1-1987

Lithologic Controls on Karst Groundwater Flow, Lost River Groundwater Basin, Warren County, Kentucky

Christopher Groves
Western Kentucky University

Recommended Citation

Groves, Christopher, "Lithologic Controls on Karst Groundwater Flow, Lost River Groundwater Basin, Warren County, Kentucky" (1987). *Masters Theses & Specialist Projects.* Paper 1554.
http://digitalcommons.wku.edu/theses/1554

LITHOLOGIC CONTROLS ON KARST GROUNDWATER FLOW, LOST RIVER GROUNDWATER BASIN, WARREN COUNTY, KENTUCKY

A Thesis

Presented to

The Faculty of the Department of Geography and Geology

Western Kentucky University

Bowling Green, Kentucky

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science

by

Christopher G. Groves

January, 1987

AUTHORIZATION FOR USE OF THESIS

Permission is hereby

☒ granted to the Western Kentucky University Library to make, or allow to be made photocopies, microfilm or other copies of this thesis for appropriate research or scholarly purposes.

☐ reserved to the author for the making of any copies of this thesis except for brief sections for research or scholarly purposes.

Signed Christopher G Grover

Date March 29, 1987

Please place an "X" in the appropriate box.

This form will be filed with the original of the thesis and will control future use of the thesis.

LITHOLOGIC CONTROLS ON KARST GROUNDWATER FLOW,
LOST RIVER GROUNDWATER BASIN, WARREN COUNTY, KENTUCKY

Recommended December 28, 1986
(Date)

Nicholas C. Crawford
(Director of Thesis)

Kenneth W. Kuehn

Ronald R. Dilamarter

Approved April 7, 1987
(Date)

Elmer Gray
(Dean of the Graduate College)

ACKNOWLEDGEMENTS

Many people have made contributions to this work, and it is a composite of these efforts. First, I would like to thank my parents, Gordon and Jane Groves, for their constant support and encouragement of my academic endeavors over a period now spanning many years.

This project received financial support from the Cave Research Foundation, the Graduate Student Research Grant Committee at Western Kentucky University, and the Center for Cave and Karst Studies at Western Kentucky University.

The general ideas behind the research were developed over several years during many discussions and field ramblings with my thesis advisor, Dr. Nicholas Crawford. He has greatly encouraged my interest in the geological end of the research efforts of the Center for Cave and Karst Studies, and it is primarily Dr. Crawford that I have to thank for whatever skills as a scientist that I have developed.

I have also learned much about the sinkhole plain from discussions with my friend Dr. Ron Dilamarter. Looking back now, it seems that much of the geomorphology (particularly of the Pennyroyal) that I know came not as much from the classroom as from lengthy discussions, and perhaps even gentle arguments, at the chalkboard of Dr. Dilamarter's cluttered work lab, which was always open when I had an idea to discuss.

The most difficult parts of planning this project, the development and comparison of 3-D surfaces with computer graphics, were worked out in a series of discussions and work sessions with Drs. Jay Sloan and Ken Kuehn. Dr. Sloan spent an inordinate amount of time with my project and me (which he did not have to spare) and our many hours of work together were shared with a constant stream of people through his office needing expertise, advice, or signature. As well as his help with project design, Dr. Kuehn has shared with me his extensive knowledge of stratigraphy, along with making extensive reviews of my proposal and thesis.

I also thank Mr. Glen Conner, Kentucky's State Climatologist, for his help and advice, and for making available the Climate Center's equipment and personnel. Mr. Vernon Pyse of the Climate Center staff unlocked the DISSPLA package's powerful cartographic capabilities, writing many application programs that made the graphics of this project possible.

In the field, many friends helped me gather data, some suffering through the severe drought and heat wave that plagued the Southeast U. S. during the summer of 1986. These included Phil Reeder, Bryan Kinkle, Jim Webster, Tony Able, Tom Feeney, Ben Keller, and my primary field assistant, my wife, Deana Groves.

Apart from her long, hot days in the field, Deana also worked by my side

during other phases of the project, at the computer terminal as well as the drafting table. Most importantly, she kept our lives going during a period when I concentrated on little other than this project. During the long writing process, Deana gently prodded while I plodded. It is to her most of all that this work is lovingly dedicated.

TABLE OF CONTENTS

Page

CHAPTER

APPENDIX

LIST OF FIGURES

LITHOLOGIC CONTROLS ON KARST GROUNDWATER FLOW, LOST RIVER GROUNDWATER BASIN, WARREN COUNTY, KENTUCKY

Christopher G. Groves January 1987 69 pages

Directed by: Nicholas C. Crawford, Ronald R. Dilamarter, and Kenneth W. Kuehn

Department of Geography and Geology Western Kentucky University

The Lost River Groundwater Drainage Basin in Warren County, Kentucky, is a karst drainage system encompassing 55 square miles (143 square kilometers) developed within the Mississippian St. Louis and Ste. Genevieve Limestones. Near the contact between these two formations are two bedded chert units, the Lost River Chert Bed (Elrod, 1899) within the Ste. Genevieve and the Corydon Chert Member (Woodson, 1983) of the St. Louis, which appear to be perching layers to shallow karst groundwater flow. Groundwater may be seen flowing on top of these beds in various cave streams and at swallets and springs throughout the basin.

In order to compare the vertical positions of these layers to shallow karst groundwater flow, geologic structure maps of the Lost River Chert Bed and the Corydon Chert Member were prepared for the basin, along with a contour map of the water table (at or near which shallow karst groundwater flow is assumed to take place) over the same area. These surfaces were digitized, then contoured and compared using SURFACE II and DISSPLA computer graphics systems. Correlation was accepted for points where the water table is either 20 feet (6.1 meters) above or below the top of the two chert layers. The water table (at baseflow conditions) was found to correlate with the Lost River Chert Bed over 42.6% of the basin, as well as 40.7% for the Corydon Member. Shallow karst groundwater flow is found to correlate with bedded chert layers over 83.3% of the study area, and therefore it is concluded that chert layers have a dominant effect on the vertical position of

groundwater flow within the Lost River Groundwater Drainage Basin.

CHAPTER I

INTRODUCTION

The Lost River Groundwater Drainage Basin is a karst drainage system encompassing 55 square miles (143 square kilometers) located on the Pennyroyal Plateau in southern Warren County, Kentucky (Figure 1). As in other parts of the plateau, most drainage occurs through solutionally enlarged subsurface conduits within the Mississippian Ste. Genevieve and Upper St. Louis Limestone formations (Figure 2). Surface drainage is rare, and usually is intermittent where it does occur. Because most groundwater recharge to the system occurs quickly through swallet input at discrete points, rather than through diffuse recharge, the system may be characterized as a conduit-flow aquifer (Smith, Atkinson, and Drew, 1976).

The headwaters of the Lost River are located in the southern part of the basin (Figure 3) where several surface streams flow across a somewhat resistant mantle of clay-chert residuum and sink into the Ste. Genevieve. As these subsurface streams flow northward, they converge to become the Lost River which may be observed at the Church Karst Window (Figure 3) in the central part of the basin. The river resurges downstream at the Lost River Blue Hole, and after 400 feet (121 meters) of surface flow sinks into the massive entrance to Lost River Cave. The river then flows beneath the City of Bowling Green to eventually resurface at the Lost River Rise. Flow continues on the surface into the Barren River, the major base level stream for the area.

The hydrology of the Lost River Groundwater Basin has been intensively monitored since the late 1970's (Crawford, 1981a, 1981b, 1982, 1985b). Much of the karst research that has taken place within the basin has been of an applied nature,

Figure 1. Location of study area.

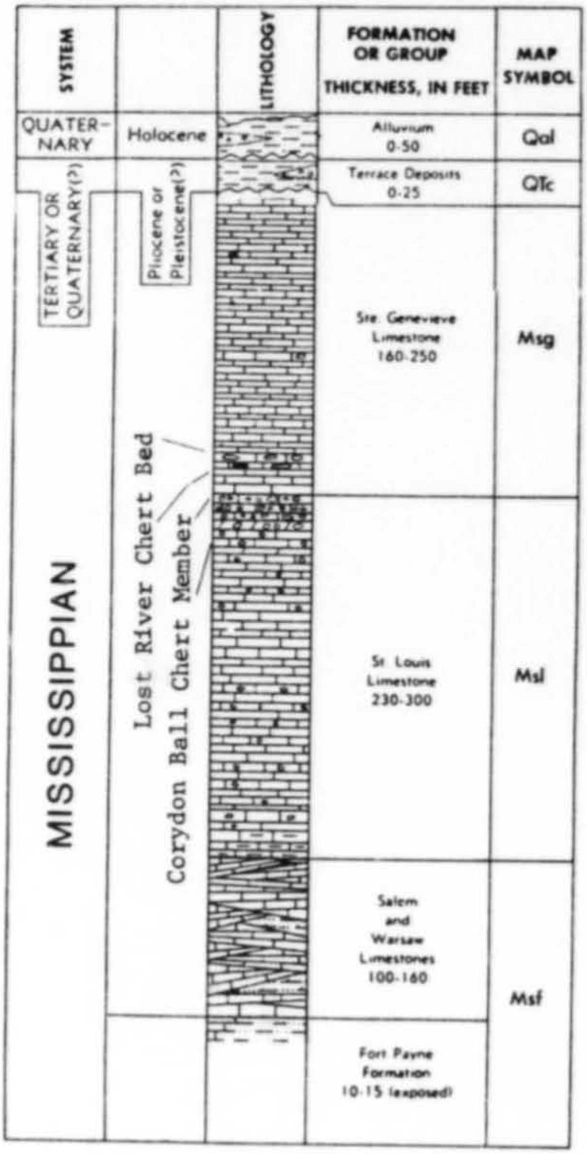


Figure 2. Stratigraphic section of local area. Source: McGrain and Sutton (1973).

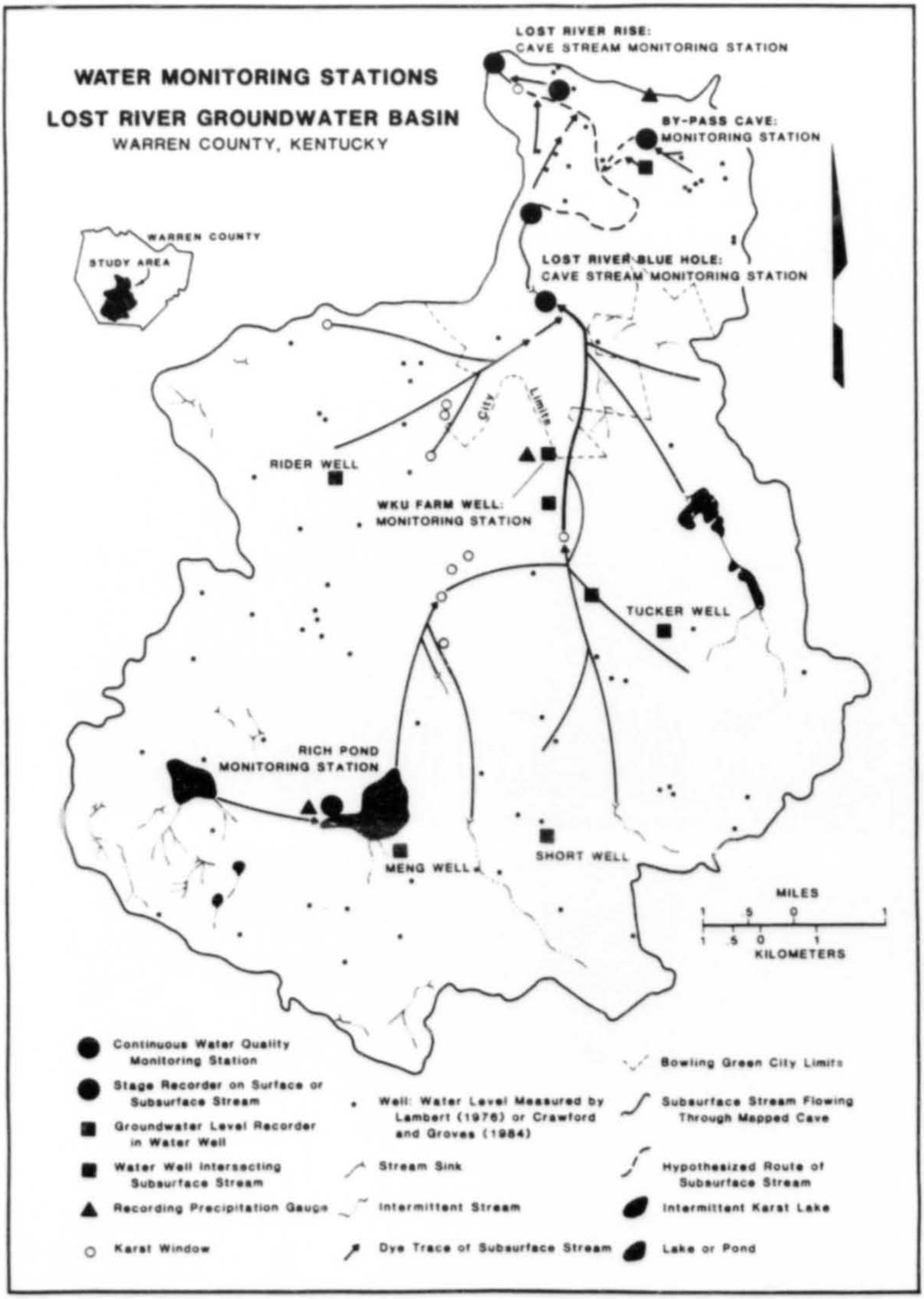


Figure 3. The Lost River Groundwater Basin. Source: Crawford and Groves (1987).

