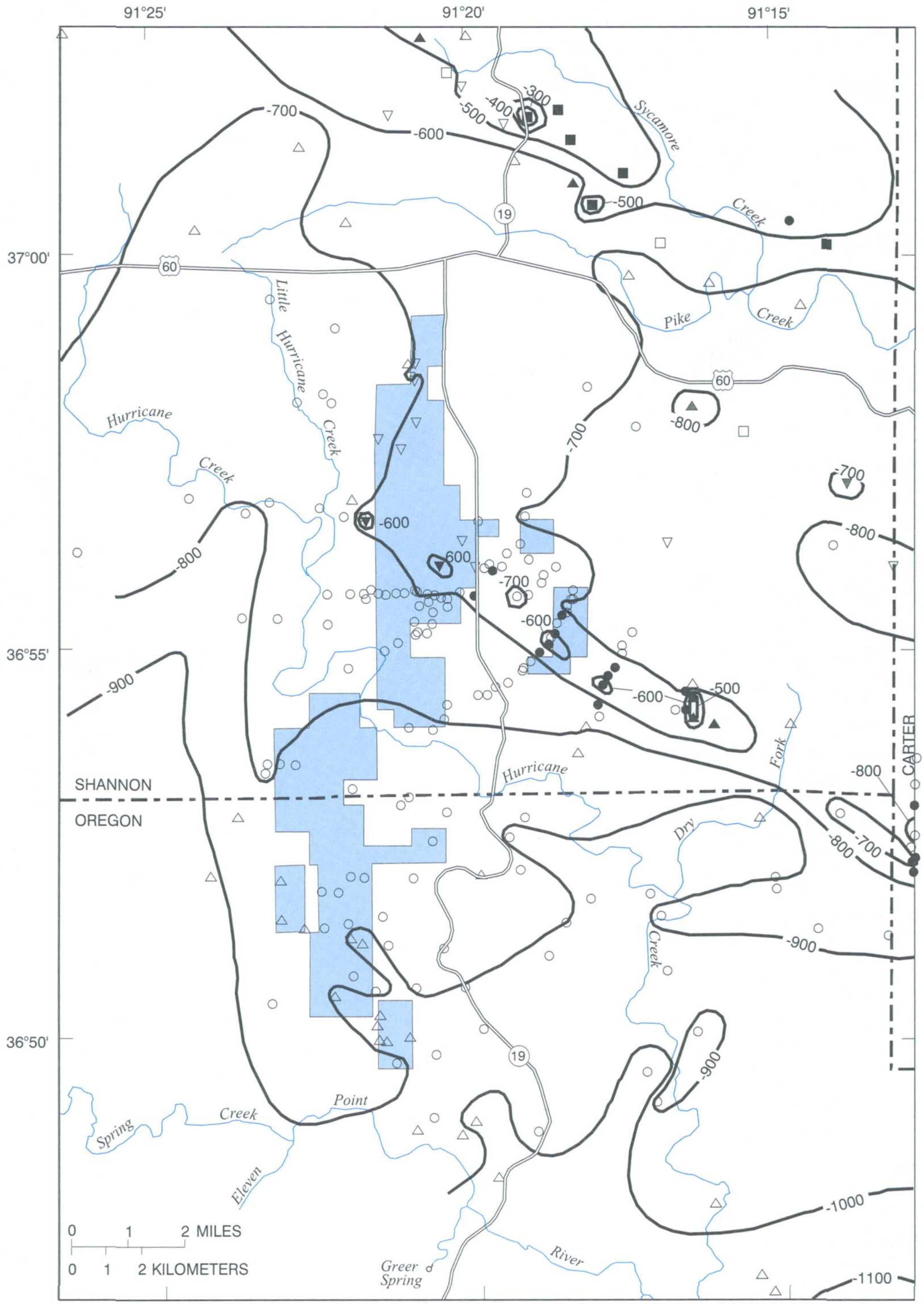
Based on 234 data points, the depth from land surface to the top of the Bonneterre Formation ranges from 1,358 to 2,002 feet. The altitude of the top of the formation ranges from 278 feet below sea level (borehole 179) to 1,152 feet below sea level (borehole 236; table 1, figs. 6 and 8) and generally dips to the south or southeast. Evidence for the two Precambrian ridges in the study area can again be observed as domed features. Also, the previously mentioned trough structure in the southern part of the study area is evident. The structure map of the top of the Bonneterre Formation indicates problems associated with using core logs from various sources to map formation tops. The fingering effect of the contours in the southern part of the prospecting area may be caused by different criteria used during core logging for identifying the top of the Bonneterre Formation, as opposed to the presence of structural features.

Davis Formation

The Davis Formation is composed of interbedded shales and carbonates, with both shale- and carbonate-dominant sequences. It ranges from less than 50 to more than 300 feet thick. The thinner core intervals are over Precambrian knobs. Shales generally are light to dark green, with some gray to dark gray beds. Individual shale layers range from partings to 5 feet thick. Shale-dominant sequences can be as thick as 50 feet, and contain as much as 90 percent shale. Limestone-filled burrows comprise the only carbonate in some shale layers. Carbonate layers in shale-dominant horizons vary from less than 1 inch to several feet thick. Carbonate-dominant zones may be 70 feet thick or greater. Shale percentages in these zones can be as much as 50 percent or less than 10 percent. Shale interbeds in carbonate-dominant zones vary from partings to several feet thick.

Davis Formation carbonates primarily are limestone, with dolostone at the top and base of the formation. The shales restricted the flow of dolomitizing fluids from reaching most Davis Formation limestones. The limestones are mudstone, grainstone, and mudstone-matrix boundstone, with some wackestone and occasional packstone. They are light tan to brown or gray to dark gray and light gray-tan in color. They are fine- to medium-grained and fine to medium crystalline. The limestones contain pellets, fossil fragments (type not specified), oolites, glauconite (some are pelletal), relict crypt-algal laminates and infrequent digitate stromatolites. Mudstones are sometimes bioturbated; burrows are horizontal and may be selectively dolomitized. Some layers are composed of carbonate intraclast conglomerate. Scattered vertical fracturing is present, but is less common than in formations above and below. Solution features include horizontal and vertical stylolites, and local solution and slump breccias. Scattered arkosic or porphyry conglomeratic layers are present.

The dolostones are similar to the limestones described above. Coarse crystalline dolostone is present, especially in the upper Davis Formation, where it is sometimes medium to pale gray or green whiterock. Some gray mottling is present. The dolo-



EXPLANATION

PROSPECTING AREA

— -900 — STRUCTURE CONTOUR—Shows altitude of the top of the Bonneterre Formation. Dashed where approximately located. Contour interval 100 feet. Datum is sea level

BOREHOLE—Solid black symbol represents borehole completed in the Precambrian basement. Gray symbol with contour represents borehole with data dissimilar to that in surrounding boreholes

○ Amax Exploration, Inc.

△ St. Joe Lead Company

▽ Asarco/Amselco

□ Cominco American, Inc./Phelps Dodge Mining Company

Figure 8. Structure of the top of the Bonneterre Formation.

stone has more vugs and is more porous than the limestone; vugs are partially occluded by calcite and dolomite. Core descriptions report limonite coatings in vugs in the upper part of the Davis Formation; this coating probably is a very ferroan (containing ferrous iron) dolomite.

Based on 227 data points, the depth from land surface to the top of the Davis Formation ranges from 1,171 to 1,692 feet and the altitude of the top of the formation ranges from 200 feet below sea level (borehole 212) to 878 feet below sea level (borehole 229, 0.6 mile south of the study area) (table 1, figs. 6 and 9). The structure map is similar to that of the top of the Bonneterre Formation with the presence of the two structural highs in the study area and the general dip of the formation to the south.

Derby-Doerun Dolomite

The Derby-Doerun Dolomite is composed of light gray to gray or light tan to brown mudstones, grainstones, and mudstone-matrix boundstones, with some wackestones and wackestone-matrix boundstones. Dolostones are fine to coarse crystalline and fine- to medium-grained. Whiterock is scattered throughout and some mottling was reported. Bedding is thin to massive; thin disturbed beds may be burrowed. The dolostones contain fossil fragments (type not specified), oolites, and carbonate lithic clasts. Digitate stromatolites and crypt-algal laminates are present. Occasional scattered porphyry clasts are present. Thin black to dark gray and green shales are scattered throughout; shale content and bed thickness increases near the contact with the Davis Formation.

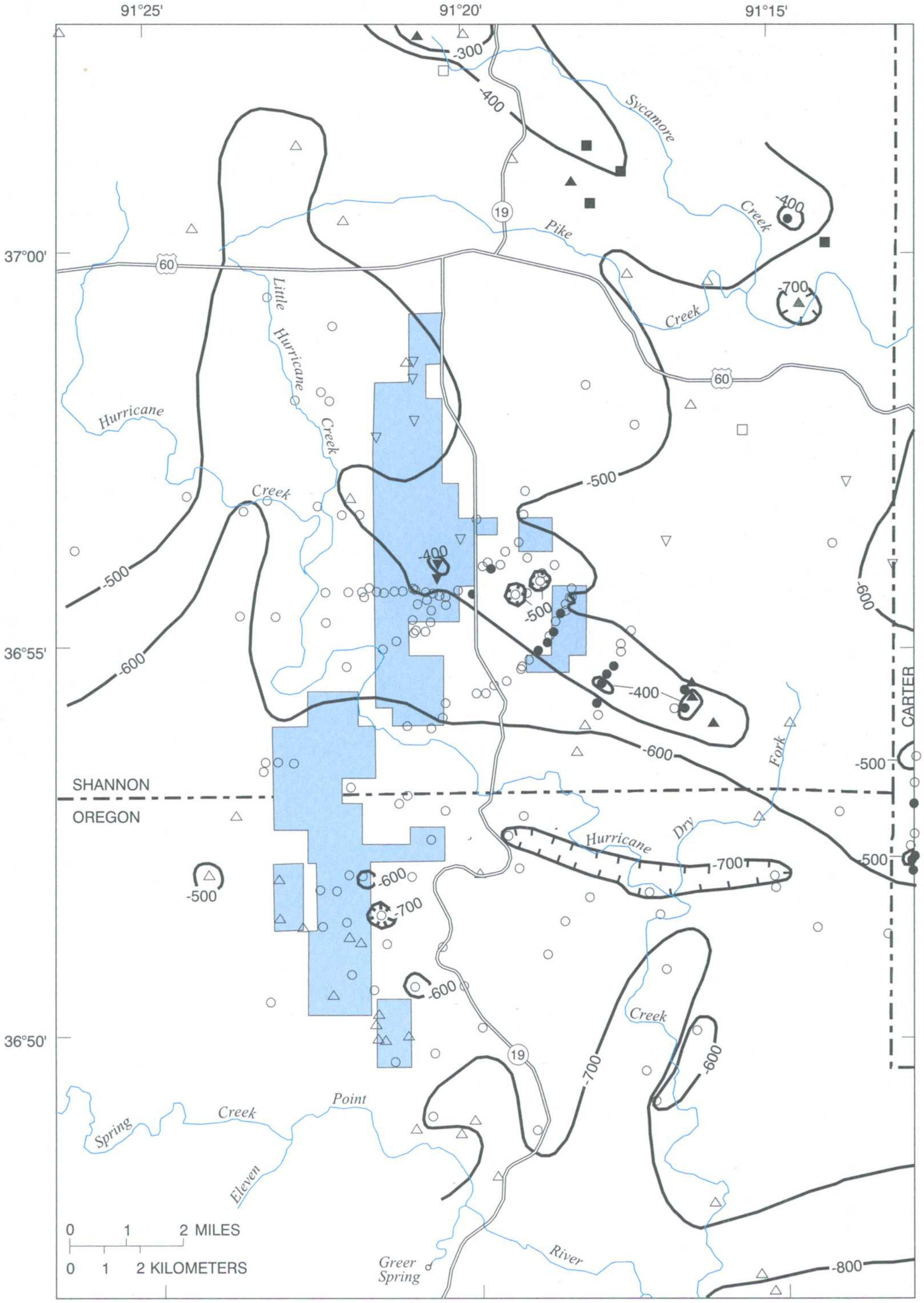
Glauconite is present near the base, where dolostones are interbedded with shales. Dolostones vary in visible porosity from none to extremely vuggy. Unlike the overlying Potosi Dolomite, the Derby-Doerun Dolomite contains only minor chalcedony and quartz vug linings. Highly fractured zones are present, although not ubiquitous; some fractures are healed by dolomite and calcite. Breccias are present, but are in part healed by the same cements. Some fractures have minor to abundant iron oxide staining on the fracture surface. Many mining companies did not begin coring until they had already penetrated the Derby-Doerun Dolomite; consequently, complete core intervals of the Derby-Doerun Dolomite are not equally distributed.

The Derby-Doerun Dolomite is the uppermost formation mapped during this study. Based on the data from 212 control points, the depth from land surface to the top of this formation ranges from 970 to 1,598 feet, and the altitude of the top of the formation ranges from 18 feet above sea level (borehole 221, 1.5 miles north of the study area) to 788 feet below sea level (borehole 229, table 1, figs. 6 and 10). The Derby-Doerun Dolomite structure map is similar to that of the Davis Formation with the two structural highs in the study area and the general slope of the formations to the south.

The St. Francois confining unit thickness as determined by core logs ranges from 173 to 656 feet (table 1; fig. 11) in the study area. Most boreholes in which the confining unit was logged at more than 400 feet thick had abnormally thick Derby-Doerun Dolomite sequences. Eight boreholes [boreholes 162, 199, 216, 218, 219, and 230 (fig. 6) are shown on figure 11; boreholes 221 and 236 (fig. 6) were slightly outside the study area boundary] were logged with abnormally thick confining unit sequences. This may have been a result of different criteria being used to define the Potosi and Derby-Doerun Dolomites and consequently part of the Potosi Dolomite near the conformable contact may have been logged as Derby-Doerun Dolomite. Typically the confining unit has a thickness ranging from 250 to 375 feet thick (table 1; fig. 11) in the study area.

The net shale thickness of the St. Francois confining unit also was mapped (table 1, fig. 12). The thickness ranged from less than 50 feet in the northeastern part of the study area to more than 150 feet in the southwest. This is consistent with the current understanding of the environment at the time these formations were deposited. The deeper part of the basin would have been to the west of the prospecting area. This would have been a low-energy setting allowing the deposition of the silts and clays and the formation of shale deposits.