particularly with respect to karst-related environmental problems. As a city of nearly 50,000 located entirely upon a sinkhole plain, Bowling Green offers a natural laboratory for the study of contamination of karst groundwater by agricultural, urban, and industrial activities, as well as sinkhole flooding and sinkhole collapse. In 1984 the U. S. Centers for Disease Control (CDC) issued a health advisory for the Bowling Green area in response to potentially toxic and explosive fumes rising from caves beneath the city into homes, schools, and businesses. These fumes have been found to contain benzene, toluene, methylene chloride, xylene, and other volatile organic chemicals and have reached explosive concentrations on several occasions (Crawford, 1984). As a result of the CDC health advisory, in June, 1985 the U. S. Environmental Protection Agency (EPA) initiated a 'Superfund' emergency response which included an investigation into the relationship of the fumes to the subsurface Lost River.

While this research has resulted in a greater understanding of hydrogeology of the system and associated karst environmental problems, there are still frustrating informational gaps. One of these gaps, and the area toward which this research is directed, is a detailed understanding of the relation of lithology to groundwater flow within the basin.

Although groundwater flows under an area of 55 square miles (143 square kilometers) within the basin, much of the flow (and associated cavern development) is concentrated within the lowermost 75 feet (23 meters) of the Ste. Genevieve Limestone. Within, and at the base of, this zone are two bedded chert units which appear to influence groundwater flow and cavern development (Crawford, 1982; Groves and Crawford, 1986b). The Corydon 'Ball Chert' Member of the St. Louis Limestone (Woodson, 1981 and 1983) provides a base for the zone and consists of a limestone matrix packed with irregularly shaped chert nodules (Figure 2). The Lost River Chert Bed (Elrod, 1899), the top of which is about 40 feet (12 meters) above the top of the Corydon Member, is a 10 to 25 foot (3 to 7.5 meter) thick fossiliferous bed that ranges in composition from chert to partially silicified limestone limestone to limestone. It is somewhat ironic that the Lost River Chert Bed, which appears to have such an influence on the hydrogeology of the Lost River Groundwater Basin in Kentucky, is actually named for exposures along the famous Lost River of Indiana (Elrod, 1899).

Within the Lost River Groundwater Basin the cherts can be seen in various cave stream passages and appear to have a strong influence, at least locally, on groundwater flow. Outcrops of the two cherts are often visible at springs and swallets, and are very difficult to find at other locations within the basin. Crawford (1982) observed this and hypothesized that the two chert confining units should form a preferred zone for cavern development.

The importance of lithologic heterogeneity on stratigraphic control of groundwater flow and cave passage development in karst areas (including the roles of the Lost River Chert and Corydon Member where they occur) is not completely understood and is still somewhat controversial. While these beds apparently influence groundwater flow in some areas, several investigators have assigned a very minor role to their importance (Palmer, 1981; Quinlan and Ewers, 1981; Wells, 1976) and it is the goal of the study to examine these relationships within the Lost River Basin. This research will provide a quantitative measure of the influence of the two bedded chert layers on present groundwater flow within the Lost River Groundwater Basin.

CHAPTER II

THE STUDY AREA

Location

The Lost River Groundwater Basin comprises an area encompassing 55 square miles (143 square kilometers) within southern Warren County, Kentucky (Figures 1 and 3). It extends from the town of Woodburn northward for about 12 miles (19 kilometers) to Bowling Green where the outlet for the basin, the Lost River Rise, resurges into Jennings Creek. At its widest, the basin is about 9 miles (14 kilometers) wide, from just east of Rockfield in the west to near Drake's Creek in the east. The study area comprises parts of the Bowling Green North, Bowling Green South, Woodburn, Drake, and Rockfield U. S. G. S. 7.5 minute topographic maps of Kentucky.

Physiographically, the basin lies within the Pennyroyal Plateau of the Interior Lowland Province (Figure 4). The Pennyroyal (along with the adjacent Mitchell Plain in Indiana and Highland Rim in Tennessee) is a classic sinkhole plain, with gently rolling topography dominated by an abundance of sinkholes and other karst features. This landscape has developed on the nearly horizontal Late Mississippian limestones of the St. Louis, Ste. Genevieve, and Girkin formations. These units have a gentle northwesterly dip of about 30 feet per mile (5.6 meters per kilometer), when measured from the top of the Chattanooga Shale, toward the axis of the Illinois Basin. Localized structures, however, may cause dips to vary considerably from this regional trend.

Stratigraphy

The St. Louis Limestone is the oldest of the three formations exposed within

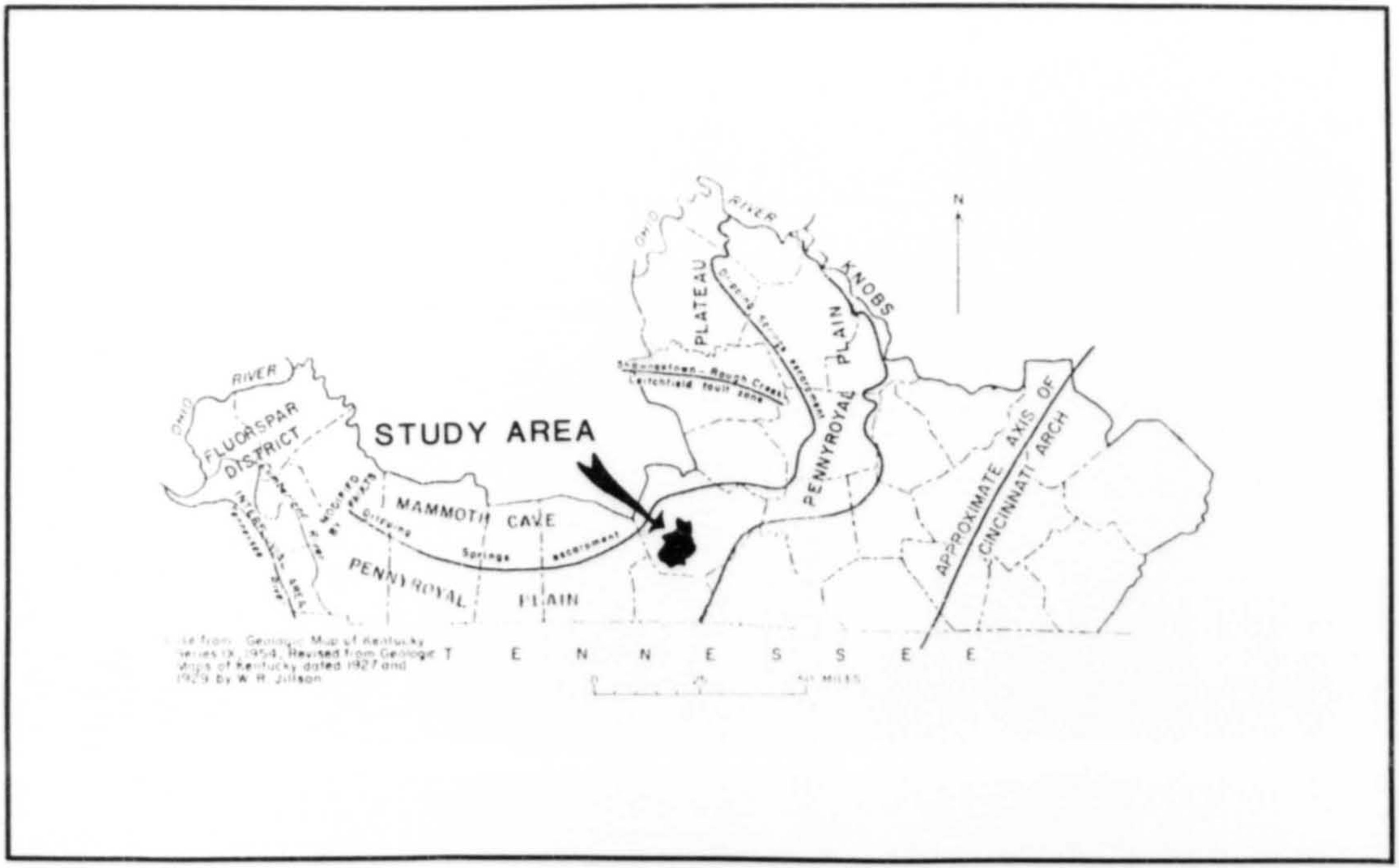


Figure 4. Location of study area with respect to regional physiographic setting. Source: Brown and Lambert (1963).

the study area (Figures 2 and 5). It is generally a light to dark grey, very fine to coarse grained, thin to medium bedded, cherty limestone (McGrain and Sutton, 1973). Only the uppermost beds of the St. Louis are exposed; these consist of 20 (exposed) feet (6.1 meters) of dolomite and dolomitic limestone packed with a great number of irregularly shaped chert nodules and discontinuous chert beds. The unit is sometimes informally called the St. Louis Ball Chert (Badiei, 1981; Woodson, 1981; Crawford, 1982; Groves and Crawford, 1986b). In Indiana it has been designated (along with a zone just above consisting of 4 to 8 feet (1.2 to 2.4 meters) of brown dolomite or dolomitized micrite) the Corydon Member (Woodson, 1981 and 1983). Although usage of the Corydon Chert has not been extended to include these beds within the state of Kentucky, the term is used herein, because the unit is clearly recognizable throughout the study area and it is felt that this formal name is preferable to the informal St. Louis Ball Chert. The Corydon Chert is the lower of two bedded chert units that may affect the vertical position of groundwater flow within the Lost River Groundwater Basin (Figure 2), as well as other areas within the Pennyroyal Plateau, Mitchell Plain, and Highland Rim.

The location of the contact between the St. Louis and the overlying Ste. Genevieve Limestone has been the subject of a lengthy debate among stratigraphers working within the Illinois Basin. Various criteria have been (and are still) used to define and identify this boundary, based on both lithologic and fossil characteristics. Most workers have used the easily identifiable Lost River Chert Bed as a marker, though their use has been subject to various interpretations: 1) 8 feet (4.2 meters) above the Lost River Chert (Pohl, 1970), 2) 10-37 feet (3 to 11 meters) below the Lost River Chert (McGrain, 1942), 3) at the top of the Lost River Chert (Moore, 1963) and 4) 10-15 feet (3 to 4.5 meters) below the Lost River Chert (Miller, 1969). Pohl (1970) lists five additional interpretations of the boundary accepted by a number of different workers. He cites microfaunal evidence to support his criteria,

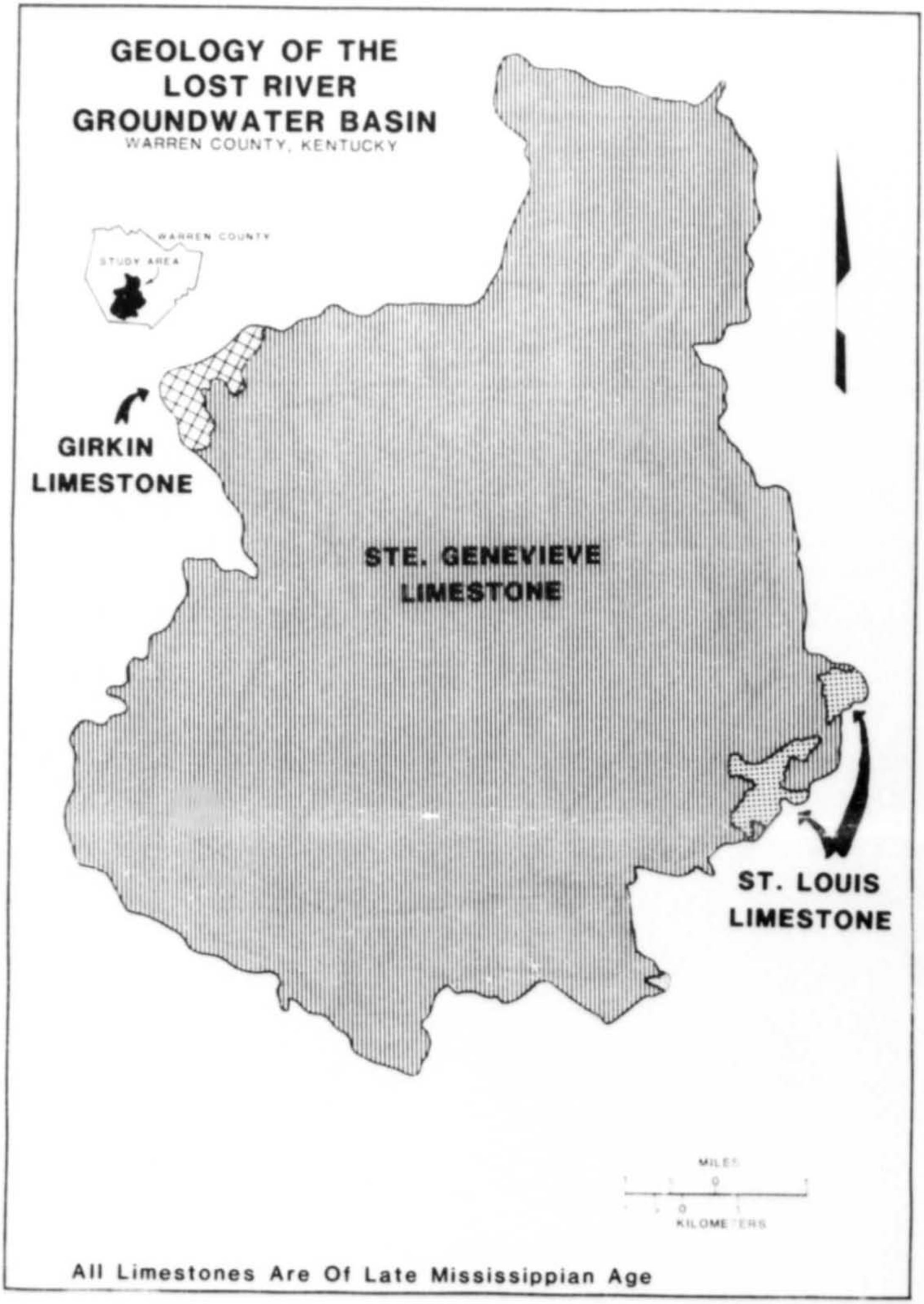


Figure 5. Geology of the Lost River Groundwater Basin. Source: McGrain and Sutton (1973).

but admits that the decision is somewhat arbitrary. For this study, the contact between the two formations was chosen so that it would be consistent with mapping of the local area by the Kentucky Geological Survey (McGrain and Sutton, 1973) and is considered to be at the top of the Corydon Member of the St. Louis Limestone. This places the contact 40 feet (12 meters) below the top of the Lost River Chert Bed within the study area.

The Ste. Genevieve Limestone is a white to light grey, fine to coarse grained, medium to thick bedded, commonly oolitic limestone which is exposed at the surface over a large part of the study area (McGrain and Sutton, 1973). It has a thickness of about 200 feet (61 meters) within the area (Shawe, 1963a).

The Girkin Limestone is exposed only in several small patches in the extreme western part of the study area (Figure 5). It is a coarsly crystalline, oolitic, fossiliferous, massive to thin bedded, light grey to tan limestone (McGrain and Sutton, 1973).

The Lost River Chert Bed

The Lost River Chert Bed (Figure 2) was named by Elrod (1899) for exposures along the Lost River of Orange County, Indiana. It has played an important role as a stratigraphic marker in Indiana, Kentucky, Tennessee, and Alabama (Ferguson and Stearns, 1967; McGrain, 1969; Woodson, 1981) because it is easily recognizable in outcrop, widespread, and in many places provides the only clue to the location of the contact between the St. Louis and Ste. Genevieve Limestones (how ever one chooses to relate the contact to the chert bed). McGrain (1969) recognized that the Lost River Chert Bed could be extended throughout parts of Kentucky, including a probable stratigraphic equivalent east of the axis of the Cincinnati Arch in Pulaski and Wayne Counties, as well as Overton County, Tennessee. Previously, all discussion of the Lost River Chert had been restricted to areas on the west side of the Cincinnati Arch. Ferguson and Stearns (1967) summarized locations throughout Tennessee where the chert had been traced, and included Montgomery County, the Wells Creek area of Houston and Stewart Counties, and areas along the Cumberland Plateau Escarpment. It has also been recognized in Alabama near Huntsville.

The Lost River Chert Bed is a highly fossiliferous, discontinuously bedded replacement chert that occurs with white sparite in a zone that usually varies from about 10 to 15 feet (3 to 4.5 meters) thick throughout the study area. In Robinson Cave, however, the chert has been found to reach a thickness of 20 to 25 feet (6 to 7.5 meters)(Groves and Crawford, 1986a). Single chert beds range from a few inches to several feet thick, but 2 to 6 inches (5 to 15 centimeters) is typical. The chert reaches the surface near the center of the study area. East of the outcrop, the thick, reddish, clayey soils contain variously sized blocks of the siliceous portions of the chert, weathered so that many fossils (including spirifer brachiopods and abundant fennestellid bryozoans) are easily recognizable. Within the study area, and in other areas of the sinkhole plain where the soils contain a plethora of these weathered chert blocks, the pieces are referred to by farmers (who have removed massive quantities of the blocks from planted fields to create piles which dot the sinkhole plain) as 'burr-rocks' (Petersen, 1983; Woodson, 1981). Where the chert outcrops at hillsides and along the slopes of sinkholes, large blocks can be found. Freshly broken surfaces of the chert commonly are very white to bluish grey. Weathered blocks are usually stained reddish brown. Where the chert is exposed within cave passages, particularly where it has been weathered by stream erosion, a dark brown to black color is common, and often contrasts greatly with the light grey or white sparite host rock. Ferguson and Stearns (1967) claimed that the chert is a weathering feature of the limestones and therefore does not exist in the subsurface. This is not so, as the chert has been identified within cores taken from wells drilled in Bowling Green, Kentucky (Crawford, 1985b), and Indiana (Carr and others, 1978), although it is much more difficult to recognize in fresh condition than in outcrop.

The Corydon Member of the St. Louis Limestone

About 40 feet below the top of the Lost River Chert Bed is the Corydon Member of the St. Louis Limestone which was named for exposures near Corydon, Harrison County, Indiana (Woodson, 1983). Within the vicinity of the Lost River Groundwater Basin, groundwater can be seen flowing at or near the top of this layer in several places, including the Church Karst Window, Glacier Cave, and Woodburn Cave to the south of the basin.

The most important part of the Corydon Member in terms of the hydrogeology of the study area is a dolomitic zone containing profuse spherical, irregular, and lenticular cherts. One or more beds of blocky, non-fossiliferous chert also occur in the eight feet (2.5 meters) which lie above the top of the profuse 'ball chert' zone. Woodson (1981) noted that these beds are very similar to weathered Lost River Chert beds. Exposures of this 'pseudo' Lost River Chert are found in Greenwood Cave, where a small waterfall is perched upon this layer.

CHAPTER III

REVIEW OF LITERATURE

Introduction

The effect of lithologic heterogeneity on groundwater flow and cavern development within karst aquifers, the central focus of this research, has received considerable attention but still appears to be a controversial topic among karst hydrologists. The purpose of this review is to provide a background of previous work, in two sections: 1) a summary of the most important ideas in the development of a general theory of cavern development, and 2) a review of investigations into the effect of varying lithology on groundwater flow routes and cavern development in karst areas, particularly those with hydrogeologic settings similar to that of the Lost River Groundwater Basin.

Theories of Cavern Development

Many early (and conflicting) ideas on cavern development centered on proximity to the water table and whether caves were formed predominantly within the vadose zone, the phreatic zone, or at the water table itself. These ideas were advanced in a series of works sometimes referred to as the 'classical theories,' which sought general models for cave formation that could be applied to a majority of situations.

Dwerryhouse (1907) proposed that cave passages were carved largely within the vadose zone by water moving downwards toward a lower, preexisting water table (Figure 6a). These ideas were based on observations by explorers of fast running underground streams. Early dye traces showed that rivers resurged with little dilution indicating that streams did not mix with the 'groundwater' (White, 1976). Early writers found these ideas attractive because 1) water flowing into caves

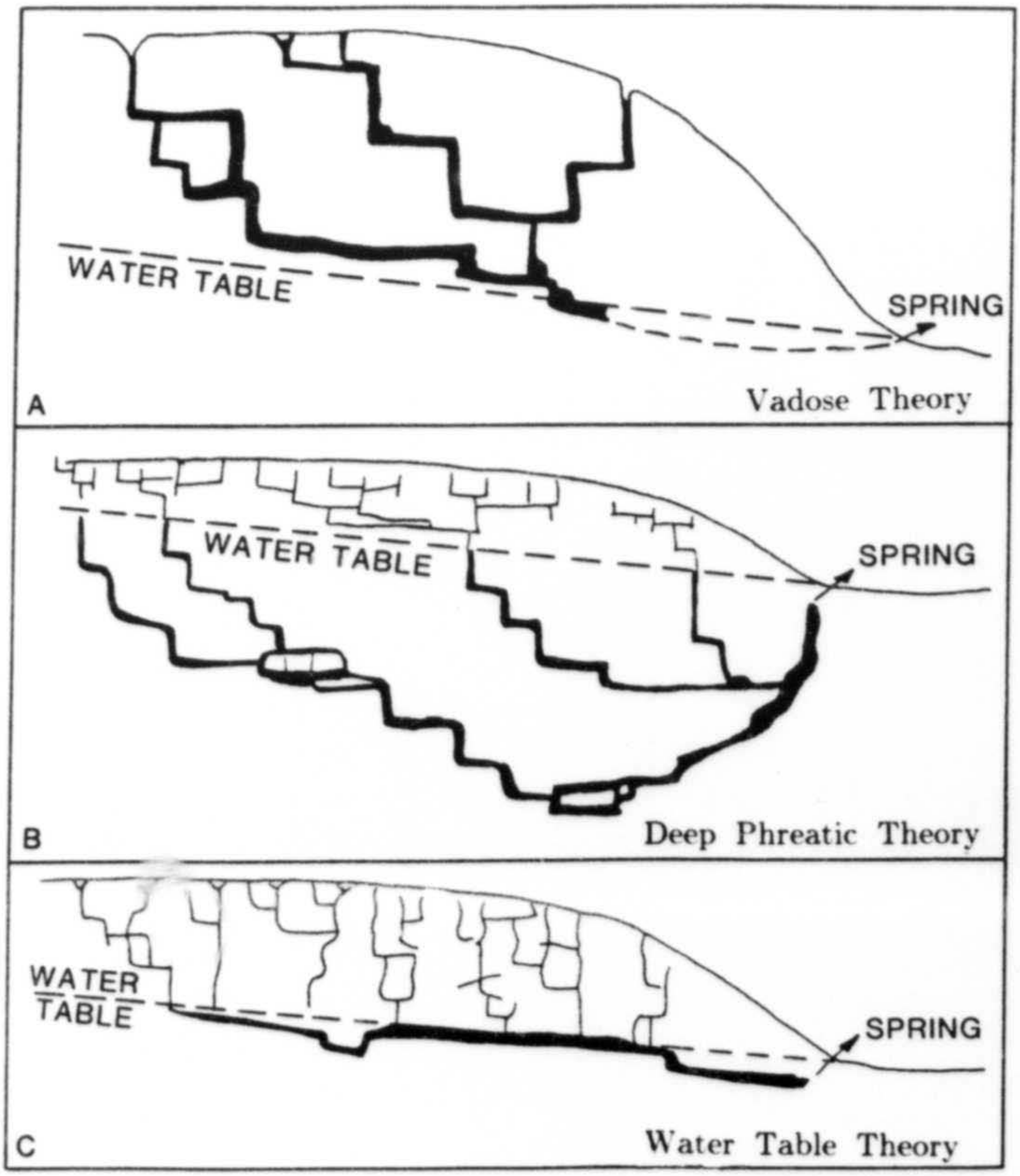


Figure 6. Generalized sections showing cavern development as proposed by the vadose, deep phreatic, and water table theories. Source: Ford and Ewers (1978).

encountered the vadose zone first, where the water was most aggressive, or able to dissolve limestone, and 2) the high velocities of vadose cave streams made them more capable of mechanical corrasion, or enlarging of the cave by the mechanical work of the stream's sediment load (Ford and Ewers, 1978). Piper (1932) advanced a theory of vadose cave development based on an application of the Geographic Cycle (Davis, 1899) to karst terranes. The Geographic Cycle was a theory of landscape development that involved recurring cycles, with three recognizable stages (youth, maturity, and old age) which could be used to interpret the history of a landscape. Piper (1932) defined youthful, mature, and old age stages of development of underground drainage systems, complete with an underground peneplain to define the old age part of the cycle. Gardner (1935) and Malott (1937) proposed similar theories which were largely restricted to limestones of very gentle dip. Gardner (1935) emphasized downdip flow along favorable bedding planes, and Malott (1937), who did much of his work on the Lost River of Indiana, discussed vadose flow through primitive routes that had been started below the water table, also attaching major importance to the effect of floodwaters in carving out cave passages.