These conclusions are consistent with Fletcher (1974) who states that the clastic (includes sand and shales)-to-carbonate ratio in the Davis Formation increases westward from the presently exposed Precambrian highlands in the St. Francois Mountains east of the Viburnum Trend (fig. 1). Thacker and Anderson (1979) also show the clastic-to-carbonate ratio in the Davis Formation increasing to the west of buried Precambrian knobs identified by Fletcher (1974) in the Viburnum Trend. The decrease in thickness and clastic/carbonate composition of the Davis Formation can



EXPLANATION

PROSPECTING AREA

-600 STRUCTURE CONTOUR—Shows altitude of the top of the Davis Formation. Hachures indicate depression. Contour interval 100 feet. Datum is sea level

BOREHOLE—Solid black symbol represents borehole completed in the Precambrian basement. Gray symbol with contour represents borehole with data dissimilar to that in surrounding boreholes

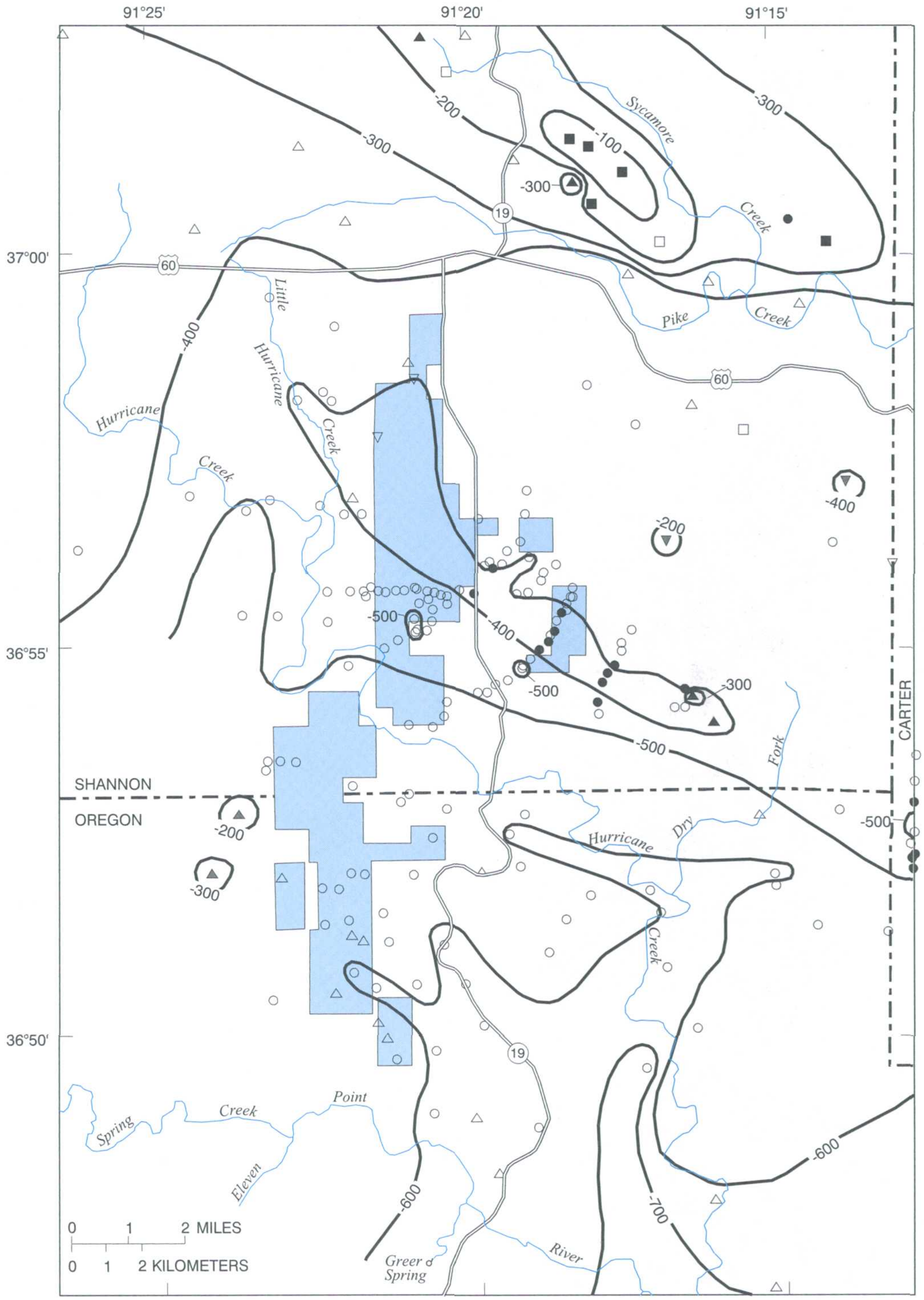
○ Amax Exploration, Inc.

△ St. Joe Lead Company

▽ Asarco/Amselco

□ Cominco American, Inc./Phelps Dodge Mining Company

Figure 9. Structure of the top of the Davis Formation.



EXPLANATION

PROSPECTING AREA

—-400— STRUCTURE CONTOUR—Shows altitude of the top of the Derby-Doerun Dolomite. Contour interval 100 feet. Datum is sea level

BOREHOLE—Solid black symbol represents borehole completed in the Precambrian basement. Gray symbol with contour represents borehole with data dissimilar to that in surrounding boreholes

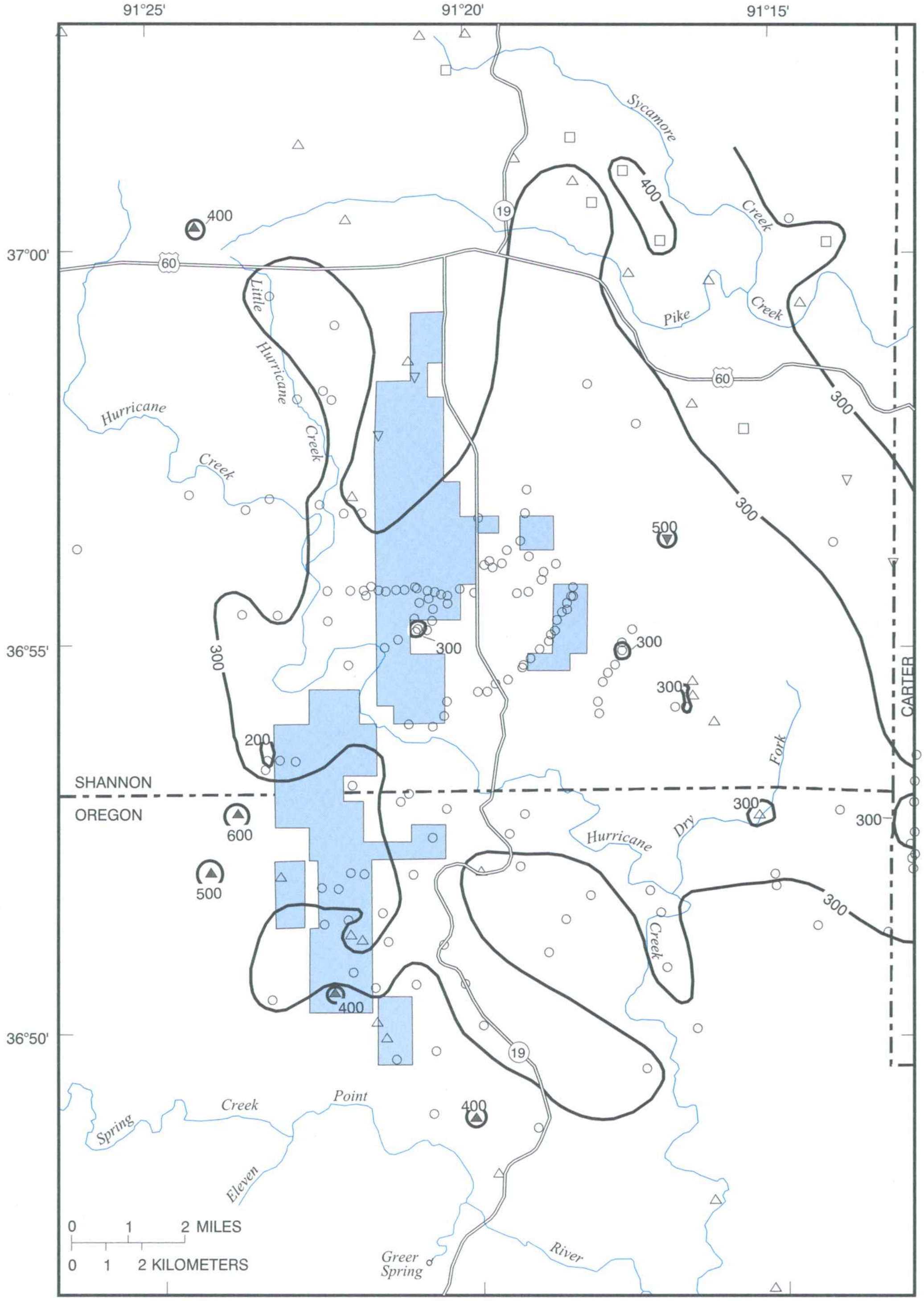
○ Amax Exploration, Inc.

△ St. Joe Lead Company

▽ Asarco/Amselco

□ Cominco American, Inc./Phelps Dodge Mining Company

Figure 10. Structure of the top of the Derby-Doerun Dolomite.



EXPLANATION

PROSPECTING AREA

— 400 — LINE OF EQUAL THICKNESS—Shows thickness of the St. Francois confining unit. Contour interval 100 feet. Datum is sea level

BOREHOLE—Gray symbol with contour represents borehole with data dissimilar to that in surrounding boreholes
- ○ Amax Exploration, Inc.
- △ St. Joe Lead Company
- ▽ Asarco/Amselco
- □ Cominco American, Inc./Phelps Dodge Mining Company

Figure 11. Thickness of the St. Francois confining unit.

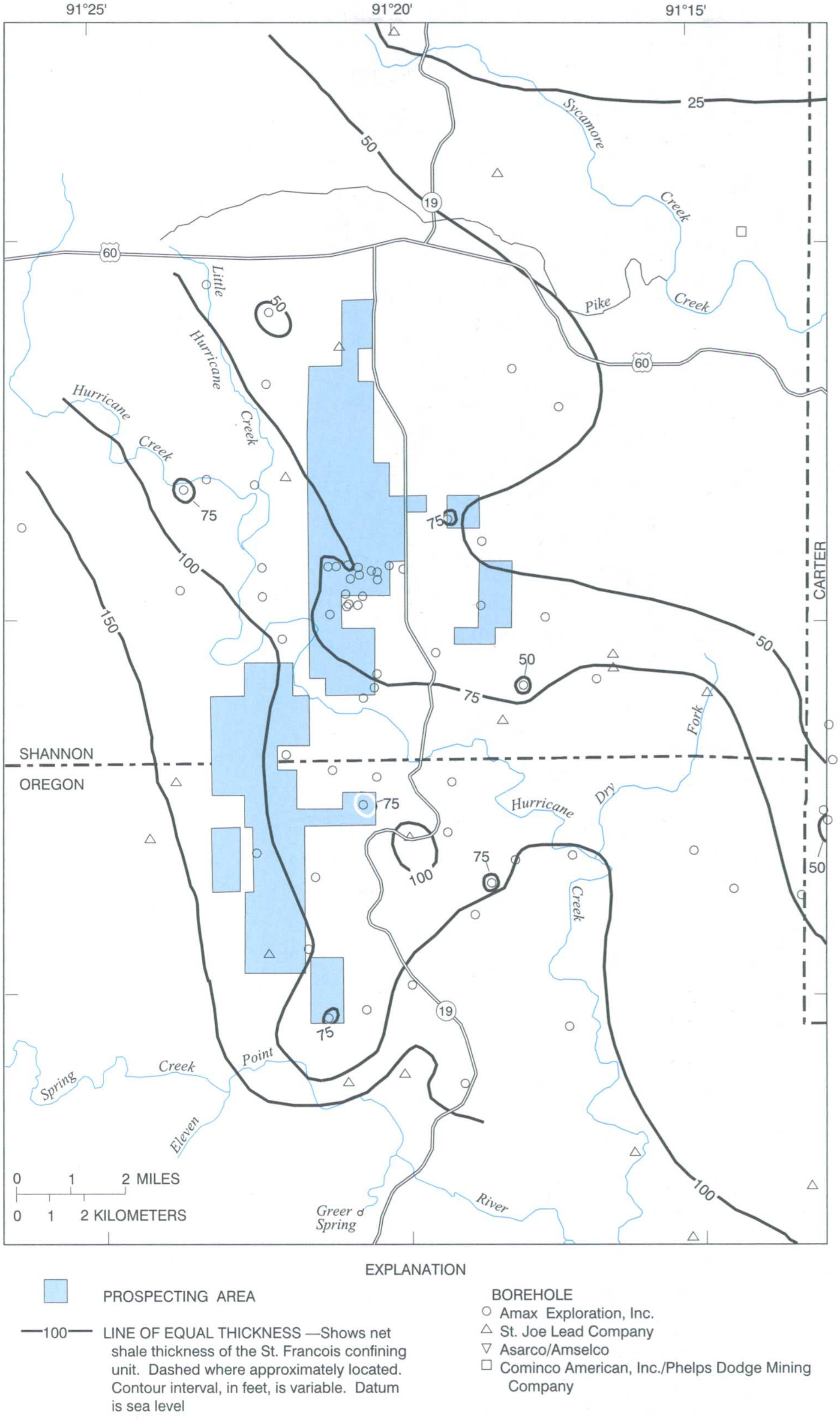


Figure 12. Net shale thickness of the St. Francois confining unit.

reduce the ability of the confining unit to impede flow between the Ozark and St. Francois aquifers near the Precambrian knobs.

VERTICAL HYDRAULIC CONDUCTIVITY

Laboratory testing was used to determine the vertical hydraulic conductivity and porosity of various rock types present in the St. Francois confining unit. Shale typically has a smaller permeability than carbonate rocks (Freeze and Cherry, 1979). By determining the thickness of the confining unit, the net shale thickness of the unit, and the vertical hydraulic conductivity range of the various rock types present in the unit, the data are available to quantitatively estimate the confining ability of the unit. Permeability is a function of the medium (rock core) alone and is not dependent on the fluid used or the force field causing the movement of the liquid (Lohman and others, 1972). Hydraulic conductivity is a measure of the ease with which a specific fluid can be transmitted through a porous medium, and is a function of the medium and of the density and viscosity of the fluid being transmitted. The transmitted fluid used during the permeability tests was similar to water that flows through the confining unit in the study area. This allowed representative vertical hydraulic conductivities to be determined from laboratory core permeability results.

Rock cores from both the study area and the Viburnum Trend were sent to the Core Petrophysics, Inc. laboratory in Houston, Texas, for vertical hydraulic conductivity analysis. Samples from the Viburnum Trend were collected and analyzed for comparison with the results of the core analyzed from the study area. The potential lead-zinc deposits in the prospecting area probably have formed in a similar geologic depositional environment and by the same processes that formed the deposits that are currently (2000) being mined in the Viburnum Trend. The vertical hydraulic conductivity of the confining unit in the Viburnum Trend is minimal, allowing effective dewatering and mining. A comparison of the vertical hydraulic conductivity of the confining units in the two areas can give insight as to the potential of the confining unit in the prospecting area to inhibit ground-water flow between aquifers.

Rock core samples that represent the entire St. Francois confining unit sequence were selected and sent to the laboratory for analysis. Sixty-four core samples were selected from 11 boreholes in the Fristoe Unit and 24 samples were selected from 5 boreholes in the southern part of the Viburnum Trend (table 2, at the back of this report). Twenty-six core samples were from the Derby-Doerun Dolomite and 59 samples were from the Davis Formation. One sample (sample number 35, table 2) was logged as the Derby-Doerun Dolomite, but after further inspection, the core was determined to probably be from the lower Potosi Dolomite; two samples (sample numbers 6 and 29, table 2) after further inspection were determined to be from the upper Bonneterre Formation.