Cvijic (1893) and Grund (1903) proposed that cave formation took place deep in the phreatic zone (Figure 6b) as water circulated through bedding planes, joints, and fractures within the limestone just as it did in other types of aquifers. Davis (1930), and Bretz (1942) also published phreatic theories that are closely tied to Davis' Geographic Cycle. In the Davis 'two cycle theory' cave formation took place during the landscape's old age stage, far below the water table along deep, curving flow lines as water moved toward its outlet. Flow was driven by the hydrostatic head between the water table in interstream areas and base level. In the next cycle, regional uplift caused a relative lowering of the water table, allowing the caverns to eventually drain to become air-filled passages. Water then entered the cave and began a cycle of deposition, forming various types of travertine speleothems. A major feature of this theory was that it provided a mechanism whereby water could at times dissolve limestone and at other times deposit limestone (as travertine). Bretz's (1942) phreatic theory is similar to Davis' model, with the addition of a third stage (in between solution and deposition of limestone) where caverns below peneplains became saturated with stagnant water, resulting in a clay fill that was removed after rejuvenation of the area.

Swinnerton (1932) argued that while Davis' proposed deep flow paths may have been correct for porous aquifers, flow paths are much different in fractured limestones. He proposed that once vadose groundwater reached the phreatic zone, it travelled along the water table (Figure 6c). Cavern development then took place along the water table and in the floodwater zone just above. As the entrenched surface streams continued their downcutting, higher levels were abandoned and cave streams were pirated into lower (water table) routes. White (1976) pointed out that while the theories of both Swinnerton and Davis had ties to the Geographic Cycle, cave formation in Davis' scheme took place during old age of a previous cycle. Swinnerton placed their formation in the youth and maturity stages of the present cycle. White (1960) and Davies (1960) also presented arguments for cave formation near the water table.

Since these classical theories on the origin of caves were published, investigators have tried to relate cave formation with groundwater motion and overall hydrology of drainage basins (White, 1976). This involves recognizing a single cave as but a small segment of a larger drainage system, and attempting to understand the cave in terms of its (current or past) role in the delivery of groundwater. Perhaps the most important change from the classical ideas is the observation (Ford, 1965 and 1971; Ford and Ewers, 1978) that neither vadose, phreatic, or water table theories can be thought of as the general case. The dominance of one or more depends greatly on the hydrogeologic setting of the particular cave in question. This idea is in direct conflict with earlier writers, particularly Woodward (1961) and Davies (1960), who said of his own scheme 'the theory of cave origin proposed here is applicable to all types of solution caves in all types of rock structures. The need for special development area by area is not necessary.'

In the Lost River Groundwater Basin, a region of gently dipping, Mississippian limestone beds, it appears that most passages have made extensive use of bedding planes as initial flow paths. If any of the three classical ideas can be said to dominate in this terrane, it is that most groundwater flow, and therefore cavern development, takes place in close proximity to the water table as groundwater flows along the path of least resistance from input point to spring. In their review of the Central Kentucky Karst, White and others (1970) stated that major passages there always form at, or just below, regional base level. Varying passage types along continuous lines indicate that a seasonally fluctuating base level would create conditions leading sometimes to vadose flow and at other times to phreatic flow.

Lithologic Heterogeneity and Groundwater flow in Karst Aquifers

What effect does lithologic heterogeneity play in the selections of these flowpaths and therefore, on groundwater flow? The question is a matter of some debate among workers who have studied the karst hydrogeology of many regions, including the Pennyroyal sinkhole plain of Kentucky.

Swinnerton (1932) accepted that relatively impervious layers have an effect groundwater flow. He quoted from Smith and Siebenthal (1907, p. 18) who point out that:

> Hannibal or Devonian shales, though thin, probably act as an efficient cover to circulating waters of the Cambro- Ordovician rocks and limit the downward movement of the overlying Mississippian. Not only the shales, but all relatively impervious rocks as well, serve to retain and direct the

> circulation of the waters beneath. Especially do the unfractured cherts confine the movement along the bedding planes.

Howard (1968, p. 108) argued for a strong relationship between stratigraphy, structure, and karst phenomena within the Pennyroyal sinkhole plain. With respect to groundwater flow routes, he observed that due to chert stringers and beds (as well as argillaceous and dolomitic zones) within the limestones of the St. Louis and lower Ste. Genevieve:

> ...some portions of the stratigraphic column are more soluble than others. This should result in an anisotropy in the 'effective permeability' of the limestone to groundwater flow. Groundwater flowing parallel to the bedding can evenly dissolve the limestone along the more soluble layers. In contrast, when the groundwater is constrained to cross the bedding, the flow should be impeded by the less soluble layers. Therefore, when the stratigraphic dip is approximately parallel to the slope of the water table, the development of subterranean drainage should be most favored.

Ford and Ewers (1978) also suggested that some features may explain preferential selection of bedding planes during cave formation. These included (among others) shale partings or discontinous chert fillings. Rauch and White (1970) showed that different solubilities of various beds within a formation may lead to preferential selection of bedding planes for cave development. White (1976, p.48) stated that 'it is really stratigraphy and structure that determine the location, orientation, and pattern of caves.'

Palmer (1981), after conducting an extensive program of stratigraphic description and transit leveling within the Mammoth-Flint Ridge Cave System, concluded that major passage levels did not form within particularly soluble beds or at the tops of resistant layers. He observed that major passage levels within the cave can occur through a variety of limestone types. While resistant chert beds of the lower St. Genevieve and upper St. Louis (including the Lost River Chert) may floor passages for short distances, they do not exert a major control on passage levels. Quinlan and Ewers (1981, p. 501) concurred, noting that the Lost River Chert Bed is not a significant enough barrier to 'cause major disruption of the established system'. Saunders (1984) has observed that within Crump Springs Cave (Hart County, Kentucky) that the Lost River Chert is not a barrier to passage development, although another chert bed 35-40 feet (10.5 to 12 meters) below (the Corydon Chert) appears to be more of a barrier. Hess (1976) also concluded that variations in lithology are of secondary importance in controlling the vertical postion of flow path development.

Regarding sinkhole plain portions of the Pennyroyal and Mitchell Plains, investigators (Palmer, 1976; Wells, 1976) have concluded that structure is discordant to both the land surface and groundwater flow paths. It is worth noting, however, that most studies on the sinkhole plain have relied upon structure contours drawn on top of the Devonian Chattanooga Shale, which lies several hundred feet below the surface throughout the area. Howard (1968) and Woodson (1981) suggested that the Chattanooga Shale probably does not accurately reflect that of the lower Ste. Genevieve.

Within the Lost River Groundwater Basin, both the Corydon Member and the Lost River Chert Bed appear to play significant roles in the development of groundwater flow routes and cave passage development (Crawford, 1982; Groves and Crawford, 1986). However, these conclusions are based on discrete and widely spaced observations. This research will show the effects that these layers have throughout the basin, and by comparison, shed light on the importance of these effects throughout similar portions of the sinkhole plain.

CHAPTER IV

HYPOTHESES AND RESEARCH DESIGN

Hypotheses

Throughout the Lost River Groundwater Basin, one can observe many locations--within caves, at springs, and at swallets--where water is flowing upon the relatively insoluble chert beds of the Lost River Chert Bed and the Corydon Chert Member of the St. Louis Limestone. It cannot be denied that the tops of these resistant beds do favor, at least in some areas, the development of groundwater flow routes. As groundwater moves downward under the influence of gravity, it meets these resistant strata and is directed (more or less) horizontally down the gentle dip of the beds. However, the locations where groundwater may be seen flowing on the cherts constitute only a small fraction of the total length of groundwater flow paths. Cave streams can also be observed that do not appear to be related to a particularly insoluble or resistant layer. Some investigators (Palmer, 1981; Quinlan and Ewers, 1981; Wells, 1976) have concluded that other influences, particularly the position and movements of the base level stream towards which the system drains, outweigh the the effects of varying lithology (except in local and limited cases) and are dominant in controlling the vertical position and gradient of groundwater flow.

It is the purpose of this research to determine the importance of the Lost River Chert Bed and the Corydon Chert as influences in the control of the vertical position of groundwater flow within the Lost River Groundwater Basin. Specifically, the following hypotheses will be tested:

Hypothesis #1:

The Lost River Chert Bed and the Corydon Chert are perching layers throughout the basin and are the dominant influence in the control of the vertical position of shallow karst groundwater flow within the Lost River Groundwater Basin.

Hypothesis #2:

Influence on shallow karst groundwater flow and cavern development by the two cherts is limited or non-existent. The gradient of groundwater flow and its vertical position within the stratigraphic section are influenced primarily by other factors.

Hypothesis #3:

Groundwater flow is affected by a combination of responses to the perching effects of the two chert layers and other influences. These effects are felt to some degree throughout the basin, although the dominant effect may vary from place to place within the basin.

Research Design

In order to test these hypotheses, two structure maps of the basin were prepared: one having the top of the Lost River Chert Bed as datum and one of the top of the Corydon Member. A contour map of the water table for the shallow karst aquifer beneath the study area was also constructed and compared to the chert structure maps. The amount of area that corresponds between each of the chert layers and the water table was expressed as a percentage of the total area within the basin, then the percentages for the two chert layers were summed. The percentage of area within the basin over which groundwater flow is correlated to the chert beds was then used to accept or reject the appropriate hypotheses. The following range values were used as criteria:

≥70% correspondence: acceptance of hypothesis #1. Resistant chert beds are the dominant influence on the vertical position of groundwater flow.

≤30% correspondence: acceptance of hypothesis #2. Chert beds have limited or no influence on the vertical position of groundwater flow.

>30% but <70% correspondence: acceptance of hypothesis #3. Mixed controlling influences are responsible for the vertical position of groundwater flow.

Construction of Geologic Structure Maps

Existing structure contour maps of the area (McGrain and Sutton, 1973; Shawe, 1963a, 1963b, 1963c; Moore, 1963; and Rainey, 1964) use the top of the Chattanooga Shale, a Devonian unit that occurs several hundred feet below the Lost River Chert, as datum. These maps are not adequate for the detail required for this study. Although the Ste. Genevieve Limestone and the Chattanooga Shale are affected by similar regional influences (gently dipping nothwest towards the axis of the Illinois Basin), considerable variations in the thickness of the three formations between the layers mean that the structure is not precisely translated upwards through the section. Woodson (1981) found that differences between dips of the Devonian and Mississippian strata caused discrepancies as much as 60 feet (18 meters) between inferred (from the Chattanooga Shale elevation) and actual elevations of the Lost River Chert in southern Kentucky. Gentle structural elements within the Ste. Genevieve that may have significant influence on groundwater flow could certainly be absent on a structure map of the Chattanooga Shale.

Sources of Data

A problem in **constructing** such a map within the study area is that the Pennyroyal sinkhole plain typically offers few rock outcrops at which to gather elevation data. The following sources of data were utilized:

1) Surface Exposures.

Although not plentiful, outcrops of the chert layers are located throughout the study area. The first phase of this research was to make an inventory of known chert outcrops from previous fieldwork within the area (Crawford, 1982; Schindel, 1984a and 1984b; Groves and Crawford, 1986b) along with identifying new exposures at places in and around the basin by field checking areas that had not been thoroughly checked. Outcrops were often located at springs, swallets, and karst windows, and a few were found in recent sinkhole collapses and storm water retention basins. Roadcuts, quarries, and construction sites were also checked for chert outcrops, but with little success.

Outcrops of the Lost River Chert were more common than those of the Corydon Member within the study area. Fortunately, the top of the Corydon lies consistently about 40 feet below the top of the Lost River Chert (Woodson, 1981), so the elevation of one of the chert beds can be used to infer the elevation of the other. Although only a few locations were found to check this relationship, the assumption was supported.

The elevations of the top of the chert beds at outcrops throughout the study area were found through leveling by transit from the nearest point of known elevation to each outcrop, then back to the point of known elevation (to check accuracy) using standard procedures (Kissam, 1971). The most common sources of known elevations, particularly within the rural parts of the study area, were elevations marked at road intersections on U. S. G. S. 7.5 minute topographic maps. Benchmarks were used where they were available, and within the city limits of Bowling Green known elevations were found using the excellent Atlas of Bowling Green, Kentucky (City-County Planning Commission of Warren County, Kentucky, 1974) which depicts the entire city at 1:2,400 scale with a contour interval of 2 feet (61 centimeters). The elevations of many points located within the city are shown to the nearest 1/10 of a foot (2.5 centimeters) in this Atlas.

Additional chert elevations at outcrops were determined using an altimeter. These were found by calibrating the altimeter at a benchmark, moving to and measuring the outcrop, then quickly returning to the benchmark. By this method changes in barometric pressure that could affect readings were detected and corrected for. Temperature corrections were also applied to the readings. Even under the best circumstances, elevation measurements taken with an altimeter are less accurate than those found by leveling. The time saved by its use for outcrops far from known elevations, however, as well as the fact that the instrument can be used in situations where leveling is impractical (fields of tall corn, for example) made the instrument well worthwhile for obtaining additional data.

2) Exposures within cave passages.

In a soil-covered sinkhole plain, caves often offer the best exposures of strata, athough much of their true appearance may be masked by sediment and water. In this study, eight of the chert exposures were found within caves (Figure 7). Elevations of the cherts were found by transit leveling to a point near a particular cave's entrance, then continuing inward using a Suunto hand-held clinometer and standard cave surveying techniques. Clinometer readings and backsights were estimated to one half of one degree, and were required to agree within one degree. Cave surveying gives less accurate elevation data than at those points where the transit could be used right up to the outcrop, but the small, wet nature of many sinkhole plain caves made transit leveling impractical. The author's experience shows that careful use of Suunto instruments with backsights agreeing to within one degree can produce surveys with closure errors in the range from 0.1 to 0.2 of one percent. This will give a vertical error of only one to two feet (30 to 60 centimeters) per 1,000 feet (312 meters) of survey.

Some of the clearest exposures of the Lost River Chert found within the study area occur underground, where the chert sometimes stands conspicuously out from passage walls. It often weathers to a dark brown or black color when exposed to stream erosion and thus contrasts greatly with the light grey color of the limestone

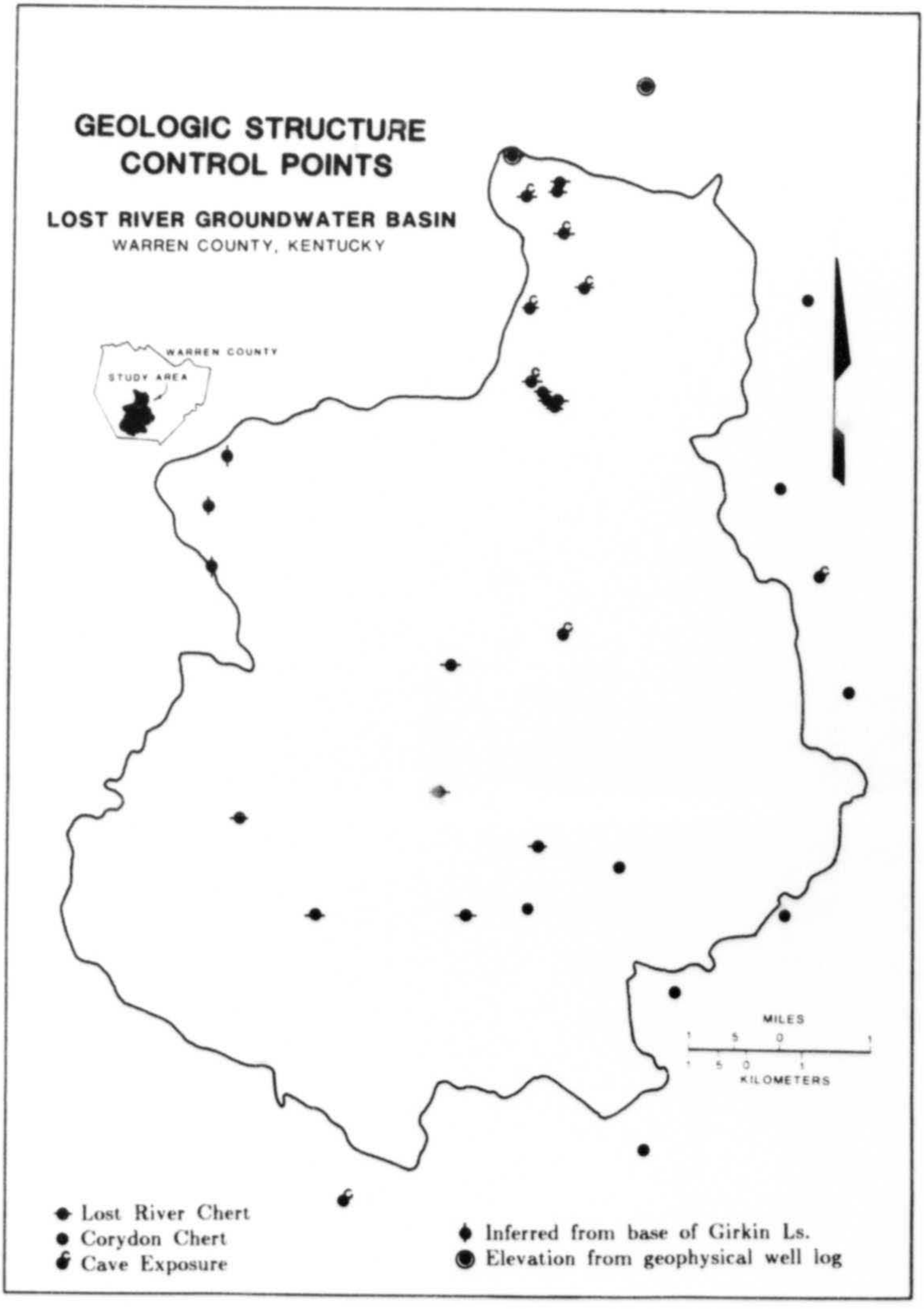


Figure 7. Geologic structure control points.

host rock. Where the chert is visible within caves throughout the study area it is most often seen at floor level or perhaps at about the lowest two or three feet (0.6 to 1 meter) of the passage walls where the stream has cut downwards into this layer. Two exceptions are in Sullivan's Cave and Robinson Cave where streams flowing atop the chert layer breach it at joint related canyons, forming waterfalls. Exposures of the Corydon Chert are found within Woodburn Cave and the cave on the downstream side of the Church Karst Window near Rich Pond, Kentucky.

3) Existing well log information.

Warren County has a varied history of oil and gas production stretching back to the early part of this century. Dilamarter (1985) notes that before encountering oil bearing strata, drillholes are likely to encounter shallow cavernous zones, including the Ste. Genevieve Limestone. Records on wells that have been logged are available at the Kentucky Geological Survey office in Lexington, and were investigated for additional information on chert elevations. Logs were located for 396 wells in or adjacent to the study area, however none were of any help in providing chert elevations. Many wells were logged only from the Chattanooga Shale (an important layer to oil drillers) downwards, and the ones that began at the surface were not in sufficient detail, primarily because the wells were logged from cuttings. This development was particularly frustrating because most of the wells, particularly in the western sections of the basin, were started in the Ste. Genevieve or higher, and therefore penetrated both chert layers.

4) Geophysical well logging.

Important sources of stratigraphic information in the study area are the many wells that have been drilled but are lacking stratigraphic logs. Over 450 storm water drainage wells have been drilled or dug, mostly within the urban parts of Bowling Green and the rapidly growing area to the south (Crawford and Groves, 1984). Many water supply wells also exist in the more rural parts of the basin.

The Dresser-Atlas Company of Henderson, Kentucky, was hired to attempt to find chert elevations using bulk density logging equipment. The Lost River Chert has a bulk density of about 2.5 g/cm^3 (Carr and others, 1978) and that of calcite (which makes up the great bulk of the Ste. Genevieve Limestone surrounding the chert) is 2.7 g/cm^3 (Pough, 1976). The well-logging program was only partially successful. Two tests were run in wells where the elevation of the Lost River Chert Bed was known, and clear negative density anomalies occured at the predicted elevations in both cases. The chert was found in most of the other wells, but since small voids also produced negative density anomalies, these produced similar readings which often masked the chert. Of the seven wells that were logged (not including the two test wells) new chert elevations were accepted for only two wells. The wells accepted were in areas of better control, where there was a good idea of the approximate elevation of the chert. Interpretation was also aided by simultaneous caliper logging, which identified some of the voids that would produce non-chert negative density anomalies. Some wells in areas of poorer control produced possible chert readings, but interpretations were not considered to be reliable enough to use the data as control points for the structure map. The appendix consists of complete records of all wells logged, along with a map of the well locations (Figure 15).

5) Existing geologic maps.

Additional chert elevations were taken from the contact between the St. Louis and Ste. Genevieve on the geologic map of the Drake quadrangle by Moore (1963) who draws this contact at the top of the Lost River Chert. This procedure added points to the area to the east of the drainage basin. Data for the far western edge of the basin were taken from the Bowling Green North geologic map (Shawe, 1963a), inferred from elevations at the base of the Girkin Limestone.

Map Production

Once the field data were collected, the surfaces were contoured using a combination of SURFACE II (Sampson, 1978) and DISSPLA (Integrated Software Systems Corporation, 1984) computer graphics systems. In order to input the control points into the system, they first required numerical encoding. This was done by plotting the points on a map of the study area, then measuring (from an arbitrary point chosen to the southwest of the study area) northward and eastward to each point. This procedure gave a unique 'x' and 'y' coordinate for each control point, and the elevation then supplied the 'z' coordinate. Once a computer file was created for the points, SURFACE II took the unevenly distributed data points and created a grid of evenly spaced 'nodes' over the study area, estimating the elevation at each node. For this project, a local fit procedure was used to estimate the node elevations, using the six nearest neighbors from each known value. At this point the surfaces are described as x, y, and z values at 88 evenly spaced nodes, and and the computer drew in contour lines at the appropriate locations. The Lost River Chert surface was contoured, then the Corydon Member structure map was produced by lowering the elevation of the Lost River Chert by 40 feet (12 meters). In this manner a model for the Corydon structure was produced in an area where few outcrops of that unit are accessable. Thirty-three control points were used in the construction of these maps (Figure 7).

Construction of the Water Table Map

Several water table contour maps have been constructed within the study area (Groves, 1983; Crawford, 1985a; Able, 1986) and surrounding region (Lavalle, 1967; Lambert, 1976; Quinlan and Ray, 1981; Plebuch, Faust, and Townsend, 1985). These maps are useful for understanding general directions of groundwater flow, although carbonate aquifers tend to be highly anisotropic with flow routes largely controlled by the locations of available openings in the rock. Groundwater flow routes at (or just below) the water table are contained within the surface shown on such a map. Water table maps are also useful for estimating the depth from the surface that a well must be drilled in order to intersect the water table.