Methodology

Vertical permeability and porosity were determined in the laboratory for the rock core samples using methods described by the American Petroleum Institute (1998). The test conditions simulated the in situ conditions at the depth from which each core sample was collected. The permeability of a medium is inversely proportional to the net confining stresses to which the medium is subjected. A net confining stress [calculated using a pressure gradient of 0.758 pounds per square inch (psi) per foot depth] was applied to each core sample during the permeability analysis (Jim Seale, Core Petrophysics, Inc., written commun., 1999). A water sample collected from the city of Viburnum public-water supply, which pumps water from an abandoned lead mine in the Bonneterre Formation about 50 miles north of the study area was sent with the core samples to the laboratory. The transmitting fluid used in the laboratory vertical permeability analysis had similar density and viscosity properties as the water sample from Viburnum; this allowed the laboratory-derived vertical permeability to be converted to vertical hydraulic conductivity.

The following procedure was used to prepare each core sample at the laboratory. Upon receiving the 88 core samples, the cores were trimmed to right-angle cylinders using air as the bit lubricant. The samples then were extracted with methanol to remove any precipitated salt, then oven dried for 24 hours at a temperature of 240 degrees Fahrenheit. The bulk volumes of the cores were determined by fluid displacement (Archimedes' principle). Dry weights were recorded and the grain densities calculated. Helium porosity of the rock core at room conditions was obtained by measuring a grain volume using Boyle's Law (Jim Seale, Core Petrophysics, Inc., written commun., 1999).

The core samples were evacuated and pressure saturated at 1,000 psi with the simulated Viburnum water. Saturations were verified gravimetrically upon removal from the saturation cell. The core samples were then placed in individual coreholders and the calculated net confining stress was applied. The differential flow pressure, time, and water volumes produced were recorded. When the permeability was below the reporting limit, the test was allowed to conclude after 48 hours. The effective vertical permeability of the rock core was calculated using the following equation (Jim Seale, Core Petrophysics, Inc., written commun., 1999):

$$k = \frac{Q\mu L}{A(Pu - Pd)}$$

k = effective permeability, in darcies (1 darcy = 9.87 x 10^{-9} centimeters squared)
Q = flow rate, in cubic centimeters per second
μ = fluid viscosity, in centipoise (1 centipoise = 0.01 gram per centimeter-second)
L = length, in centimeters
A = area, in square centimeters
Pu = upgradient pressure, in atmospheres
Pd = downgradient pressure, in atmospheres

Hydraulic conductivity is related to permeability by (American Petroleum Institute, 1998):

$$K = \frac{k\rho g}{\mu}$$

K = hydraulic conductivity, in centimeters per second
k = effective permeability, in darcies
ρ = mass density of the fluid, in grams per cubic centimeters
g = acceleration of gravity, in centimeters per second squared
μ = fluid viscosity, in centipoise

After substitution, the conversion of vertical permeability in darcies to vertical hydraulic conductivity in foot per second (ft/s) becomes:

$$K = (3.17) \times 10^{-5} k$$

Evaluation of Results

Vertical hydraulic conductivities ranged from 8.70 x 10^{-8} ft/s for one sample to less than 3.17 x 10^{-14} ft/s (the reporting limit) for 39 samples (table 2). The porosity values ranged from a high of 17.47 percent to a low of 0.36 percent. There did not appear to be a strong correlation between the vertical hydraulic conductivity and porosity.

With the outliers, the reported vertical hydraulic conductivity values span six orders of magnitude; this, compounded with the large number of values below the reporting limit, cause the mean and standard deviation statistic values for this data set to be strongly distorted. Therefore, box plots (fig. 13) using logarithmic scales are used to present the results.

Figure 13 shows the variation in vertical hydraulic conductivity of different formations and different rock types within the Fristoe Unit (A and C) and the Viburnum Trend (B and D). The variation in vertical hydraulic conductivity between similar formations and rock types in the Fristoe Unit and the Viburnum Trend is also shown on figure 13 (E-J).

The Lilliefors (two-tailed) test for normality (Iman and Conover, 1983) showed the vertical hydraulic conductivity data are not normally distributed. Because these data are not normally distributed, the data were ranked. All of the statistical analysis used to evaluate the significant differences between data sets were performed on the ranked data. The Wilcoxon-Mann-Whitney rank sum test (two-tailed) was used when comparing two data sets and an analysis of variance was used to perform multiple-comparisons when more than two data sets were evaluated (Iman and Conover, 1983).

In all of the statistical analysis, a level of significance (α-value) of 0.05 was used to test the null hypothesis which states, the vertical hydraulic conductivity of the data sets being compared are equal. The attained significance level (p-value) is a probability value determined by the data (Iman and Conover, 1983). The null hypothesis was rejected for all analysis with p-values for the pooled data that were less than 0.05.

No significant difference (p-value = 0.375) exists between the ranked vertical hydraulic conductivity of samples collected from the Derby-Doerun Dolomite and Davis Formation in the Fristoe Unit. The similarity is also visually expressed (fig. 13A), by the considerable overlap of the two boxplots and the similarity of the median values of the two data sets. However, the interquartile range (the range between the upper and lower quartiles) of vertical hydraulic conductivity shown for the Derby-Doerun Dolomite samples has more than an order of magnitude greater span than the interquartile range shown for the Davis Forma-

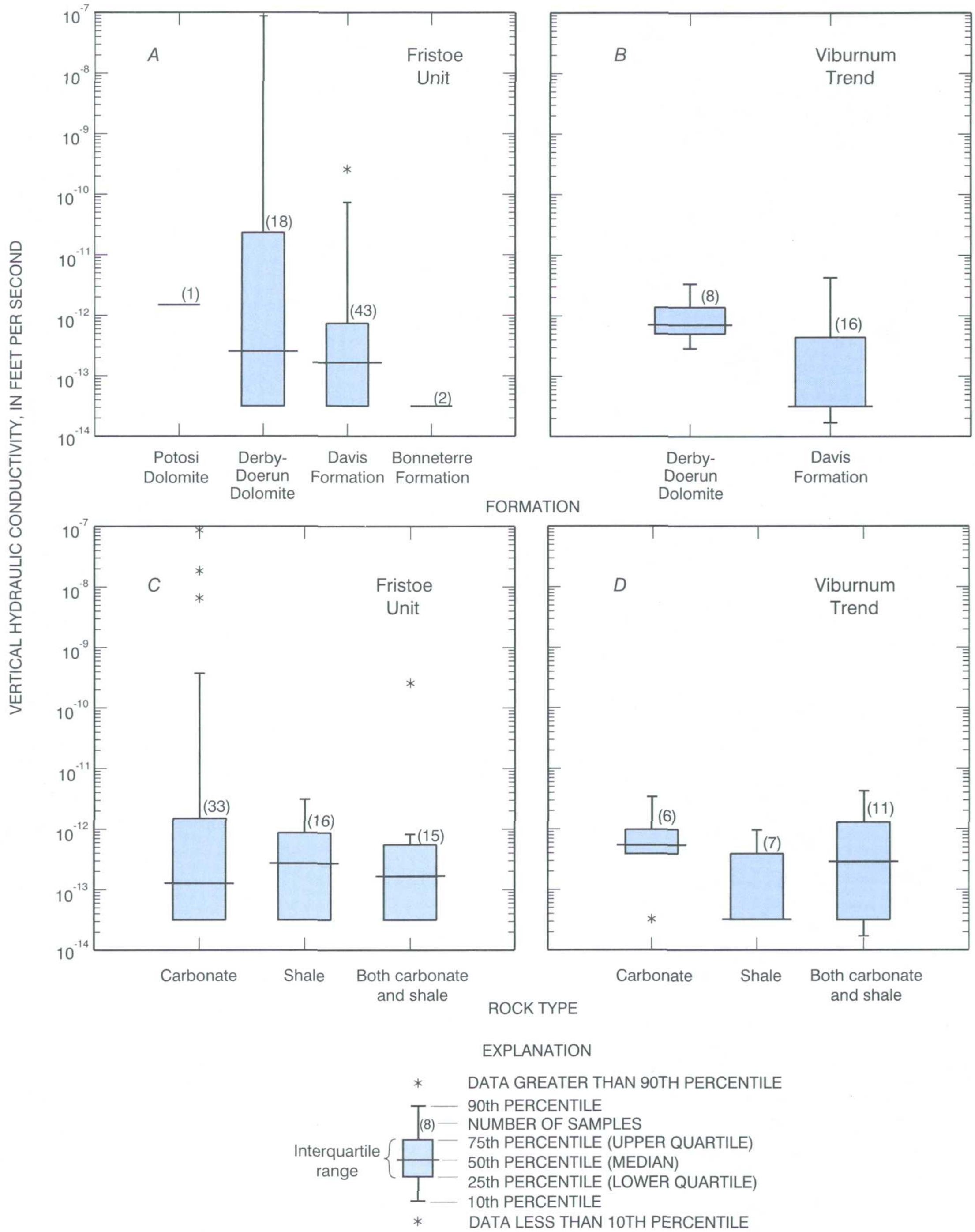


Figure 13. Boxplots showing the vertical hydraulic conductivities of formations and rock types in the Fristoe Unit and Viburnum Trend.

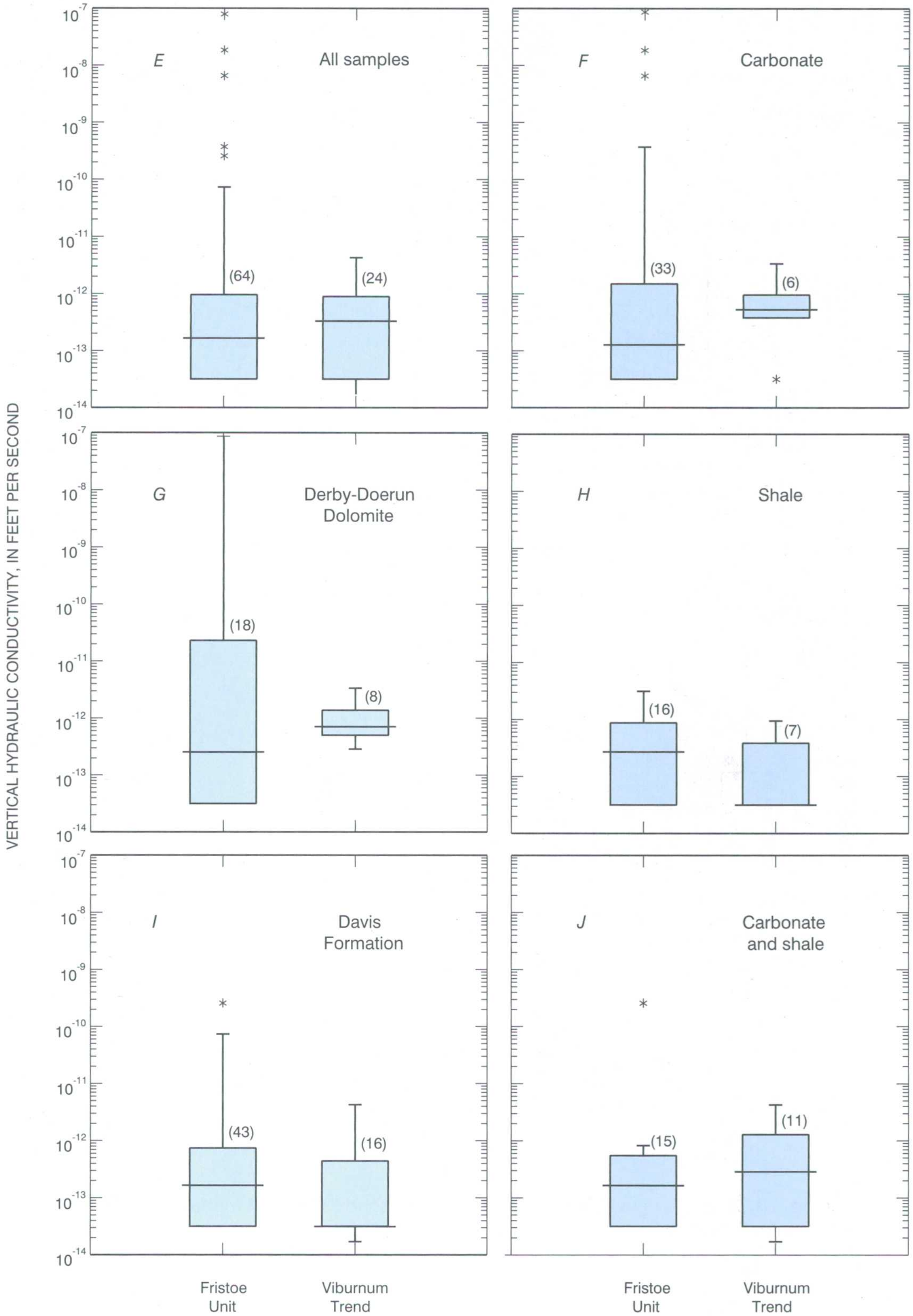


Figure 13. Boxplots showing the vertical hydraulic conductivities of formations and rock types in the Fristoe Unit and Viburnum Trend—Continued.

tion samples. The samples collected from the Potosi Dolomite and the Bonneterre Formation are shown for comparison purposes, although they are of no importance in evaluating the St. Francois confining unit. The samples from the upper Bonneterre Formation have a low vertical hydraulic conductivity, possibly related to the transitional nature of the contact between the Davis Formation and the Bonneterre Formation.

In the Viburnum Trend, there is a statistically significant difference (p-value = 0.006) between the ranked vertical hydraulic conductivity of the Derby-Doerun Dolomite and the Davis Formation. Although the vertical hydraulic conductivity of both formations is small, the median vertical hydraulic conductivity of the Derby-Doerun Dolomite is more than an order of magnitude greater than the median vertical hydraulic conductivity of the Davis Formation (fig. 13B).

In the Fristoe Unit, there is no statistically significant (p-value = 0.790) vertical hydraulic conductivity difference in ranked samples containing carbonate or shale, or both rock types. This is shown visually (fig. 13C) by the interquartile range of the box plots having considerable overlap and the median values being similar.

In the Viburnum Trend, there is no statistically significant (p-value = 0.412) vertical hydraulic conductivity difference in ranked samples containing carbonate or shale, or both rock types. Visually (fig. 13D), the carbonate rocks have more than an order of magnitude greater median vertical hydraulic conductivity than shales. The Derby-Doerun Dolomite contains primarily carbonate rocks and the Davis Formation contains primarily shale, this relation is also observed in the Viburnum Trend formation vertical hydraulic conductivity comparisons (fig. 13B). Also, samples from the Viburnum Trend that contain both carbonate and shale have a larger vertical hydraulic conductivity variability than samples from either individual rock type. Samples containing both rock types span the same vertical hydraulic conductivity range as the carbonate and shale together.

The interquartile range of vertical hydraulic conductivity for individual formations and rock types in the Fristoe Unit was compared with those in the Viburnum Trend. A larger variability of some core samples from the Fristoe Unit was observed (fig. 13, F-I). The cause of this variability can be attributed to the carbonate rock samples from the Derby-Doerun Dolomite, which have more than two orders of magnitude greater range in vertical hydraulic conductivity than the Derby-Doerun Dolomite in the Viburnum Trend. In spite of this variability, the vertical hydraulic conductivity of rock samples from the Fristoe Unit are similar to those from the Viburnum Trend.