The succeeding water table maps of the basin have been improved as more data points have been added. The map constructed for this study contains 183 control points (Figure 8), and is the first one to be contoured by computer. Control points were gathered largely from existing data sources (Lambert, 1976; Crawford, Groves, and others, 1984; Able, 1986) and a few were added by the author. The many storm water drainage wells that have been drilled in the vicinity of the study area were a help in constructing the water table map, along with the many water supply wells that exist to the south in the more rural parts of the basin. The inventory of these drainage wells made by Crawford, Groves and others (1984) for the U.S. Environmental Protection Agency lists the locations (and water elevations) for 444 wells in the area. Unfortunately, these water level measurements were taken at a variety of antecedent moisture conditions and not all represent a probable base level condition, which was assumed for this map. In order to utilize these data, a filtering system was established: the date of each measurement was checked in the records of the College Heights Weather Station (on the Western Kentucky University campus in the northern part of the basin), and the measurement was not used if 0.5 inches (1.2 centimeters) of rain had fallen in the two days previous to the measurement or if two inches (5 centimeters) had fallen in the previous week. In addition, a minimum well depth of 30 feet (9 meters) was required along with a minimum depth of three feet (0.9 meters). Many wells that were found to be unusable were remeasured during dry conditions, and water measurements of wells taken in later efforts were concentrated during dry periods to prevent this problem.

The water table control points were digitized and the surface contoured by SURFACE II in a manner similar to the construction of the geologic structure maps.

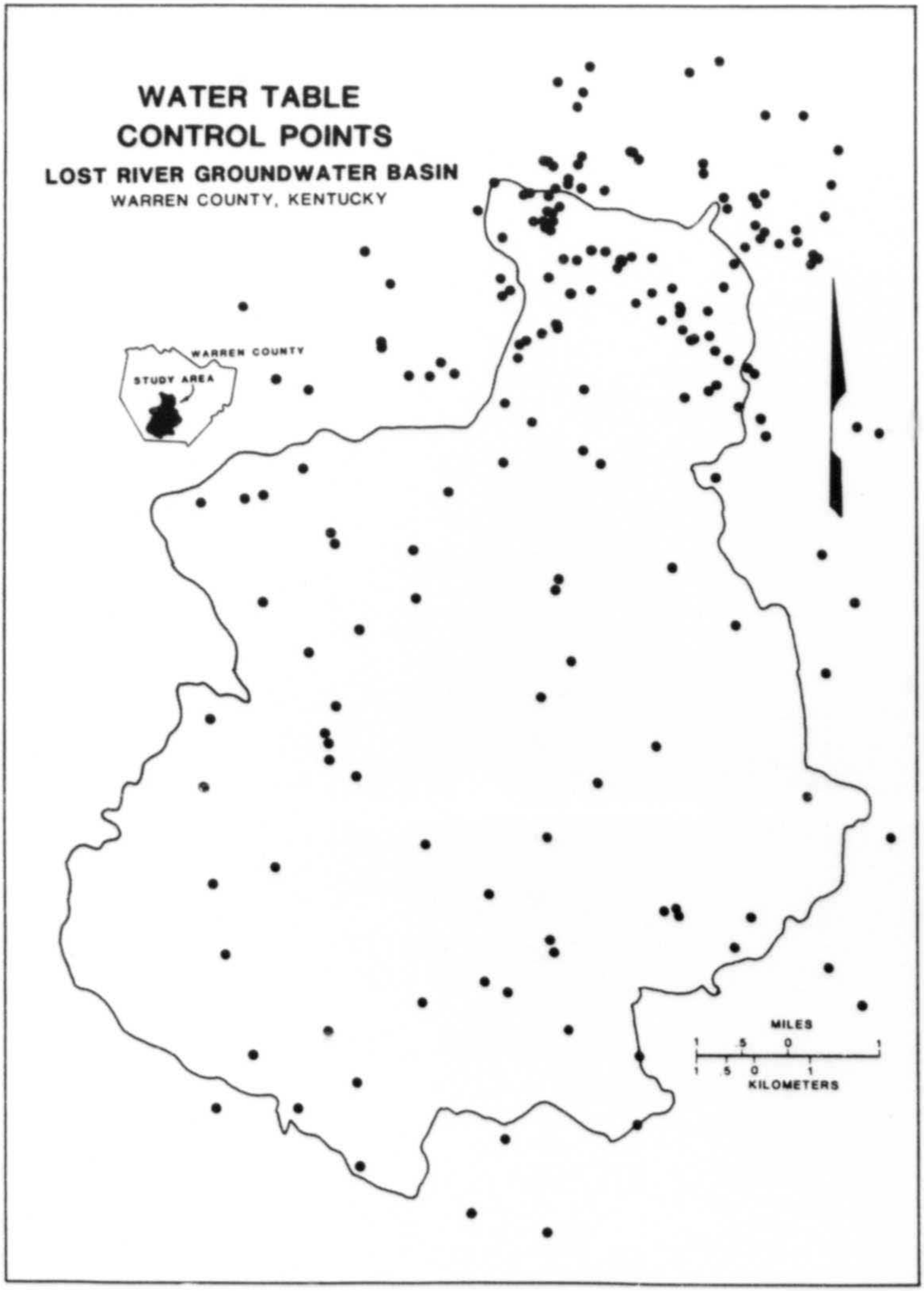


Figure 8. Water table control points. Sources: Lambert (1976), Crawford, Groves, and others (1984), and Able (1986).

Data Analysis

The procedures for analysis are described below for the comparison of the Lost River Chert and the water table. The process then was repeated for comparison of the water table and the Corydon Chert Member. Once the maps were contoured by the computer, the 3-dimensional surfaces of the Lost River Chert and the water table were numerically described as x, y, and z values at 88 evenly spaced grid nodes within the study area. Each node on the chert map has a corresponding, 'partner' node on the water table map that occupies the same x, y position when the maps are superimposed. The two surfaces were then tested for correspondence by comparing the z values at each pair of partner nodes. A pair of values was said to correspond if the elevation of the water table at a node was within 20 feet (6.1 meters) above or below the elevation at the top of the chert bed. This range was chosen because 1) some cave streams have cut down into the chert beds, 2) the water table in interstream areas will be somewhat higher, but may have a vertical position controlled by the chert beds as the water flows downgradient towards cave streams that are perched on the chert, 3) collapses of cave roofs can dam the cave stream and cause the water table to rise upstream from the breakdown dam, and 4) since a contoured surface is largely inferred, some tolerance must be allowed for the differences between the elevations on the map and reality.

CHAPTER V

RESULTS AND CONCLUSIONS

The results of this research are presented in a series of maps produced by the DISSPLA computer cartography software package. These include geologic structure maps of the two cherts, a contour map of the water table, and maps produced by comparison of the water table with the cherts. The percentage of the total area within the basin over which the water table is found to correlate with chert layers is used to accept or reject the appropriate hypotheses.

Geologic Structure

Figure 9 shows the geologic structure of the Lost River Groundwater Basin, based on the top of the Lost River Chert Bed. The Chert generally strikes northeast-southwest, and dips northwest toward the axis of the Illinois Basin. Total structural relief of the Chert is just over 200 feet (61 meters), which compares with 320 feet (97 meters) for the Chattanooga Shale over the same area (McGrain and Sutton, 1973). The southern half of the basin is quite flat, with dips on the order of 10 feet per mile (1.8 meters per kilometer), increasing to 20-40 feet per mile (3.6-7.2 meters per kilometer) as one moves toward the northwest. A relatively steep syncline in the northwest part of the basin plunges to the northwest. As mapped, the eastern flank of this structure has dips that exceed 100 feet per mile (18 meters per kilometer). A low dome is mapped in the southwest. Neither of these features is apparent on structure maps of the Chattanooga Shale.

Based on the assumption that the top of the Corydon Member consistently lies 40 feet (12 meters) below the top of the Lost River Chert (Woodson, 1981 and

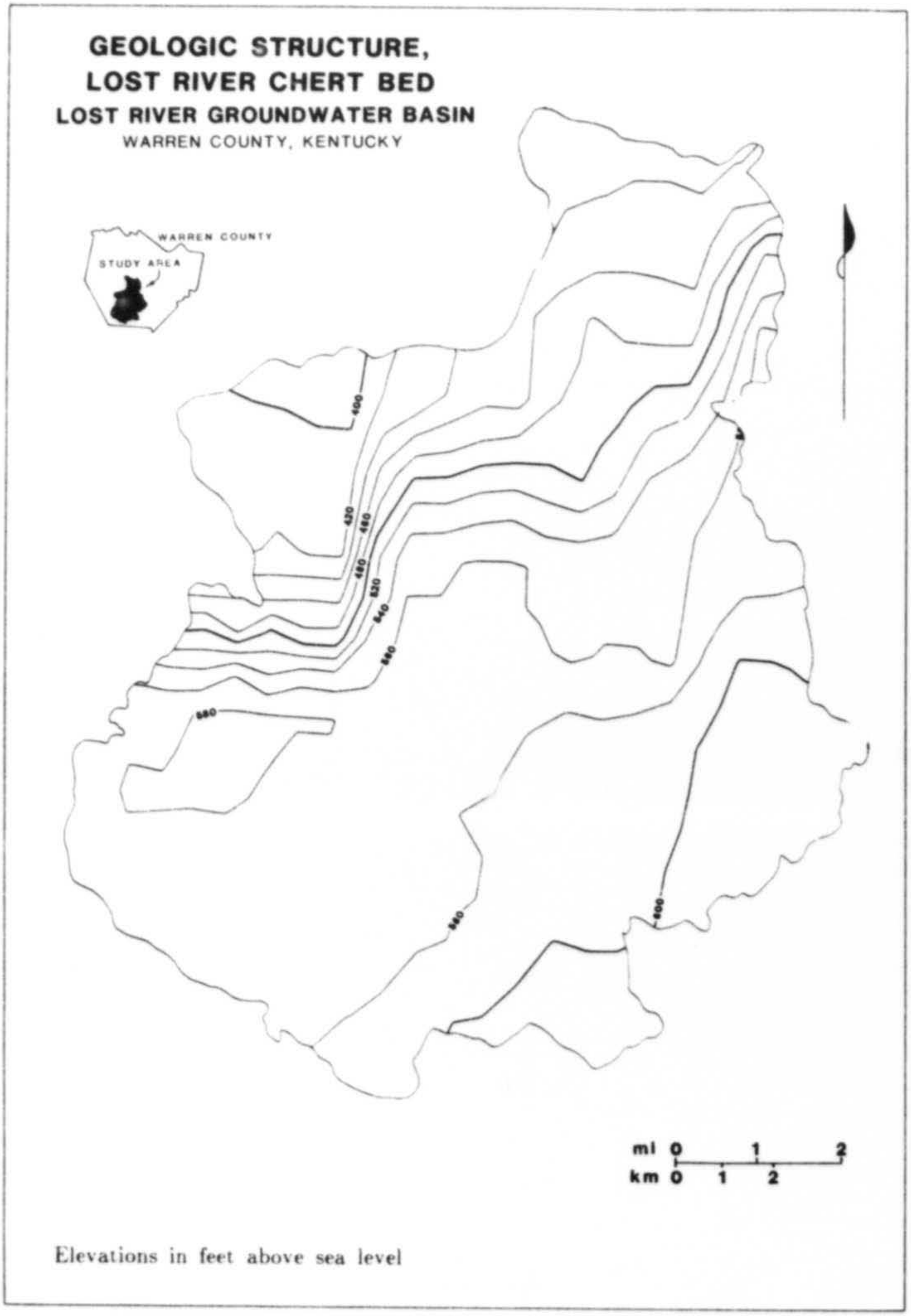


Figure 9. Geologic structure of the Lost River Chert Bed, Lost River Groundwater Basin.

1983) the surface of the Lost River Chert was lowered by 40 feet (12 meters) to provide a structure map of the Corydon (Figure 10).

The Water Table

The contour map of the water table for the Lost River Groundwater Basin (Figure 11) is similar to previous, hand-contoured water table maps of the basin (Groves, 1983; Crawford, 1985a; Able, 1986). The water table reaches a high of about 620 feet (188 meters) at the southern edge of the basin, and has a base level elevation of 424 feet (128 meters) at the Lost River Rise. The general gradient of groundwater flow is 10-20 feet per mile (1.8-3.6 meters per kilometer), northward toward the Barren River. The main trunk of the Lost River has a measured average gradient of 16 feet per mile (2.9 meters per kilometer) along the mapped and inferred route between the swallet of Big Sinking Creek and the Lost River Rise.

A potential problem with construction of this map is that some water levels in wells may represent elevations other than the true water table for the shallow karst aquifer. Local, perched water bodies are known to exist within the study area, as well as at least one lower, confined aquifer. There is a chance, therefore, that some water levels may be too high, representing the tops of minor perched water bodies, or too low, representing the potentiometric surface of the lower confined aquifer. Water elevations within uncased wells (as are virtually all drainage and water supply wells within the study area) that pass through minor perched water tables to intersect the principal aquifer (as well as intersecting good crevices) would be expected to drain down to the correct level. Most problematic readings were taken from those wells which reach into, but do not pass through, these perched water bodies. Wells drilled into completely impermeable zones of limestone may also give false readings, although well coring within the study area (Crawford, 1985b) indicates that such wells are relatively rare.

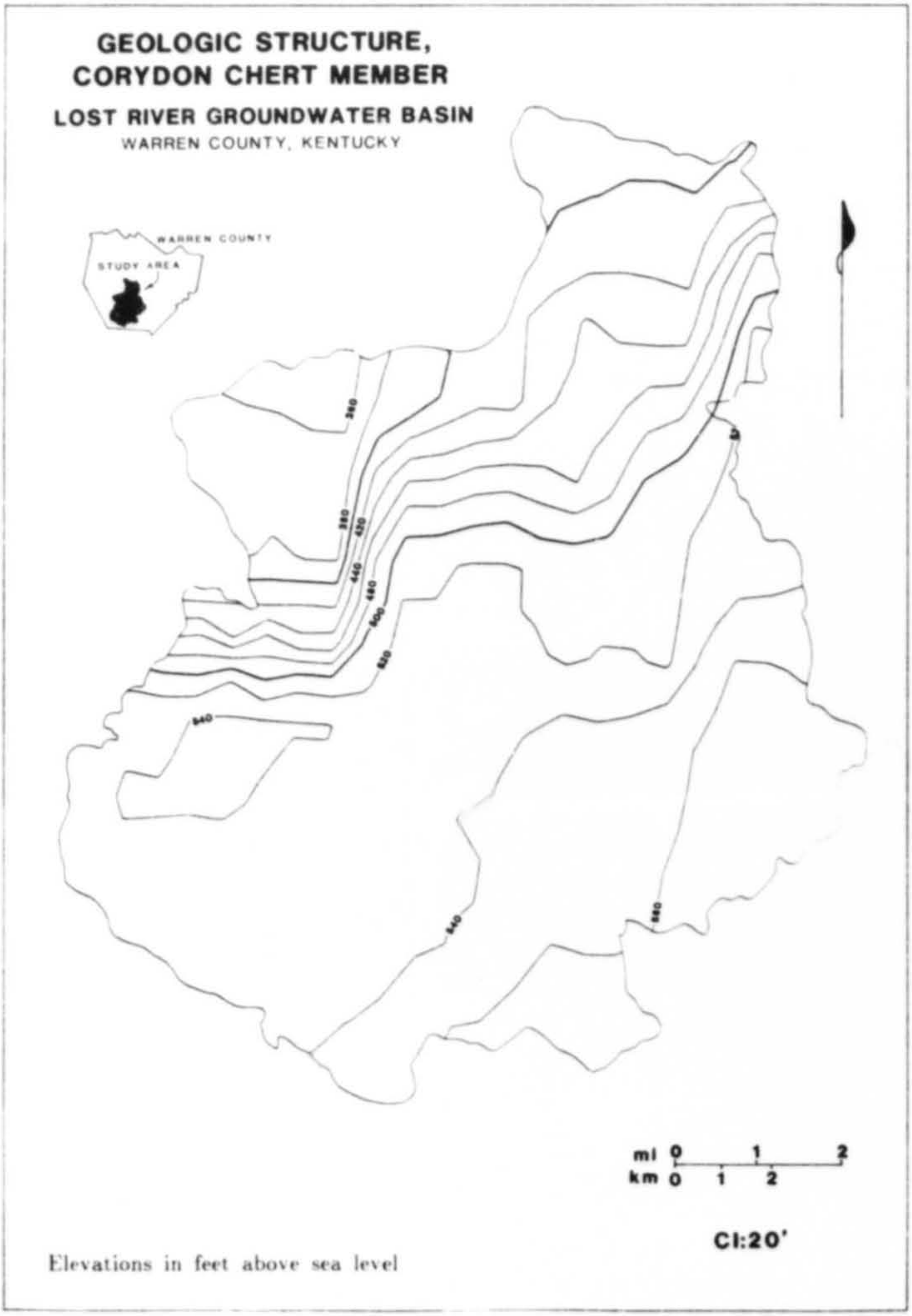


Figure 10. Geologic structure of the Corydon Chert Member, Lost River Groundwater Basin.

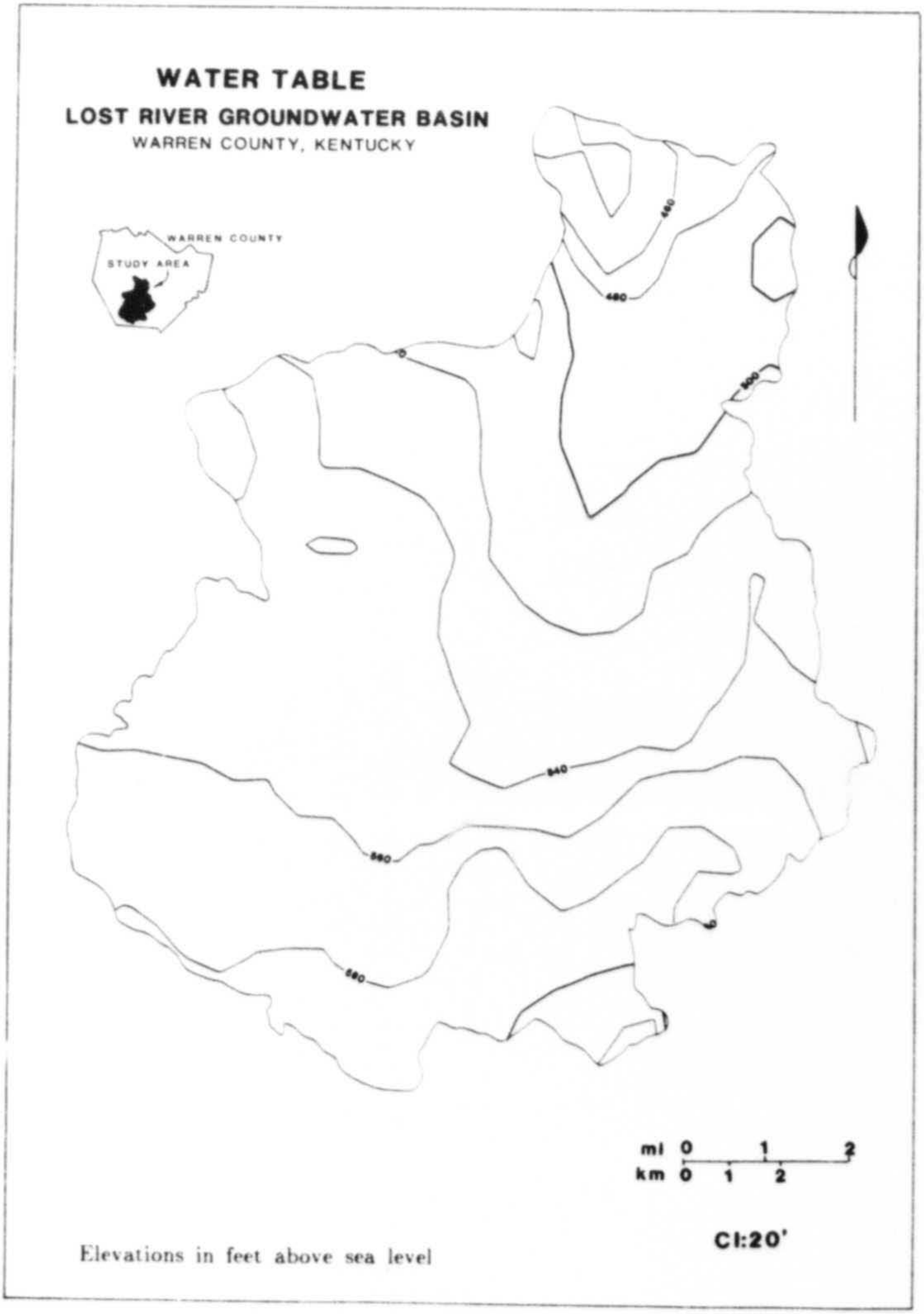


Figure 11. Water table, Lost River Groundwater Basin.

The potentiometric surface of the deeper, confined aquifer may be higher or lower than the water table for the principal, shallow aquifer. Water from the lower aquifer is higher in dissolved solids, however, and wells that tap this water may often be recognized by an odor of hydrogen sulfide.

Comparison and Correlation of Cherts and Water Table

Of the 88 grid nodes within the study area at which the Lost River Chert and water table elevations can be compared, 42.6% show a correlation between the two surfaces as defined for this research. In addition, 40.7% of the nodes show correlation between the Corydon Chert Member and the water table. Summing these two quantities shows that the water table correlates with bedded chert layers over 83.3% of the study area, and therefore hypothesis #1 is accepted: the Lost River Chert Bed and the Corydon Chert Member have a dominant influence on the vertical position of shallow karst groundwater flow within the Lost River Groundwater Drainage Basin.

Figure 12 is a map of the elevation differences between the water table and the Lost River Chert Bed throughout the study area. A value of zero indicates a perfect correlation between the water table and chert; positive values show areas where the water table is higher than the chert, and conversely, negative values occur where the top of the chert is higher than the water table. Figure 13 is a similar map showing comparison between the water table and the Corydon Chert. On both of these maps the areas that show correspondence are shaded.

Conclusions

With the results of this analysis, one can see the relationship between the chert beds and shallow groundwater flow for various parts of the basin. A cross section of the basin (Figure 14) shows the relationship between groundwater flow and the cherts. At Big Sinking Creek, near the headwaters of the basin,