One conclusion that can be drawn from the vertical hydraulic conductivity measurements on different rock types in the Fristoe Unit (fig. 13C) is that the net shale thickness is not the single controlling factor that determines the effectiveness of the St. Francois confining unit. Because the vertical hydraulic conductivity of the carbonate rocks and shale in the confining unit are similar, the entire carbonate-shale thickness is important in determining the effectiveness of the confining unit.

Using the results of this study, the range of estimated effective vertical hydraulic conductivity values for the St. Francois confining unit in the Fristoe Unit was calculated. A typical thickness of the confining unit of 300 feet (fig. 11) was used in the calculations. A net shale thickness of 50 feet was used for the minimum effective vertical hydraulic conductivity of the confining unit calculation and 150 feet was used for the maximum (fig. 12). Vertical hydraulic conductivities as represented by the upper and lower quartiles range from about 1 x 10^{-12} to 3 x 10^{-14} ft/s for the carbonate rocks and 9 x 10^{-13} to 3 x 10^{-14} ft/s for shale in the Fristoe Unit.

The effective vertical hydraulic conductivity of a unit composed of several layers aligned in series, with each layer having different vertical hydraulic conductivities can be calculated using the formula:

$$\frac{d_t}{K_t} = \frac{d_1}{K_1} + \frac{d_2}{K_2} + \frac{d_3}{K_3} + \frac{d_n}{K_n}$$

d_t = total thickness of the confining unit
d_1, d_2, d_3, d_n = thickness of layer 1, layer 2, layer 3, and layer n
K_t = effective vertical hydraulic conductivity of unit
K_1, K_2, K_3, K_n = vertical hydraulic conductivity of layer 1, layer 2, layer 3, and layer n

By using appropriate extreme values of net shale thickness and vertical hydraulic conductivity, the range of effective vertical hydraulic conductivity for the confining unit in the study area was estimated to be a maximum of 1 x 10^{-12} ft/s and a minimum of 3 x 10^{-14} ft/s. These vertical hydraulic conductivity values are small, allowing the confining unit to effectively impede the flow of ground water between the Ozark aquifer and the St. Francois aquifer, unless preferred-path secondary permeability has developed along faults and fractures.

SUMMARY AND CONCLUSIONS

This report assesses the confining ability of the St. Francois confining unit in six townships (T25-27N and R03-04W) of the Fristoe Unit of the Mark Twain National Forest in Oregon and Shannon Counties of southeastern Missouri. This was accomplished by describing the depositional environment and stratigraphy of the St. Francois confining unit, and quantifying the vertical hydraulic conductivity of rock core samples from the confining unit using laboratory techniques. Stratigraphic data for this study were obtained by analysis of 238 exploration borehole core logs and rock core from exploration boreholes that typically described a 600- to 800-foot interval from near the bottom of the Potosi Dolomite into the Lamotte Sandstone or Precambrian basement rock.

The Upper Cambrian sediments are composed of alluvial and fluvial clastics that grade upward into marine sandstones and carbonates and are characteristic of intrashelf basin areas. These sediments were deposited during repeated cycles of marine transgressions and subsequent shallowing. This sedimentation was controlled by pre-Late Cambrian uplift and erosion of the igneous basement rock and by faulting during the Late Cambrian Epoch. Faulting created a Precambrian highland area (St. Francois Mountains) and basins; erosion gave the Precambrian igneous knobs an irregular shape. This erosion and a marine transgression with continued deposition of clastic material led to the accumulation of sediments that formed the Lamotte Sandstone, which is interpreted as a near shore barrier and shallow tidal flat complex. Transgression caused shelf drowning and gradual development of a large intrashelf basin with a narrow, discontinuous rim (lowermost Bonneterre Formation) which allowed the carbonate-dominant facies to form. The transition from shaley deposits with a limited stromatolite zone to carbonate with more frequent stromatolites suggest a general shallowing of the sequence as the Bonneterre Formation was deposited. Several rock sequences in the Bonneterre Formation show a cyclic pattern of deepening, then becoming shallow. Retention of limestone in the basal part of the Bonneterre Formation suggests that the southern and extreme northwestern parts of the study area were deeper offshore environments.

The Bonneterre Formation-Davis Formation contact denotes abrupt intrashelf basin development that was filled during cycles of transgression and shallowing. The intrashelf basin likely had a wide, continuous shelf rim producing the shale-dominant Davis Formation. Horizontal burrows in the Davis Formation suggest a slow periodic deposition in a marine subtidal setting, where the shelf underwent gradual drowning during a slow transgression. The Derby-Doerun Dolomite was formed during a pair of carbonate depositional cycles. The basal shaley sequence represents a transition with the Davis Formation.

Arkosic and porphyry conglomeratic material throughout the section indicates Precambrian highlands remained exposed during Upper Cambrian carbonate deposition. Continued exposure of the Precambrian highlands may have been caused by the original height of the highlands, or be the result of continued uplift on fault-related structures.

Thirty-three exploration holes penetrated Precambrian knobs. These boreholes appear to intercept two linear structures or ridges that trend northwest-southeast. These knobs generally protrude less than 200 feet above the surrounding Precambrian basement rock; however, some knobs along both of these ridges extend more than 500 feet above the surrounding basement rock. Structural evidence of the Precambrian knobs or ridge in the central part of the study area appears to extend as high as the Roubidoux Formation.

The Lamotte Sandstone is present throughout the study area, except where it pinches out against some Precambrian knobs. The greatest thicknesses of this formation indicated by borehole data are 50 to 60 feet. The depth from land surface to the top of the Lamotte Sandstone, where present, ranges from 1,552 to 2,450 feet with an altitude ranging from a high of 502 feet below sea level to a low of 1,600 feet below sea level. The general dip of the formation is to the south or southeast. Both of the Precambrian ridges can be identified as prominent structural high features or domes. A structural high is evident in the southeastern part of the study area and is adjacent to a structural trough that trends to the south. This trough is also a distinct feature on structural maps of overlying formations.

The lower Bonneterre Formation is subdivided into a basal part composed of carbonate with interbedded shale and an upper part composed of dolostone with occasional shale layers or partings. Algal structures present in the basal part are digitate stromatolites as much as 1 foot high, occasional crypt-algal laminates, and minor hummocky algal forms. Grains are oolites and fossil fragments (type not specified). The upper part of the lower Bonneterre Formation is composed of interbedded dolostone grainstones, mudstones, and grainstone- and mudstone-matrix boundstones, with occasional wackestones. Algal reef zones in this upper part are also common and are well-defined digitate stromatolites with infrequent hummocky algal features; reef zones reach thicknesses of 100 feet. Dark green shale partings are present throughout the Whetstone Creek Member of the upper Bonneterre Formation and a prominent shale (1 to 27 feet thick) at the base of unit is informally known as the False Davis.

The depth from land surface to the top of the Bonneterre Formation ranges from 1,358 to 2,002 feet and the altitude of the top of the formation ranges from 278 feet below sea level to 1,152 feet below sea level. The formation generally dips to the south or southeast. Evidence for the two Precambrian ridges in the study area can again be observed as domed features. The trough structure in the southern part of the study area is also evident. The structure map of the top of the Bonneterre Formation indicates problems associated with using core logs from various sources to map formation tops. The fingering effect of the contours in the southern part of the prospecting area may be caused by different criteria used during core logging for identifying the top of the Bonneterre Formation, as opposed to the presence of structural features.

The Davis Formation is composed of interbedded shales and carbonates, with both shale- and carbonate-dominant sequences and ranges from less than 50 to more than 300 feet thick. Shale-dominant sequences can be as thick as 50 feet, and contain as much as 90 percent shale. The Davis Formation carbonates primarily are limestone, with dolostone at the top and base of the formation. The shales restricted the flow of dolomitizing fluids from reaching most Davis Formation limestones.

The depth from land surface to the top of the Davis Formation ranges from 1,171 to 1,692 feet, and the altitude of the top of the formation ranges from 200 feet below sea level to 878 feet below sea level. The structure map is similar to that of the top of the Bonneterre Formation, with the presence of the two linear highs in the study area and the general dip of the formation to the south.

The Derby-Doerun Dolomite is composed of mudstones, grainstones, and mudstone-matrix boundstones. Digitate stromatolites and crypt-algal laminates are present. Thin shales are present throughout but shale content and bed thickness increases near the contact with the Davis Formation.

The depth from land surface to the top of the Derby-Doerun Dolomite (the uppermost formation mapped) ranges from 970 to 1,598 feet and the altitude of the top of the formation ranges from 18 feet above sea level to 788 feet below sea level. The Derby - Doerun Dolomite structure map is similar to that of the Davis Formation with the two structural highs in the study area and the general slope of the formation to the south.

Typically the combined thickness of the Derby-Doerun Dolomite and Davis Formation (St. Francois confining unit) ranges from 250 to 375 feet thick in the study area; however, the confining unit was logged at more than 400 feet thick for several boreholes. Most of these boreholes had abnormally thick Derby-Doerun Dolomite sequences. This may have been a result of the Potosi Dolomite near the conformable contact with the Derby-Doerun Dolomite being logged as Derby-Doerun Dolomite. The net shale thickness of the St. Francois confining unit ranges from less than 50 feet in the northeast part of the study area to more than 150 feet in the southwest.

Laboratory vertical hydraulic conductivity and porosity analysis were performed on 88 core samples primarily representing the various rock types present in the St. Francois confining unit of the Fristoe Unit and the Viburnum Trend area. The vertical permeability values were converted to vertical hydraulic conductivity. Vertical hydraulic conductivity ranged from 8.70×10^{-8} foot per second for one sample to less than 3.17×10^{-14} foot per second (the reporting limit) for 39 samples. The porosity values ranged from a high of 17.47 percent to a low of 0.36 percent. There did not appear to be a strong correlation between vertical hydraulic conductivity and porosity.

There is no significant difference (p-value = 0.375) between the ranked vertical hydraulic conductivity of samples collected from the Derby-Doerun Dolomite and Davis Formation in the Fristoe Unit. The interquartile range of vertical hydraulic conductivity shown for the Derby-Doerun Dolomite samples has more than an order of magnitude greater span than the interquartile range shown for the Davis Formation samples.

In the Viburnum Trend, there is a statistically significant difference (p-value = 0.006) between the ranked vertical hydraulic conductivity of the Derby-Doerun Dolomite and the Davis Formation. Although the vertical hydraulic conductivity of both formations is small, the median vertical hydraulic conductivity of the Derby-Doerun Dolomite is more than an order of magnitude greater than the median vertical hydraulic conductivity for the Davis Formation.

In the Fristoe Unit, there is no statistically significant (p-value = 0.790) vertical hydraulic conductivity difference in ranked samples containing carbonate or shale or both rock types. This is also true when comparing ranked samples containing carbonate or shale or both rock types from the Viburnum Trend (p-value = 0.412), even though carbonate rocks have more than an order of magnitude greater median vertical hydraulic conductivity than shales. Also, samples from the Viburnum Trend that contain both carbonate and shale have a larger vertical hydraulic conductivity variability than samples from either individual rock type. Samples containing both rock types span the same vertical hydraulic conductivity range as the carbonate and shale together.

The net shale thickness is not the single controlling factor that determines the effectiveness of the confining unit. Because the vertical hydraulic conductivity of the carbonate rocks and shale in the confining unit are similar, the entire carbonate-shale thickness is important in determining the effectiveness of the confining unit.

The range of estimated effective vertical hydraulic conductivity for the St. Francois confining unit in the study area was calculated using the results of this study. The calculations used 300 feet as the typical thickness of the confining unit; 50 and 150 feet as the lower and upper net shale thickness ranges; 1×10^{-12} to 3×10^{-14} foot per second as the upper and lower vertical hydraulic conductivity range (upper and lower quartiles) of the carbonate rock; and 9×10^{-13} to 3×10^{-14} foot per second as the upper and lower vertical hydraulic conductivity range (upper and lower quartiles) of the shale. Resulting estimates of effective vertical hydraulic conductivity were calculated to be a maximum of 1×10^{-12} foot per second and a minimum of 3×10^{-14} foot per second. These vertical hydraulic conductivity values are small, allowing the confining unit to effectively impede the flow of ground water between the Ozark aquifer and the St. Francois aquifer, unless preferred-path secondary permeability has developed along faults and fractures.

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TABLES

Table 1. Core log analysis data

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
1	19760930	365658	911908	AMAX 766-002	T26N R03W 06DBB1	1,022	2,155
2	19761108	370022	911452	AMAX 801-001	T27N R03W 14CAA1	900	1,586
3	19770321	365747	911722	AMAX 801-002	T27N R03W 33CBD1	1,006	2,135
4	19761123	365607	911907	AMAX 801-003	T26N R03W 07DBA1	886	1,975
5	19761126	365658	912432	AMAX 801-004	T26N R04W 05DAB1	962	2,105
6	19761204	365400	912105	AMAX 801-005	T26N R04W 26AAA1	820	2,056
7	19761207	365614	911415	AMAX 801-006	T26N R03W 12BCB1	835	2,020
8	19770104	365154	911010	AMAX 801-007	T25N R02W 04AAD1	780	2,125
9	19770203	365716	912818	AMAX 801-008	T26N R05W 02BCA1	1,015	2,128
10	19770223	365649	912227	AMAX 801-009	T26N R04W 03DCA1	895	2,030
11	19761218	365929	912312	AMAX 801-010	T27N R04W 21DAD1	985	2,089
12	19770116	365507	911847	AMAX 801-011	T26N R03W 18DDA2	895	1,803
13	19770203	365525	912309	AMAX 801-012	T26N R04W 15BCC1	960	2,109
14	19770205	365406	911142	AMAX 801-013	T26N R02W 20DBC1	905	2,070
15	19770222	365837	911130	AMAX 801-014	T27N R02W 29DBB1	830	1,919
16	19770830	365133	911706	AMAX 801-015	T25N R03W 04DCA1	635	1,985
17	19770225	365009	911958	AMAX 801-016	T25N R03W 18BCC1	905	2,245
18	19780103	364911	911713	AMAX 801-017	T25N R03W 21ACC1	590	1,875
19	19790713	365801	911152	AMAX 801-018	T27N R02W 32BBD1	780	1,963
20	19790822	365454	911739	AMAX 801-019	T26N R03W 16CCC1	950	2,080
21	19790728	365415	911803	AMAX 801-020	T26N R03W 20DBD1	920	2,026
22	19790809	365424	911639	AMAX 801-021	T26N R03W 21DAA1	975	2,111
23	19790719	365330	911259	AMAX 801-022	T26N R02W 30BDC1	980	2,147

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
1	1,425	-403	70	1,495	-473	212	282		1,707	-685	405	2,112	-1,090			
2	1,171	-271	59	1,230	-330	196	255		1,426	-526					1,550	-650
3	1,445	-439	50	1,495	-489	241	291	71	1,736	-730	395	2,131	-1,125			
4	1,284	-398	61	1,345	-459	218	279		1,563	-677	404	1,967	-1,081			
5	1,375	-413	81	1,456	-494	290	371		1,746	-784	325	2,071	-1,109			
6	1,345	-525	85	1,430	-610	192	277		1,622	-802	427	2,049	-1,229			
7	1,335	-500	49	1,384	-549	260	309		1,644	-809	375	2,019	-1,184			
8	1,405	-625	76	1,481	-701	219	295		1,700	-920	408	2,108	-1,328			
9	1,397	-382	66	1,463	-448	304	370		1,767	-752	345	2,112	-1,097			
10	1,382	-487	43	1,425	-530	210	253	82	1,635	-740	374	2,009	-1,114			
11	1,478	-493	24	1,502	-517	266	290	84	1,768	-783	299	2,067	-1,082			
12	1,230	-335	61	1,291	-396	191	252		1,482	-587						
13	1,405	-445	58	1,463	-503	261	319		1,724	-764	363	2,087	-1,127			
14	1,354	-449	66	1,420	-515	256	322		1,676	-771	392	2,068	-1,163			
15				1,298	-468	210			1,508	-678	399	1,907	-1,077			
16	1,235	-600	59	1,294	-659	238	297		1,532	-897	431	1,963	-1,328			
17	1,525	-620	62	1,587	-682	225	287	125	1,812	-907	427	2,239	-1,334			
18				1,171	-581	250			1,421	-831	445	1,866	-1,276			
19	1,335	-555					183		1,518	-738	422	1,940	-1,160			
20	1,370	-420	57	1,427	-477	255	312		1,682	-732	381	2,063	-1,113			
21	1,346	-426	85	1,431	-511	194	279		1,625	-705					2,021	-1,101
22	1,384	-409	58	1,442	-467	246	304		1,688	-713	397	2,085	-1,110	20	2,105	-1,130
23	1,348	-368	97	1,445	-465	260	357	33	1,705	-725	399	2,104	-1,124			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
24	19791008	365820	911143	AMAX 801-024	T27N R02W 29CDA1	730	1,867
25	19791020	365543	911825	AMAX 801-025	T26N R03W 17BAB1	940	2,048
26	19790728	365214	911302	AMAX 801-026	T26N R02W 31CDC3	975	1,924
27	19791207	365543	912159	AMAX 801-027	T26N R04W 14BBA1	990	2,136
28	19790927	365541	912038	AMAX 801-028	T26N R04W 13BAA1	985	2,055
29	19790921	365442	911915	AMAX 801-029	T26N R03W 19ABC1	920	2,102
30	19790830	365424	911949	AMAX 801-030	T26N R03W 19CBB1	880	2,095
31	19791002	365301	912114	AMAX 801-031	T26N R04W 35AAC1	920	2,190
32	19791011	365536	911825	AMAX 801-032	T26N R03W 17BAC2	920	2,033
33	19800206	365619	911915	AMAX 801-033	T26N R03W 07ACB1	880	1,977
34	19791026	365500	911739	AMAX 801-034	T26N R03W 16CCB1	930	2,116
35	19791113	365449	911907	AMAX 801-035	T26N R03W 19ABA1	880	2,020
36	19791112	365443	911746	AMAX 801-036	T26N R03W 20AAD1	970	1,983
37	19791210	365437	911753	AMAX 801-037	T26N R03W 20ADB1	1,035	2,090
38	19791031	365526	911831	AMAX 801-038	T26N R03W 17BCA1	920	2,097
39	19791106	365518	911841	AMAX 801-039	T26N R03W 17CBB1	830	1,832
40	19791127	365410	911639	AMAX 801-040	T26N R03W 21DDA1	980	1,945
41	19800123	365510	911729	AMAX 801-041	T26N R03W 16CBD1	960	2,120
42	19791213	365646	912338	AMAX 801-042	T26N R04W 04DCC1	980	2,147
43	19791218	365406	911802	AMAX 801-043	T26N R03W 20DCD1	905	2,106
44	19800215	365430	911758	AMAX 801-044	T26N R03W 20ADC1	970	1,738
45	19800111	365545	912057	AMAX 801-045	T26N R04W 13BBB1	940	2,007
46	19791228	365543	912115	AMAX 801-046	T26N R04W 14AAB1	830	1,957

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
24	1,270	-540					189		1,459	-729	397	1,856	-1,126			
25	1,351	-411	63	1,414	-474	212	275		1,626	-686	420	2,046	-1,106			
26	1,405	-430	64	1,469	-494	233	297	30	1,702	-727					1,914	-939
27	1,396	-406	120	1,516	-526	202	322		1,718	-728	388	2,106	-1,116			
28	1,430	-445	62	1,492	-507	207	269		1,699	-714	348	2,047	-1,062			
29	1,427	-507	67	1,494	-574	204	271		1,698	-778	375	2,073	-1,153			
30	1,366	-486	88	1,454	-574	208	296		1,662	-782	426	2,088	-1,208			
31	1,465	-545	77	1,542	-622	222	299	80	1,764	-844	416	2,180	-1,260			
32	1,371	-451	34	1,405	-485	214	248		1,619	-699	412	2,031	-1,111			
33	1,287	-407	78	1,365	-485	205	283	94	1,570	-690	369	1,939	-1,059			
34	1,373	-443	38	1,411	-481	220	258	61	1,631	-701	481	2,112	-1,182			
35	1,336	-456	47	1,383	-503	213	260		1,596	-716	413	2,009	-1,129			
36	1,372	-402	25	1,397	-427	214	239		1,611	-641					1,981	-1,011
37	1,414	-379	66	1,480	-445	205	271		1,685	-650	370	2,055	-1,020	30	2,085	-1,050
38	1,349	-429	74	1,423	-503	217	291		1,640	-720	437	2,077	-1,157			
39	1,192	-362	63	1,255	-425	206	269		1,461	-631	360	1,821	-991			
40	1,307	-327	58	1,365	-385	260	318		1,625	-645					1,914	-934
41	1,418	-458	54	1,472	-512	213	267		1,685	-725	413	2,098	-1,138			
42	1,506	-526	79	1,585	-605	228	307	71	1,813	-833	315	2,128	-1,148			
43	1,368	-463	97	1,465	-560	202	299	46	1,667	-762	419	2,086	-1,181			
44	1,297	-327	63	1,360	-390	188	251		1,548	-578					1,672	-702
45	1,358	-418	69	1,427	-487	224	293		1,651	-711	348	1,999	-1,059			
46	1,284	-454	71	1,355	-525	212	283	49	1,567	-737	358	1,925	-1,095			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
47	19800418	365104	911854	AMAX 801-047	T25N R03W 08BCB1	895	2,247
48	19800606	365654	912315	AMAX 801-048	T26N R04W 04DAD1	890	2,038
49	19800229	365818	911808	AMAX 801-049	T27N R03W 32BAA1	1,030	2,137
50	19800503	365410	911649	AMAX 801-050	T26N R03W 21DDB1	960	2,072
51	19800328	365147	911813	AMAX 801-051	T25N R03W 05ACD1	840	2,185
52	19800328	365310	911301	AMAX 801-052	T26N R02W 30CDB1	990	2,200
53	19800314	365222	911306	AMAX 801-053	T26N R02W 31CDB1	985	2,169
54	19800319	365129	911837	AMAX 801-054	T25N R03W 05CDB1	920	2,267
55	19800416	365249	911413	AMAX 801-055	T26N R03W 36BCA1	795	1,947
56	19800326	365041	912102	AMAX 801-056	T25N R04W 12CCB1	920	2,247
57	19800409	365206	912150	AMAX 801-057	T25N R04W 02BAC1	980	2,234
58	19800716	365307	912106	AMAX 801-058	T26N R04W 35AAA1	920	2,195
59	19800228	365642	912147	AMAX 801-059	T26N R04W 02CDD1	985	1,968
60	19800207	365555	911853	AMAX 801-060	T26N R03W 07DDA1	865	1,972
61	19800125	365549	911855	AMAX 801-061	T26N R03W 07DDC1	855	1,977
62	19800408	365121	911436	AMAX 801-062	T25N R03W 02DDD1	1,010	2,325
63	19800220	365540	912000	AMAX 801-063	T26N R04W 13AAA1	980	1,972
64	19800628	365618	912620	AMAX 801-064	T26N R04W 07BCA1	980	2,099
65	19800425	365152	911515	AMAX 801-065	T25N R03W 02BDC1	950	2,557
66	19800503	365511	912057	AMAX 801-066	T26N R04W 13CBC1	915	2,137
67	19800813	365513	912055	AMAX 801-067	T26N R04W 13CBD1	945	2,148
68	19800905	365543	912221	AMAX 801-068	T26N R04W 15AAB1	900	2,062
69	19800512	365424	911958	AMAX 801-069	T26N R03W 19CBB1	885	2,117

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
47	1,455	-560	71	1,526	-631	278	349	106	1,804	-909	424	2,228	-1,333			
48	1,337	-447	131	1,468	-578	194	325	96	1,662	-772	350	2,012	-1,122			
49	1,455	-425	55	1,510	-480	202	257	57	1,712	-682	387	2,099	-1,069			
50	1,355	-395	65	1,420	-460	203	268	77	1,623	-663	427	2,050	-1,090			
51	1,430	-590	62	1,492	-652	254	316	100	1,746	-906	432	2,178	-1,338			
52	1,459	-469	66	1,525	-535	195	261		1,720	-730	468	2,188	-1,198			
53	1,452	-467	50	1,502	-517	255	305	58	1,757	-772	390	2,147	-1,162			
54	1,470	-550	64	1,534	-614	286	350	72	1,820	-900	428	2,248	-1,328			
55	1,235	-440	72	1,307	-512	180	252		1,487	-692	444	1,931	-1,136			
56	1,451	-531	63	1,514	-594	283	346		1,797	-877	436	2,233	-1,313			
57	1,487	-507	64	1,551	-571	293	357		1,844	-864	383	2,227	-1,247			
58	1,488	-568	82	1,570	-650	202	284		1,772	-852	416	2,188	-1,268			
59	1,317	-332	73	1,390	-405	237	310		1,627	-642	330	1,957	-972			
60	1,297	-432	63	1,360	-495	190	253		1,550	-685	402	1,952	-1,087			
61	1,284	-429	72	1,356	-501	193	265		1,549	-694	422	1,971	-1,116			
62	1,567	-557	70	1,637	-627	238	308	88	1,875	-865	441	2,316	-1,306			
63	1,348	-368	67	1,415	-435	217	284	51	1,632	-652					1,931	-951
64	1,366	-386	99	1,465	-485	240	339	162	1,705	-725	360	2,065	-1,085			
65	1,497	-547	65	1,562	-612	237	302	80	1,799	-849	441	2,240	-1,290			
66	1,430	-515	71	1,501	-586	220	291	71	1,721	-806	399	2,120	-1,205			
67	1,417	-472	112	1,529	-584	199	311	59	1,728	-783	308	2,036	-1,091			
68	1,375	-475	77	1,452	-552	187	264	79	1,639	-739	394	2,033	-1,133			
69	1,382	-497	88	1,470	-585	205	293		1,675	-790	420	2,095	-1,210			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
70	19800523	365004	911633	AMAX 801-070	T25N R03W 15BDC1	640	1,926
71	19800520	365531	911831	AMAX 801-071	T26N R03W 17BCA2	930	2,100
72	19800530	365536	911827	AMAX 801-072	T26N R03W 17BAC1	930	2,068
73	19800614	365115	911329	AMAX 801-073	T25N R03W 12AAA1	990	2,345
74	19800618	365430	911941	AMAX 801-074	T26N R03W 19BCD1	900	2,108
75	19800723	365433	911929	AMAX 801-075	T26N R03W 19BDC1	830	2,018
76	19800718	365906	912210	AMAX 801-076	T27N R04W 27AAD1	1,090	2,052
77	19800826	365533	912053	AMAX 801-077	T26N R04W 13BCA1	985	2,088
78	19800819	365521	912058	AMAX 801-078	T26N R04W 13BCC1	940	2,135
79	19800725	365543	912014	AMAX 801-079	T26N R04W 13AAB1	950	2,036
80	19800623	365536	912044	AMAX 801-080	T26N R04W 13BAC1	975	2,078
81	19800628	365539	912032	AMAX 801-081	T26N R04W 13BAD1	960	2,084
82	19800703	365542	912045	AMAX 801-082	T26N R04W 13BAB1	955	2,058
83	19800714	365544	912055	AMAX 801-083	T26N R04W 13BBA1	920	1,989
84	19800718	365538	912026	AMAX 801-084	T26N R04W 13ABC1	920	2,053
85	19800806	365201	911516	AMAX 801-085	T25N R03W 02BAC1	920	2,285
86	19800801	364934	911722	AMAX 801-086	T25N R03W 21BAA1	690	2,148
87	19800812	364950	912044	AMAX 801-087	T25N R04W 13CDB1	890	2,248
88	19800903	365601	911841	AMAX 801-088	T26N R03W 08CBC1	870	1,974
89	19801025	365302	911256	AMAX 801-089	T26N R02W 30CDD1	1,000	2,165
90	19801103	365243	911254	AMAX 801-090	T26N R02W 31BDA1	970	2,218
91	19801107	365254	911302	AMAX 801-091	T26N R02W 31BAC1	980	2,173
92	19801124	365231	911302	AMAX 801-092	T26N R02W 31CAB1	990	2,223

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
70	1,159	-519	66	1,225	-585	237	303		1,462	-822	439	1,901	-1,261			
71	1,354	-424	73	1,427	-497	206	279		1,633	-703	465	2,098	-1,168			
72	1,358	-428	72	1,430	-500	198	270		1,628	-698	425	2,053	-1,123			
73	1,562	-572	71	1,633	-643	213	284	71	1,846	-856	496	2,342	-1,352			
74	1,393	-493	87	1,480	-580	202	289		1,682	-782	416	2,098	-1,198			
75	1,299	-469	80	1,379	-549	208	288	54	1,587	-757	414	2,001	-1,171			
76	1,538	-448	109	1,647	-557	158	267	43	1,805	-715	337	2,142	-1,052			
77	1,453	-468	66	1,519	-534	204	270	74	1,723	-738	342	2,065	-1,080			
78	1,442	-502	63	1,505	-565	213	276	72	1,718	-778	407	2,125	-1,185			
79	1,340	-390	61	1,401	-451	204	265	62	1,605	-655	396	2,001	-1,051			
80	1,450	-475	65	1,515	-540	198	263	50	1,713	-738	354	2,067	-1,092			
81	1,393	-433	74	1,467	-507	202	276	62	1,669	-709	398	2,067	-1,107			
82	1,374	-419	78	1,452	-497	203	281	62	1,655	-700	387	2,042	-1,087			
83	1,345	-425	64	1,409	-489	207	271	98	1,616	-696	352	1,968	-1,048			
84	1,351	-431	74	1,425	-505	208	282	63	1,633	-713	402	2,035	-1,115			
85	1,562	-642	59	1,621	-701	204	263		1,825	-905	437	2,262	-1,342			
86	1,413	-723	75	1,488	-798	210	285	143	1,698	-1008	445	2,143	-1,453			
87	1,496	-606	57	1,553	-663	269	326	87	1,822	-932	408	2,230	-1,340			
88	1,288	-418	63	1,351	-481	186	249	44	1,537	-667	410	1,947	-1,077			
89	1,471	-471	68	1,539	-539	226	294	47	1,765	-765	342	2,107	-1,107	46	2,153	-1,153
90	1,477	-507	70	1,547	-577	236	306		1,783	-813	400	2,183	-1,213			
91	1,454	-474	71	1,525	-545	231	302		1,756	-776	399	2,155	-1,175	14	2,169	-1,189
92	1,502	-512	86	1,588	-598	248	334		1,836	-846	383	,2219	-1,229			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
93	19800823	364902	912047	AMAX 801-093	T25N R04W 24CAC1	580	1,962
94	19801003	365150	911716	AMAX 801-094	T25N R03W 04ACC1	640	2,002
95	19800919	365051	911701	AMAX 801-095	T25N R03W 09DAB1	830	2,221
96	19800910	365417	912028	AMAX 801-096	T26N R04W 24DBC1	910	2,128
97	19800927	365406	912031	AMAX 801-097	T26N R04W 24DCC1	890	2,111
98	19800919	365358	912042	AMAX 801-098	T26N R04W 25BAB1	840	2,096
99	19800912	365512	912046	AMAX 801-099	T26N R04W 13CAC1	900	2,085
100	19800920	365519	912041	AMAX 801-100	T26N R04W 13CAB1	900	2,073
101	19800927	365528	912040	AMAX 801-101	T26N R04W 13BDB1	960	2,124
102	19801011	365444	911914	AMAX 801-102	T26N R03W 19ABC2	910	2,088
103	19801018	365524	911836	AMAX 801-103	T26N R03W 17BCD1	940	1,854
104	19801002	365532	912026	AMAX 801-104	T26N R04W 13ACB1	900	2,058
105	19801211	365203	911304	AMAX 801-105	T25N R02W 06BAB1	970	2,204
106	19801209	365156	912231	AMAX 801-106	T25N R04W 03ACD1	986	2,278
107	19801122	365543	912132	AMAX 801-107	T26N R04W 14ABB1	950	2,138
108	19801018	365510	911843	AMAX 801-108	T26N R03W 17CBC1	840	1,882
109	19800000	365502	911849	AMAX 801-109	T26N R03W 18DDA3	910	1,832
110	19801108	365456	911858	AMAX 801-110	T26N R03W 18DDC1	900	1,944
111	19801111	365604	911945	AMAX 801-111	T26N R03W 07CBC1	880	1,987
112	19801112	365559	911942	AMAX 801-112	T26N R03W 07C 1	930	1,884
113	19801217	364850	911907	AMAX 801-114	T25N R03W 19DDC1	925	2,328
114	19801230	365546	912139	AMAX 801-115	T26N R04W 14BAA1	960	2,099
115	19801230	365542	912125	AMAX 801-116	T26N R04W 14ABA	945	2,100

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
93	1,193	-613	97	1,290	-710	221	318		1,511	-931	437	1,948	-1,368			
94	1,279	-639	67	1,346	-706	213	280	102	1,559	-919	427	1,986	-1,346			
95	1,505	-675	78	1,583	-753	196	274		1,779	-949	438	2,217	-1,387			
96	1,429	-519	63	1,492	-582	203	266	74	1,695	-785	424	2,119	-1,209			
97	1,399	-509	87	1,486	-596	200	287	77	1,686	-796	418	2,104	-1,214			
98	1,385	-545	72	1,457	-617	213	285	89	1,670	-830	413	2,083	-1,243			
99	1,387	-487	59	1,446	-546	206	265	73	1,652	-752	418	2,070	-1,170			
100	1,381	-481	67	1,448	-548	197	264	73	1,645	-745	407	2,052	-1,152			
101	1,413	-453	75	1,488	-528	212	287		1,700	-740	405	2,105	-1,145			
102	1,390	-480	70	1,460	-550	189	259		1,649	-739	417	2,066	-1,156			
103	1,291	-351	65	1,356	-416	185	250		1,541	-601					1,845	-905
104	1,334	-434	68	1,402	-502	206	274	41	1,608	-708	413	2,021	-1,121			
105	1,467	-497	70	1,537	-567	217	287		1,754	-784	406	2,160	-1,190	33	2,193	-1,223
106	1,533	-547	99	1,632	-646	209	308	104	1,841	-855	422	2,263	-1,277			
107	1,412	-462	85	1,497	-547	197	282		1,694	-744	412	2,106	-1156			
108	1,221	-381	60	1,281	-441	192	252	57	1,473	-633	398	1,871	-1,031	8	1,879	-1,039
109	1,237	-327	75	1,312	-402	180	255		1,492	-582	239	1,731	-821	13	1,744	-834
110	1,296	-396	63	1,359	-459	191	254		1,550	-650	382	1,932	-1,032	10	1,942	-1,042
111	1,301	-421	61	1,362	-482	152	213		1,514	-634	426	1,940	-1,060			
112	1,308	-378	56	1364	-434	195	251		1,559	-629					1,878	-948
113	1,564	-639	44	1,608	-683	266	310	114	1,874	-949	430	2,304	-1,379			
114	1,412	-452	83	1,495	-535	197	280		1,692	-732	407	2,099	-1,139			
115	1,393	-448	83	1,476	-531	198	281		1,674	-729	398	2072	-1,127			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
116	19801229	365207	912203	AMAX 801-117	T25N R04W 02BBC1	979	2,258
117	19810116	365155	912215	AMAX 801-118	T25N R04W 03ADD1	960	2,258
118	19810110	365205	912103	AMAX 801-119	T25N R04W 01BBC1	960	2,258
119	19810122	365041	912015	AMAX 801-120	T25N R04W 12DDB1	920	2,268
120	19810130	365233	912044	AMAX 801-121	T26N R04W 36CAC1	940	2,251
121	19810207	365136	912133	AMAX 801-122	T25N R04W 02DCB1	930	2,254
122	19810226	365210	911920	AMAX 801-123	T25N R03W 06AB1	935	2,263
123	19810305	365250	911915	AMAX 801-124	T26N R03W 31ACB1	900	2,428
124	19810307	365809	912214	AMAX 801-125	T27N R04W 34ADA1	1,020	2,178
125	19810311	365543	912107	AMAX 801-126	T26N R04W 14AAA1	945	2,078
126	19810313	365543	912146	AMAX 801-127	T26N R04W 14BAB1	990	2,123
127	19810321	365111	912035	AMAX 801-128	T25N R04W 12BDA1	940	2,278
128	19810321	365131	912206	AMAX 801-129	T25N R04W 02CCC1	855	2,148
129	19810330	365114	912128	AMAX 801-131	T25N R04W 11ABD1	890	2,248
130	19810416	365602	911933	AMAX 801-132	T26N R03W 07C 2	870	1,990
131	19810406	365601	911950	AMAX 801-133	T26N R03W 07CBC1	885	2,008
132	19810416	365612	911928	AMAX 801-134	T26N R03W 07DBB1	950	2,068
133	19810417	365505	912114	AMAX 801-135	T26N R04W 14DDB1	960	2,160
134	19810425	365235	911930	AMAX 801-136	T26N R03W 31CAD1	880	2,258
135	19810504	365255	912030	AMAX 801-137	T26N R04W 36ACB1	905	2,208
136	19810727	365642	912204	AMAX 801-138	T26N R04W 02CCC1	925	2,041
137	19810606	365031	912320	AMAX 801-139	T25N R04W 16AAA1	680	1,968
138	19810613	365640	911910	AMAX 801-142	T26N R03W 06DCC1	950	2,074

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
116	1,532	-553	94	1,626	-647	214	308		1,840	-861	400	2,240	-1,261			
117	1,521	-561	112	1,633	-673	198	310		1,831	-871	415	2,246	-1,286			
118	1,546	-586	67	1,613	-653	224	291		1,837	-877	409	2,246	-1,286			
119	1,528	-608	70	1,598	-678	223	293		1,821	-901	428	2,249	-1,329			
120	1,518	-578	97	1,615	-675	199	296	63	1,814	-874	425	2,239	-1,299			
121	1,523	-593	110	1,633	-703	192	302	75	1,825	-895	417	2,242	-1,312			
122	1,519	-584	98	1,617	-682	207	305	79	1,824	-889	425	2,249	-1,314			
123	1,485	-585	70	1,555	-655	216	286	76	1,771	-871						
124	1,481	-461	74	1,555	-535	203	277	60	1,758	-738	378	2,136	-1,116			
125	1,396	-451	68	1,464	-519	201	269	66	1,665	-720	400	2,065	-1,120			
126	1,434	-444	88	1,522	-532	197	285		1,719	-729	400	2,119	-1,129			
127	1,544	-604	81	1,625	-685	214	295		1,839	-899	427	2,266	-1,326			
128	1,404	-549	98	1,502	-647	201	299		1,703	-848	424	2,127	-1,272			
129	1,481	-591	74	1,555	-665	219	293		1,774	-884	426	2,200	-1,310			
130	1,283	-413	72	1,355	-485	201	273		1,556	-686	376	1,932	-1,062			
131	1,303	-418	49	1,352	-467	201	250		1,553	-668	361	1,914	-1,029			
132	1,374	-424	68	1,442	-492	200	268		1,642	-692	390	2,032	-1,082			
133	1,456	-496	74	1,530	-570	198	272	64	1,728	-768	412	2,140	-1,180			
134	1,524	-644	73	1,597	-717	203	276		1,800	-920	428	2,228	-1,348			
135	1,498	-593	70	1,568	-663	201	271	82	1,769	-864	417	2,186	-1,281			
136	1,340	-415	89	1,429	-504	204	293		1,633	-708	388	2,021	-1,096			
137	1,246	-566	67	1,313	-633	222	289		1,535	-855	405	1,940	-1,260			
138	1,390	-440	66	1,456	-506	196	262		1,652	-702	395	2,047	-1,097			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
139	19810625	365637	911955	AMAX 801-143	T26N R03W 07BBB1	980	2,088
140	19810619	365540	911908	AMAX 801-144	T26N R03W 18ABA1	853	1,969
141	19810717	365539	911919	AMAX 801-145	T26N R03W 18ABB1	920	2,068
142	19810725	365459	912127	AMAX 801-146	T26N R04W 14DCC1	800	2,000
143	19810815	365314	912200	AMAX 801-147	T26N R04W 26CCD1	955	2,216
144	19810918	365051	912202	AMAX 801-148	T25N R04W 11CBD1	920	2,241
145	19810828	365128	912229	AMAX 801-149	T25N R04W 03DCD1	910	2,207
146	19810824	365211	911305	AMAX 801-150	T26N R02W 31CDC3	975	1,870
147	19810904	365539	912144	AMAX 801-151	T26N R04W 14BAB2	865	2,020
148	19810923	365334	912309	AMAX 801-152	T26N R04W 27CBB1	984	2,229
149	19820216	365526	912343	AMAX 801-153	T26N R04W 16ACC1	875	2,030
150	19820319	365446	912202	AMAX 801-155	T26N R04W 23BBC1	910	2,134
151	19820304	364944	912122	AMAX 801-156	T25N R04W 14DDC1	845	2,194
152	19820423	365520	912221	AMAX 801-157	T26N R04W 15ADC1	1,035	2,228
153	19820602	365039	912141	AMAX 801-158	T25N R04W 11CDD1	927	2,268
154	19830503	365810	912247	AMAX 801-163	T27N R04W 34BAD1	935	2,063
155	19830513	365334	912321	AMAX 801-164	T26N R04W 28DAA1	930	2,188
156	19830000	365333	912254	AMAX 801-165	T26N R04W 27CAB1	930	2,208
157	19830517	365816	912222	AMAX 801-166	T27N R04W 34AAC1	940	2,078
158	19830528	365327	912323	AMAX 801-167	T26N R04W 28DA 1	960	2,208
159	19800414	365828	912059	ASARCO PK-09	T27N R04W 25CCC1	1,020	2,124
160	19800612	370209	912006	ASARCO PK-12	T27N R04W 01DBD1	1,110	1,976
161	19800527	365733	912109	ASARCO PK-13	T27N R04W 35DDD	1,025	2,117

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
139	1,388	-408	73	1,461	-481	197	270		1,658	-678	412	2,070	-1,090			
140	1,269	-416	69	1,338	-485	194	263		1,532	-679	416	1,948	-1,095			
141	1,358	-438	66	1,424	-504	198	264		1,622	-702	418	2,040	-1,120			
142	1,286	-486	68	1,354	-554	195	263		1,549	-749	401	1,950	-1,150			
143	1,506	-551	87	1,593	-638	214	301	85	1,807	-852	402	2,209	-1,254			
144	1,528	-608	88	1,616	-696	203	291		1,819	-899	419	2,238	-1,318			
145	1,488	-578	86	1,574	-664	200	286		1,774	-864	420	2,194	-1,284			
146	1,390	-415	69	1,459	-484	203	272		1,662	-687					1,860	-885
147	1,322	-457	79	1,401	-536	199	278		1,600	-735	397	1,997	-1,132			
148	1,563	-579	74	1,637	-653	208	282		1,845	-861	365	2,210	-1,226			
149	1,404	-529	79	1,483	-608	195	274	125	1,678	-803	341	2,019	-1,144			
150	1,420	-510	80	1,500	-590	202	282	99	1,702	-792	403	2,105	-1,195			
151	1,421	-576	90	1,511	-666	213	303	74	1,724	-879	422	2,146	-1,301			
152	1,507	-472	93	1,600	-565	192	285	90	1,792	-757	404	2,196	-1,161			
153	1,542	-615	68	1,610	-683	206	274	104	1,816	-889	430	2,246	-1,319			
154	1,306	-371	144	1,450	-515	206	350		1,656	-721	363	2,019	-1,084			
155	1,507	-577	57	1,564	-634	141	198		1,705	-775						
156	1,498	-568	69	1,567	-637	170	239		1,737	-807						
157	1,390	-450	80	1,470	-530	194	274		1,664	-724	374	2,038	-1,098			
158	1,540	-580	63	1,603	-643	152	215		1,755	-795						
159									1,713	-693	391	2,104	-1,084			
160									1,555	-445						
161									1,714	-689	392	2,106	-1,081			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
162	19800508	365618	911655	ASARCO PK-14	T26N R03W 09ACA1	1,005	2,164
163	19800829	365602	912000	ASARCO PK-15	T26N R04W 12DAD1	950	2,140
164	19801024	365603	912034	ASARCO PK-17	T26N R04W 12CAD1	990	1,914
165	19801104	365638	912144	ASARCO PK-18	T26N R04W 11BAB1	980	1,631
166	19810303	365701	911402	ASARCO PK-26	T26N R03W 01BDC1	970	2,128
167	19810319	365741	912131	ASARCO PK-27	T27N R04W 35DCB1	1,000	2,109
168	19810523	370148	912117	ASARCO PK-28	T27N R04W 11ABA1	1,050	2,017
169	19810415	365753	912054	ASARCO PK-30	T27N R04W 36CBB1	1,065	2,161
170	19810506	365557	911319	ASARCO PK-32	T26N R02W 07DBB1	875	2,114
171	19810604	370140	911926	ASARCO PK-35	T27N R03W 07BCA1	995	1,955
172	19840709	365622	912012	AMSELCO PK-42	T26N R04W 12ADB1	915	2,004
173	19840730	365825	912055	AMSELCO PK-43	T27N R04W 25CCC2	1,025	2,133
174	19840816	365838	912054	AMSELCO PK-44	T27N R04W 25CBC1	1,010	2,135
175	19841200	365552	912035	ASARCO PK-46	T26N R04W 12CDD1	1,000	2,035
176	19810916	370007	911656	COMINCO SF-25	T27N R03W 16DCC1	950	2,004
177	19820513	365630	911232	COMINCO SF-28	T26N R02W 06DCD1	730	1,932
178	19810512	365742	911539	COMINCO SF-6	T27N R03W 34DAC1	985	2,161
179	19791129	370145	911902	COMINCO WN-21	T27N R03W 07ABC1	1,080	1,563
180	19800106	370150	911832	COMINCO WN-22	T27N R03W 08BBB1	1,060	1,903
181	19800125	370127	911821	COMINCO WN-23	T27N R03W 08BCD1	1,065	1,870
182	19631007	370121	911803	PH DDG 068689	T27N R03W 08C1	1,055	1,478
183	19631119	370101	911731	PH DDG 068689	T27N R03W 08D1	918	1,563
184	19631231	370037	911801	PH DDG 068691	T27N R03W 17A1	921	1,917

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
162	1,200	-195	319	1,519	-514	201	520		1,720	-715	439	2,159	-1,154			
163									1,647	-697	400	2,047	-1,097			
164				1,386	-396	200			1,586	-596					1,910	-920
165									1,485	-505					1,627	-647
166	1,337	-367	204	1,541	-571	102	306		1,643	-673	477	2,120	-1,150			
167	1,318	-318	257	1,575	-575	135	392		1,710	-710	385	2,095	-1,095			
168									1,607	-557	393	2,000	-950			
169				1,600	-535	142			1,742	-677	406	2,148	-1,083			
170	1,352	-477	162	1,514	-639	195	357		1,709	-834	400	2,109	-1,234			
171									1,464	-469	446	1,910	-915			
172				1,412	-497	165			1,577	-662	405	1,982	-1,067			
173	1,400	-375	142	1,542	-517	192	334		1,734	-709						
174				1,513	-503	191			1,704	-694	416	2,120	-1,110			
175				1,422	-422										2,018	-1,018
176	1,100	-150					456		1,556	-606	417	1,973	-1,023			
177	1,190	-460	197	1,387	-657	95	292		1,482	-752	402	1,884	-1,154			
178	1,413	-428	149	1,562	-577	153	302		1,715	-730	415	2,130	-1,145			
179									1,358	-278					1,547	-467
180									1,499	-439					1,837	-777
181	1,156	-91					357		1,513	-448					1,847	-782
182	1,105	-50	305	1,410	-355										1,437	-382
183	970	-52	348	1,318	-400	80	428		1,398	-480					1,557	-639
184	1,116	-195	209	1,325	-404	87	296		1,412	-491	448	1,860	-939	50	1,910	-989

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
185	19631017	370004	911417	PH DDG 068692	T27N R03W 14D1	914	1,976
186		370220	912019	PH DDG 27N4W1-1	T27N R04W 01CAA1	1,030	
187	19680626	370254	912627	ST JOE 68W44	T28N R05W 36DDB1	917	1,876
188	19760401	365612	910810	ST JOE 76W05	T26N R02W 11AB 1	631	1,948
189	19761216	365936	911610	ST JOE 76W20	T27N R03W 22CA 1	951	1,940
190	19770223	365754	911130	ST JOE 77W02	T27N R02W 32AC 1	761	1,806
191	19770405	370112	911915	ST JOE 77W03	T27N R03W 07CC 1	1,023	1,895
192	19770510	365918	911443	ST JOE 77W05	T27N R03W 23DC 1	808	1,912
193	19770517	365918	911048	ST JOE 77W06	T27N R02W 21CA 1	731	1,886
194	19770609	370027	912158	ST JOE 77W07	T27N R04W 14CB 1	1,033	1,999
195	19770623	370247	912044	ST JOE 77W08	T28N R04W 36CC 1	1,109	1,778
196	19770825	365943	911727	ST JOE 77W11	T27N R03W 21BC 1	901	1,987
197	19790222	365802	911628	ST JOE 79W03	T27N R03W 34BC 1	871	2,065
198	19790614	365247	911530	ST JOE 79W05	T26N R03W 35BC 1	706	2,045
199	19790626	370023	912423	ST JOE 79W06	T27N R04W 17DA 1	1,081	2,156
200	19790802	370125	912242	ST JOE 79W08	T27N R04W 10CA 1	1,106	2,158
201	19810511	370248	912000	ST JOE 81W09	T28N R04W 36DD 1	1,115	1,794
202	19811209	365207	911958	ST JOE 82W03	T25N R03W 06BB1	960	2,290
203	19811230	365205	912310	ST JOE 82W07	T25N R04W 03BB1	745	2,022
204	19820126	365359	911815	ST JOE 82W11	T26N R03W 29ABB1	920	2,179
205	19820324	365358	911459	ST JOE 82W19	T26N R03W 23CDD1	790	2,248
206	19820401	365404	911632	ST JOE 82W21	T26N R03W 22CCC1	970	1,528
207	19820429	365430	911632	ST JOE 82W25	T26N R03W 22 BCC1	965	2,171

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
185	1,149	-235	289	1,438	-524	86	375		1,524	-610	406	1,930	-1,016	27	1957	-1043
186	1,183	-153	284	1,467	-437	75	359		1,542	-512	466	2,008	-978			
187	1,227	-310	119	1,346	-429	232	351		1,578	-661	286	1,864	-947			
188	1,140	-509	156	1,296	-665	217	373		1,513	-882	298	1,811	-1,180			
189	1,255	-304	189	1,444	-493	143	332		1,587	-636	320	1,907	-956			
190	1,387	-626	124	1,511	-750	49	173		1,560	-799						
191	1,288	-265	149	1,437	-414	187	336		1,624	-601	229	1,853	-830			
192	1,252	-444	257	1,509	-701	41	298		1,550	-742	328	1,878	-1,070			
193	1,130	-399	222	1,352	-621	147	369		1,499	-768	367	1,866	-1,135			
194	1,360	-327	105	1,465	-432	256	361		1,721	-688	256	1,977	-944			
195	1,216	-107	174	1,390	-281	133	307		1,523	-414	234	1,757	-648	10	1,767	-658
196	1,343	-442	103	1,446	-545	218	321		1,664	-763	303	1,967	-1,066			
197	1,365	-494	51	1,416	-545	314	365		1,730	-859	328	2,058	-1,187			
198	1,272	-566	58	1,330	-624	323	381		1,653	-947	377	2,030	-1,324			
199	1,403	-322	158	1,561	-480	271	429		1,832	-751	310	2,142	-1,061			
200	1,448	-342	164	1,612	-506	233	397		1,845	-739	294	2,139	-1,033			
201	1,231	-116	140	1,371	-256	166	306	24	1,537	-422						
202	1,528	-568	91	1,619	-659	232	323	139	1,851	-891	421	2,272	-1,312			
203	1,266	-521	87	1,353	-608	265	352		1,618	-873	385	2,003	-1,258			
204				1,517	-597	202			1,719	-799	389	2,108	-1,188			
205				1,370	-580	176		83	1,546	-756	419	1,965	-1,175			
206									1,457	-487					1,521	-551
207				1,540	-575	203			1,743	-778	399	2,142	-1,177			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
208	19820609	365339	911823	ST JOE 82W27	T26N R03W 29BDD1	870	2,155
209	19820826	364753	911619	ST JOE 82W31	T25N R03W 27CDD1	540	1,945
210	19821012	364724	911324	ST JOE 82W34	T25N R02W 31BCC1	855	2,435
211	19820112	370054	911819	ST JOE 83W06	T27N R03W 17BBA1	985	1,982
212	19830209	370405	912202	ST JOE 83W09	T28N R04W 27ADC1	1,050	1,598
213	19830330	365128	912248	ST JOE 83W12	T25N R04W 03CD1	925	2,225
214	19830415	365419	911632	ST JOE 83W14	T26N R03W 22CBB1	985	1,549
215	19830516	365359	911612	ST JOE 83W15	T26N R03W 22CDD1	785	1,960
216	19830531	365036	912220	ST JOE 83W17	T25N R04W 10DDD1	918	2,242
217	19830725	364645	911523	ST JOE 83W25	T24N R03W 02ABC1	860	2,406
218	19830810	365209	912417	ST JOE 83W30	T25N R04W 04BCC1	930	2,196
219	19830825	365254	912350	ST JOE 83W34	T26N R04W 33BDA1	960	2,206
220	19830907	365135	912310	ST JOE 83W35	T25N R04W 03CCB1	725	1,987
221	19831017	370404	912225	ST JOE 83W44	T28N R04W 27BDD1	1,040	1,786
222	19840703	364658	911536	ST JOE 84W44	T24N R03W 02BAA1	805	2,337
223	19850122	365002	912138	ST JOE 85W09	T25N R04W 14DB 2	912	2,265
224	19850130	365021	912137	ST JOE 85W11	T25N R04W 14AB1	919	2,236
225	19850827	365004	912109	ST JOE 85W31	T25N R04W 14DA1	644	1,957
226	19851014	365655	912156	ST JOE 85W35	T26N R04W 02CBD1	890	1,946
227	19851011	365838	912100	ST JOE 85W37	T27N R04W 26DAD1	997	2,080
228	19851205	365001	912131	ST JOE 86W02	T25N R04W 14DB1	874	2,183
229	19880629	364622	911434	ST JOE 88W03	T24N R03W 01BDC1	810	2,400
230	19880727	364859	912007	ST JOE 88W04	T25N R04W 24DD1	920	2,321

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
208				1,495	-625	200		100	1,695	-825	410	2,105	-1,235			
209	1,150	-610	65	1,215	-675	240	305	145	1,455	-915	454	1,909	-1,369			
210								89								
211	1,312	-327	120	1,432	-447	171	291	27	1,603	-618	286	1,889	-904	63	1,952	-967
212	1,056	-6	194	1,250	-200	150	344		1,400	-350	152	1,552	-502	39	1,591	-541
213				1,546	-621	278			1,824	-899	375	2,199	-1,274			
214	1,282	-297	60	1,342	-357	140	200	75	1,482	-497					1,548	-563
215	1,174	-389	99	1,273	-488	180	279		1,453	-668					1,937	-1,152
216	1,420	-502	128	1,548	-630	282	410	117	1,830	-912	346	2,176	-1,258			
217	1,544	-684	139	1,683	-823	254	393	148	1,937	-1,077	460	2,397	-1,537			
218	1,259	-329	242	1,501	-571	337	579	156	1,838	-908	349	2,187	-1,257			
219	1,177	-217	386	1,563	-603	270	656	129	1,833	-873	296	2,129	-1,169			
220				1,353	-628	248			1,601	-876	384	1,985	-1,260			
221	1,022	18	233	1,255	-215	242	475		1,497	-457	211	1,708	-668	46	1,754	-714
222				1,601	-796	252			1,853	-1,048	464	2,317	-1,512			
223				1,552	-640	274			1,826	-914	421	2,247	-1,335			
224				1,540	-621	315			1,855	-936	366	2,221	-1,302			
225				1,271	-627	305			1,576	-932	370	1,946	-1,302			
226	1,266	-376	58	1,324	-434	314	372	96	1,638	-748	282	1,920	-1,030			
227	1,405	-408	49	1,454	-457	289	338	58	1,743	-746	281	2,024	-1,027			
228	1,447	-573	88	1,535	-661	267	355		1,802	-928						
229	1,598	-788	90	1,688	-878	254	344		1,942	-1,132	442	2,384	-1,574			
230	1,537	-617	112	1,649	-729	312	424	159	1,961	-1,041	347	2,308	-1,388			

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number (fig. 6)	Date drilled (YYYYMMDD)	Latitude (DDMMSS)	Longitude (DDMMSS)	Mining company borehole identification	Local well number	Altitude of land surface	Borehole depth
231	19880808	364849	912020	ST JOE 88W05	T25N R04W 24DD 2	870	2,245
232	19880817	365013	912140	ST JOE 88W06	T25N R04W 14AC1	910	2,221
233	19880912	364816	911946	ST JOE 88W09	T25N R03W 30CAB1	890	2,315
234	19890405	364853	912103	ST JOE 89W01	T25N R04W 24CCC1	551	1,935
235	19891206	364628	911356	ST JOE 89W22	T24N R03W 01ADD1	830	2,590
236	19900321	364621	911315	ST JOE 90W03	T24N R02W 06BDD1	850	2,505
237	19921130	365116	912153	ST JOE 93W08	T25N R04W 11BAC1	965	2,285
238	19930203	365120	912204	ST JOE 93W18	T25N R04W 11BBB1	930	2,262
					Minimum	540	1,478
					Maximum	1,115	2,590
Boreholes in Viburnum Trend from which core samples were collected and sent for laboratory permeability analysis							
VB1		372351	910717	ASARCO AC 37	T31N R02W 11AAAC1	1,160	
VB2		372209	911058	ASARCO AC 45	T31N R02W 17DBB1	1,270	
VB3		372235	910920	ASARCO AC 84	T31N R02W 15CBBD1	1,100	
VB4		372027	910924	ASARCO LC 503	T31N R02W 34BBB1	1,000	
VB5		371757	910846	ASARCO LC 810	T30N R02W 10DCD1	1,100	

Table 1. Core log analysis data—Continued

[YYYYMMDD, year, month, day; DDMMSS, degrees, minutes, seconds; all units for depth, altitude, and thickness are in feet; depth and altitude refer to the formation top]

Site number	Derby-Doerun Dolomite			Davis Formation			Thickness of St. Francois confining unit		Bonneterre Formation			Lamotte Sandstone			Precambrian rock	
(fig. 6)	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Total	Net shale	Depth	Altitude	Thickness	Depth	Altitude	Thickness	Depth	Altitude
231				1,521	-651	313			1,834	-964	397	2,231	-1,361			
232	1,500	-590	18	1,518	-608	319	337		1,837	-927	386	2,223	-1,313			
233	1,516	-626	99	1,615	-725	296	395		1,911	-1,021	390	2,301	-1,411			
234				1,250	-699	280		131	1,530	-979	386	1,916	-1,365			
235								124								
236	1,592	-742	100	1,692	-842	310	410	100	2,002	-1,152	448	2,450	-1,600			
237	1,501	-536	108	1,609	-644	283	391		1,892	-927	373	2,265	-1,300			
238	1,498	-568	86	1,584	-654	270	356		1,854	-924	390	2,244	-1,314			
	970	-788	18	1,171	-878	41	173	24	1,358	-1,152	152	1,552	-1,600	8	1,437	-1,223
	1,598	18	386	1,692	-200	337	656	162	2,002	-278	496	2,450	-502	63.	2,193	-382
Boreholes in Viburnum Trend from which core samples were collected and sent for laboratory permeability analysis																
VB1	780	380		897	263											
VB2	800	470		900	370											
VB3	728	372		844	256											
VB4	758	242		871	129											
VB5	965	135		1,065	35											

Table 2. Porosity, vertical permeability, and vertical hydraulic conductivity data

[DDR, Derby-Doerun Dolomite; DVS, Davis Formation; BNT, Bonneterre Formation, POT, Potosi Dolomite; C, carbonate rock; S, shale; B, both carbonate rock and shale; <, less than; %, percent]

Sample number	Mining company borehole identification	Formation	Sample depth, in feet	Confining pressure, in pounds per square inch (gauged)[1]	Porosity, in percent	Density, in grams per cubic centimeter	Vertical permeability, in millidarcies	Vertical hydraulic conductivity, in feet per second	Lithology	Description
						St. Joe Lead Company				
1	83W17	DDR	1,493	1,120	2.95	2.837	0.207	6.55 X 10^{-09}	C	Dolomitic wackestone with seam
2	83W17	DDR	1,542	1,170	4.06	2.845	<.000194	6.14 X 10^{-12}	C	Dolomitic siltstone
3	83W17	DVS	1,615	1,220	5.64	2.727	<.000001	<3.17 X 10^{-14}	S	Shale
4	83W17	DVS	1,692	1,280	1.40	2.698	<.000001	<3.17 X 10^{-14}	C	Shaley limey mudstone
5	83W17	DVS	1,762	1,340	3.12	2.732	<.000001	<3.17 X 10^{-14}	B	Limey wackestone (33%) shale
6	83W17	BNT	1,853	1,400	7.31	2.683	<.000001	<3.17 X 10^{-14}	B	Shale - dolostone
7	83W35	DDR	1,333	1,010	2.37	2.804	<.000001	<3.17 X 10^{-14}	C	Dolomitic wackestone
8	83W35	DDR	1,350	1,020	4.49	2.844	.000729	2.31 X 10^{-11}	C	Dolomitic grainstone
9	83W35	DVS	1,475	1,120	4.27	2.717	.000007	2.22 X 10^{-13}	B	Shale with limey wackestone
10	83W35	DVS	1,495	1,130	5.18	2.720	.000005	1.59 X 10^{-13}	S	Shale
11	83W35	DVS	1,516	1,150	2.46	2.713	.00815	2.58 X 10^{-10}	B	Limey wackestone (50%) with shale
12	83W35	DVS	1,597	1,210	3.88	2.753	<.000001	<3.17 X 10^{-14}	B	Shale with dolomitic wackestone
13	83W30	DDR	1,445	1,100	17.47	2.826	2.74	8.70 X 10^{-08}	C	Bleached dolomitic wackestone
14	83W30	DDR	1,494	1,130	1.99	2.831	.000012	3.90 X 10^{-13}	C	Dolomitic wackestone with shale partings
15	83W30	DVS	1,591	1,210	4.47	2.715	.000026	8.24 X 10^{-13}	B	Limey wackestone (5%) with shale
16	83W30	DVS	1,727	1,310	.46	2.703	<.000001	<3.17 X 10^{-14}	C	Limey wackestone with shale partings
17	83W30	DVS	1,796	1,360	5.74	2.777	.000021	6.66 X 10^{-13}	S	Shale
18	83W34	DDR	1,511	1,150	11.76	2.843	.585	1.85 X 10^{-08}	C	Dolomitic wackestone with minor leaching

Table 2. Porosity, vertical permeability, and vertical hydraulic conductivity data

[DDR, Derby-Doerun Dolomite; DVS, Davis Formation; BNT, Bonneterre Formation, POT, Potosi Dolomite; C, carbonate rock; S, shale; B, both carbonate rock and shale; <, less than; %, percent]

Sample number	Mining company borehole identification	Formation	Sample depth, in feet	Confining pressure, in pounds per square inch (gauged)[1]	Porosity, in percent	Density, in grams per cubic centimeter	Vertical permeability, in millidarcies	Vertical hydraulic conductivity, in feet per second	Lithology	Description
						St. Joe Lead Company—Continued				
19	83W34	DVS	1,573	1,190	1.93	2.754	<0.000001	$<3.17 \times 10^{-14}$	C	Dolomitic packestone with shale seams
20	83W34	DVS	1,685	1,280	5.32	2.689	.000054	1.71×10^{-12}	S	Shale
21	83W34	DVS	1,725	1,310	5.61	2.719	.000051	1.62×10^{-12}	S	Shale
22	83W34	DVS	1,785	1,350	3.28	2.801	<.000001	$<3.17 \times 10^{-14}$	C	Digitate limey mudstone with wackestone
23	83W34	DVS	1,791	1,360	5.99	2.754	<.000001	$<3.17 \times 10^{-14}$	B	Shale with dolomitic wackestone
24	82W03	DDR	1,564	1,190	.61	2.825	<.000001	$<3.17 \times 10^{-14}$	C	Dense dolomitic wackestone
25	82W03	DDR	1,581	1,200	.80	2.820	<.000001	$<3.17 \times 10^{-14}$	C	Dense dolomitic wackestone with styolite
26	82W03	DVS	1,624	1,230	2.37	2.820	.000035	1.11×10^{-12}	C	Dolomitic wackestone with shale partings
27	82W03	DVS	1,692	1,280	3.49	2.676	<.000001	$<3.17 \times 10^{-14}$	S	Shale
28	82W03	DVS	1,841	1,400	4.93	2.750	.000098	3.11×10^{-12}	S	Shale
29	82W03	BNT	1,894	1,440	3.18	2.804	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone
30	82W27	DDR	1,445	1,100	1.08	2.832	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone with shale partings
31	82W27	DDR	1,479	1,120	1.16	2.814	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone with shale partings
32	82W27	DVS	1,522	1,150	5.00	2.675	.000019	6.15×10^{-13}	S	Shale with limey wackestone (10%)
33	82W27	DVS	1,597	1,210	3.23	2.721	<.000001	$<3.17 \times 10^{-14}$	B	Shale 60% with limey wackestone 40%
34	82W27	DVS	1,679	1,280	6.7	2.782	.000036	1.14×10^{-12}	S	Shale 90% with dolomitic wackestone 10%
						Amax Lead Company				
35	801-002	POT	1,425	1,080	2.07	2.824	0.000047	1.49×10^{-12}	C	Dolomitic mudstone
36	801-002	DDR	1,479	1,120	3.54	2.843	.000004	1.27×10^{-13}	C	Dolomitic mudstone
37	801-002	DVS	1,508	1,140	1.73	2.756	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone with shale partings

Table 2. Porosity, vertical permeability, and vertical hydraulic conductivity data

[DDR, Derby-Doerun Dolomite; DVS, Davis Formation; BNT, Bonneterre Formation, POT, Potosi Dolomite; C, carbonate rock; S, shale; B, both carbonate rock and shale; <, less than; %, percent]

Sample number	Mining company borehole identification	Formation	Sample depth, in feet	Confining pressure, in pounds per square inch (gauged)[1]	Porosity, in percent	Density, in grams per cubic centimeter	Vertical permeability, in millidarcies	Vertical hydraulic conductivity, in feet per second	Lithology	Description
						Amax Lead Company—Continued				
38	801-002	DVS	1,521	1,150	.73	2.714	0.000010	3.17×10^{-13}	C	Limy mudstone with shale partings
39	801-002	DVS	1,544	1,170	4.02	2.680	.000022	6.97×10^{-13}	B	Shale with limey mudstone
40	801-002	DVS	1,578	1,200	.88	2.746	<.000001	$<3.17 \times 10^{-14}$	C	Limy wackestone
41	801-009	DDR	1,409	1,070	4.57	2.851	.0118	3.74×10^{-10}	C	Dolomitic mudstone
42	801-009	DVS	1,435	1,090	2.31	2.835	.000025	7.83×10^{-13}	C	Dolomitic mudstone with shale partings
43	801-009	DVS	1,457	1,100	2.59	2.641	.000021	6.56×10^{-13}	S	Shale
44	801-009	DVS	1,485	1,125	2.61	2.696	.000043	1.37×10^{-12}	C	Limey mudstone with shale partings
45	801-009	DVS	1,512	1,150	4.49	2.662	<.000001	$<3.17 \times 10^{-14}$	S	Shale
46	801-009	DVS	1,535	1,160	2.15	2.701	.000019	5.86×10^{-13}	B	Limey mudstone with shale
47	801-010	DDR	1,492	1,130	2.69	2.843	.000015	4.82×10^{-13}	C	Dolomitic mudstone with styolite
48	801-010	DVS	1,512	1,150	5.14	2.850	.00231	7.31×10^{-11}	C	Dolomitic mudstone with styolite
49	801-010	DVS	1,536	1,160	7.38	2.695	.000080	2.52×10^{-12}	C	Dolomitic wackestone with shale partings
50	801-010	DVS	1,564	1,190	2.65	2.699	.000016	5.10×10^{-13}	B	Limey mudstone with shale (40%)
51	801-010	DVS	1,585	1,200	4.52	2.666	<.000001	$<3.17 \times 10^{-14}$	S	Shale
52	801-010	DVS	1,608	1,220	.82	2.719	.000016	5.17×10^{-13}	B	Limey packestone with shale
53	801-016	DDR	1,528	1,160	1.23	2.840	.000016	4.91×10^{-13}	C	Dolomitic wackestone
54	801-016	DDR	1,560	1,180	.71	2.796	.000005	1.65×10^{-13}	S	Shale
55	801-016	DVS	1,602	1,210	3.13	2.719	<.000001	$<3.17 \times 10^{-14}$	B	Shale with limey wackestone (40%)
56	801-016	DVS	1,630	1,240	2.39	2.659	<.000001	$<3.17 \times 10^{-14}$	S	Shale
57	801-016	DVS	1,649	1,250	2.51	2.687	<.000001	$<3.17 \times 10^{-14}$	B	Limey wackestone with shale (40%)

Table 2. Porosity, vertical permeability, and vertical hydraulic conductivity data

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Sample number	Mining company borehole identification	Formation	Sample depth, in feet	Confining pressure, in pounds per square inch (gauged)[1]	Porosity, in percent	Density, in grams per cubic centimeter	Vertical permeability, in millidarcies	Vertical hydraulic conductivity, in feet per second	Lithology	Description
						Amax Lead Company—Continued				
58	801-016	DVS	1,689	1,280	2.98	2.690	0.000005	1.65×10^{-13}	B	Limey wackestone with shale (20%)
59	801-031	DDR	1,478	1,120	1.4	2.837	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic mudstone with styolite
60	801-031	DDR	1,523	1,150	2.19	2.874	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone with styolite
61	801-031	DVS	1,554	1,180	0.66	2.847	<.000001	$<3.17 \times 10^{-14}$	C	Dolomitic wackestone
62	801-031	DVS	1,579	1,200	2.12	2.679	<.000001	$<3.17 \times 10^{-14}$	S	Shale
63	801-031	DVS	1,606	1,220	2.04	2.662	.000014	4.44×10^{-13}	S	Shale
64	801-031	DVS	1,640	1,240	.96	2.690	<.000001	$<3.17 \times 10^{-14}$	C	Limey wackestone with shale partings
						Asarco				
65	AC 37	DDR	8,40	640	2.63	2.827	0.000018	5.83×10^{-13}	C	Dolomitic wackestone with limey inclusions
66	AC 37	DVS	898	680	3.76	2.795	<.000001	$<3.71 \times 10^{-14}$	B	Dolomitic mudstone with shale
67	AC 37	DVS	945	720	8.39	2.823	.000098	3.11×10^{-12}	B	Limy mudstone with shale (70%)
68	AC 37	DVS	1,008	770	7.55	2.734	<.000001	$<3.17 \times 10^{-14}$	S	Shale
69	AC 37	DVS	1,041	790	5.96	2.768	<.000001	$<3.17 \times 10^{-14}$	B	Shale 70% with limey wackestone
70	AC 45	DDR	823	625	3.29	2.821	.000017	5.33×10^{-13}	B	Dolomitic wackestone with interbed shale
71	AC 45	DDR	898	680	4.43	2.814	.000030	9.62×10^{-13}	C	Dolomitic mudstone with wackestone
72	AC 45	DVS	975	740	6.82	2.733	.000009	2.87×10^{-13}	S	Shale
73	AC 45	DVS	1,034	790	6.48	2.738	.000016	5.10×10^{-13}	S	Shale
74	AC 45	DVS	1,069	810	5.44	2.778	<.000001	$<3.17 \times 10^{-14}$	B	Shale with dolomitic wackestone
75	AC 84	DDR	781	590	3.41	2.826	.000027	8.41×10^{-13}	B	Dolomitic wackestone with shale partings
76	AC 84	DDR	827	630	2.93	2.836	.000015	4.73×10^{-13}	C	Dolomitic wackestone with shale partings

Table 2. Porosity, vertical permeability, and vertical hydraulic conductivity data

[DDR, Derby-Doerun Dolomite; DVS, Davis Formation; BNT, Bonneterre Formation, POT, Potosi Dolomite; C, carbonate rock; S, shale; B, both carbonate rock and shale; <, less than; %, percent]

Sample number	Mining company borehole identification	Formation	Sample depth, in feet	Confining pressure, in pounds per square inch (gauged)[1]	Porosity, in percent	Density, in grams per cubic centimeter	Vertical permeability, in millidarcies	Vertical hydraulic conductivity, in feet per second	Lithology	Description
						Asarco—Continued				
77	AC 84	DVS	878	670	10.7	2.718	0.000030	9.41×10^{-13}	S	Shale
78	AC 84	DVS	946	720	.36	2.715	.000012	3.81×10^{-13}	C	Limey wackestone
79	AC 84	DVS	1,003	760	8.18	2.799	.000134	4.25×10^{-12}	B	Shale with dolomitic wackestone
80	LC 503	DDR	806	610	1.69	2.818	.000106	3.35×10^{-12}	C	Dolomitic wackestone
81	LC 503	DVS	910	690	5.75	2.760	<.000001	$<3.17 \times 10^{-14}$	S	Shale (90%) with limey wackestone
82	LC 503	DVS	976	740	9.05	2.689	<.000001	$<3.17 \times 10^{-14}$	S	Shale
83	LC 503	DVS	1,006	760	2.14	2.701	<.000001	$<3.17 \times 10^{-14}$	B	Limey wackestone (70%) with shale
84	LC 810	DDR	1,023	780	3.24	2.794	.000062	1.96×10^{-12}	B	Dolomitic mudstone with shale (10%)
85	LC 810	DDR	1,060	810	3.99	2.813	.000009	2.86×10^{-13}	B	Dolomitic mudstone with shale (10%)
86	LC 810	DVS	1,096	830	7.25	2.711	<.000001	$<3.17 \times 10^{-14}$	S	Shale
87	LC 810	DVS	1,159	880	2.19	2.711	<.000001	$<3.17 \times 10^{-14}$	C	Limey mudstone
88	LC 810	DVS	1,204	920	1.59	2.699	<.000001	$<3.17 \times 10^{-14}$	B	Limey mudstone 50% with shale 50%

[1]The applied confining pressure is approximately equal to the pressure calculated using a gradient of 0.758 pounds per square inch per foot of depth.

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of the St. Francois Confining Unit in the Fristoe Unit of the Mark Twain National Forest, Missouri