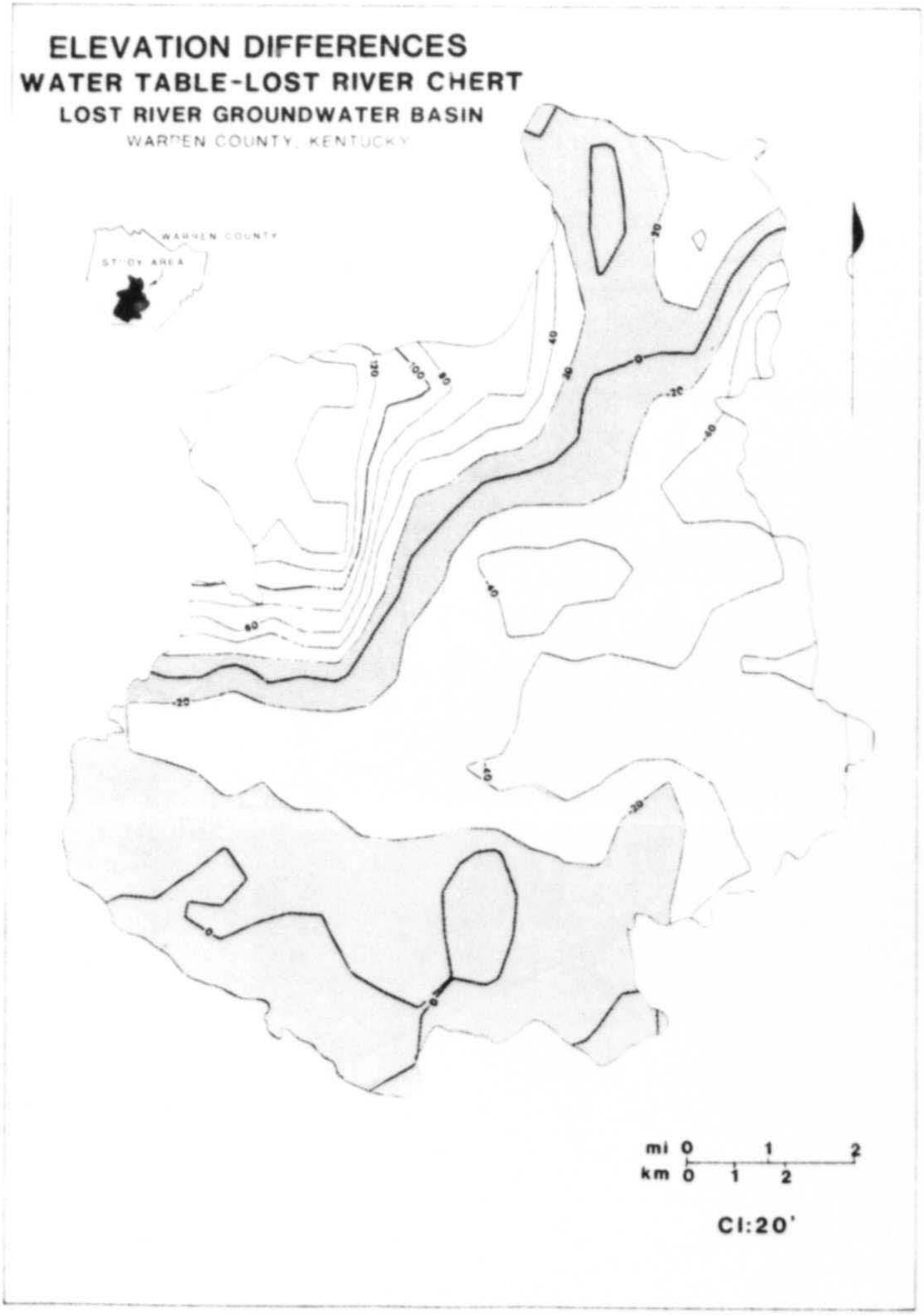
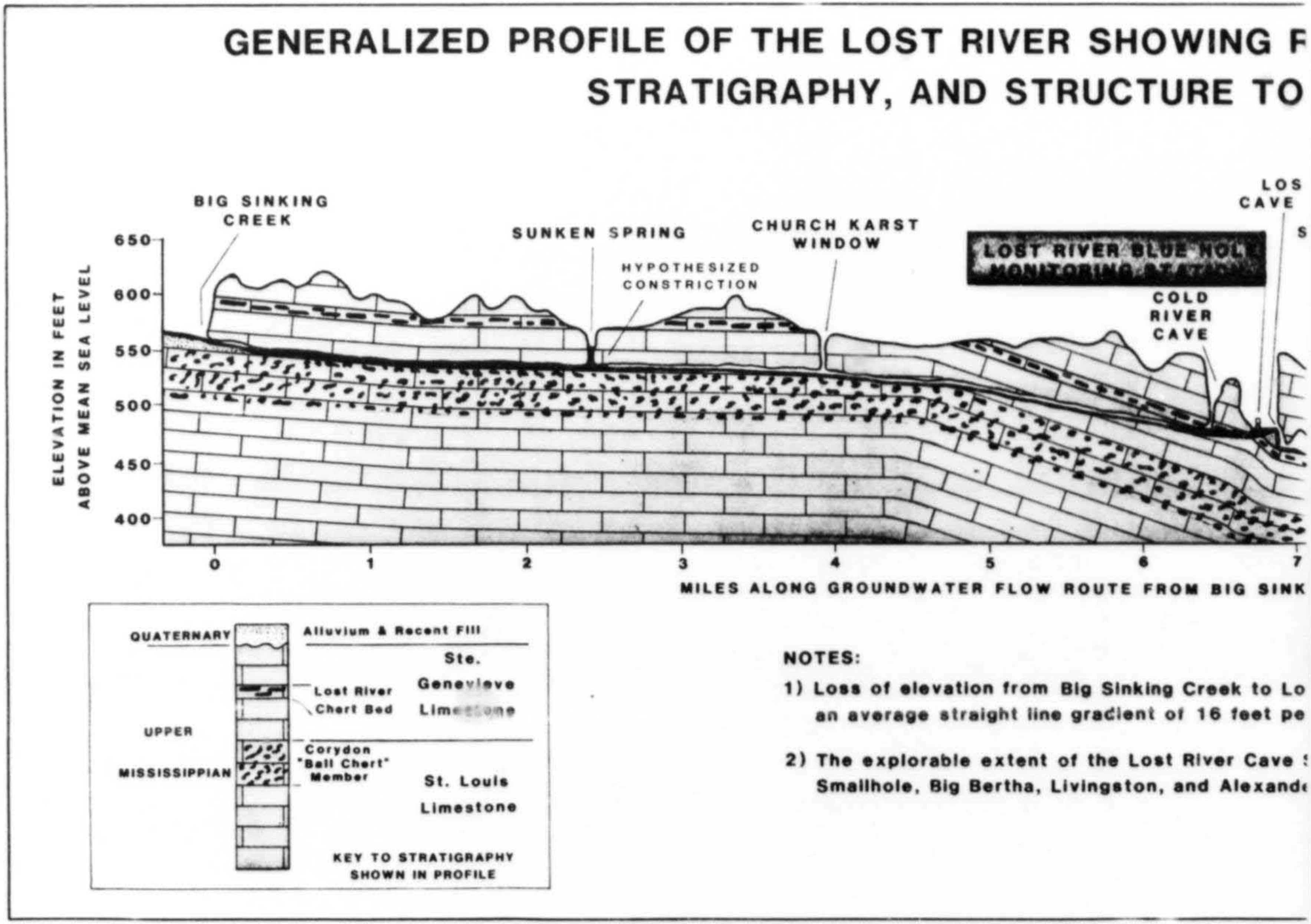


Figure 12. Contoured elevation differences between the water table and the Lost River Chert Bed. Shaded area indicates correspondence between chert and water table.

Figure 13. Contoured elevation differences between the water table and the Corydon Chert Member. Shaded area indicates correspondence between chert and water table.



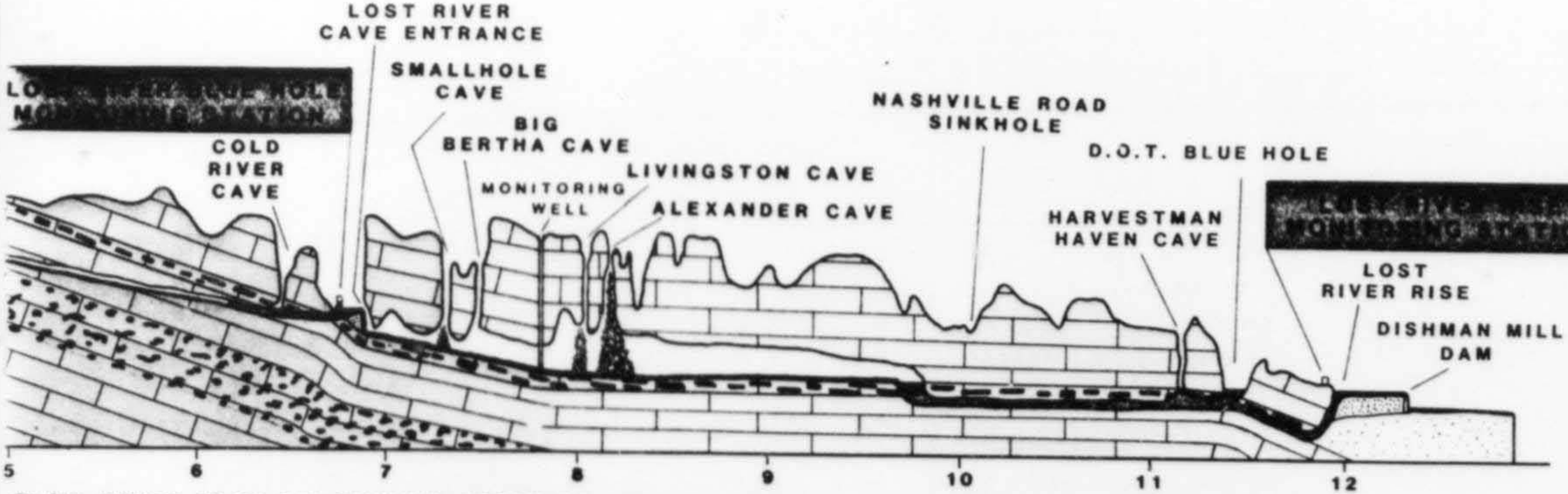
NOTES:

1) Loss of elevation from Big Sinking Creek to Lo
an average straight line gradient of 16 feet pe

2) The explorable extent of the Lost River Cave S
Smallhole, Big Bertha, Livingston, and Alexand

Figure 14. Generalized cross section, Lost River Groundwater Basin. Crawford and Groves (1987).

IVER SHOWING RELATIONSHIP OF CAVERN DEVELOPMENT,
STRUCTURE TO GROUNDWATER FLOW



FLOW ROUTE FROM BIG SINKING CREEK TO LOST RIVER RISE

from Big Sinking Creek to Lost River Rise is 135 feet, for
ght line gradient of 16 feet per mile.

xtent of the Lost River Cave System includes the Lost River,
rtha, Livingston, and Alexander Cave entrances.

CG

s section, Lost River Groundwater Basin. Source:
Groves (1987).

groundwater flow (near or at the surface in the few perennial streams) is perched upon the Corydon Chert. Water flows generally to the north, except between Chaney Lake and Rich Pond. East-southeast flow in that area is a result of downdip flow off of a small structural dome (Figure 9).

In the vicinity of the Lost River Uvala, the water moves upsection to emerge on top of the Lost River Chert, although the reason for this upsection movement is not yet clear. (One possible explanation would be high-angle faulting in the vicinity of the Uvala. No faults are mapped at this location, however, and none have been located during the course of this research, after considerable effort.) After this upsection jump, the Lost River flows upon the Lost River Chert for some distance. Several miles of stream passage within the Lost River Cave System can be followed where the cave floor has formed at or near the top of the chert layer. The river again breaches the chert at an unknown location somewhere in the downstream end of the basin, as observations in Sullivan's Cave and Robinson Cave have shown (tributary streams in these caves breach the chert and since they join and flow out of the basin at the same level as the Lost River, it too must breach the layer). In the very downstream part of the basin the water table is 'artificially' high and does not represent the original path of groundwater flow. This is due to 1) approximately 30 feet (9.1 meters) of Pleistocene alluvium and 2) an additional 8 or 10 feet (2.4 to 3.3 meters) of recent fill behind a manmade dam on Jennings Creek downstream from the Rise. Although the water table has been raised in the downstream section, groundwater still flows through its original passage and flows upward from a depth of about 34 feet (10 meters) at the Lost River Rise (Maegerlain and Dillon, 1980).

How can the results of this research in the Lost River Groundwater Basin be extended outward to other areas of the Pennyroyal Plateau? The two chert beds are present near the surface over part of this area only.

relatively flat compared to the regional dip of the strata, in areas to the northwest the cherts are buried too deeply to have an effect on shallow groundwater flow. To the southeast (updip) the two chert layers have been removed by erosion. Along the strike, however, the cherts are present over a large area, as they may be on the other side of the Cincinnati Arch (McGrain, 1969). It is suggested that in the areas of the Pennyroyal Plateau where shallow groundwater flow occurs within the same part of the geologic section as the Lost River Groundwater Basin that the relationships between the cherts and groundwater flow may be similar. Other bedded chert units appear in various parts of the upper Mississippian System (Badiei, 1981) and may also act as perching layers in some karst drainage systems.

REFERENCES

Able, A. S., 1986, Using drainage wells to study the karst aquifer beneath Bowling Green, Kentucky: unpublished paper, Western Kentucky University, Bowling Green, Kentucky, 17 p.

Badiei, J., 1981, Correlation and comparison of the Lost River Chert of the Ste. Genevieve Formation in south-central Indiana and north-central Kentucky: unpublished master's thesis, Indiana State University, Terre Haute, Indiana, 81 p.

Bretz, J. H., 1942, Vadose and phreatic features of limestone caves: Journal of Geology, v. 50, pp. 675-811.

Brown, R. F., and T. W. Lambert, 1963, Reconnaissance of ground-water resources in the Mississippian Plateau Region, Kentucky: U. S. Geological Survey Water-Supply Paper 1603, 58 p., 16 pl.

Carr, D., R. Leininger, and M. Golde, 1978, Crushed stone resources of the Blue River Group (Mississippian) of Indiana: Indiana Geological Survey, Bloomington, Bulletin 52, 225 p.

City-County Planning Commission of Warren County, Kentucky, 1974, Official atlas of Bowling Green, Kentucky: H. U. D. Project Number CPA-KY04-36-1006.

Crawford, N. C., 1981a, Karst flooding in urban areas, Bowling Green, Kentucky: Proceedings of the Eighth International Congress of Speleology, Western Kentucky University, Bowling Green, Kentucky, pp. 763-765.

____, 1981b, Karst hydrogeology and environmental problems in the Bowling Green area; Report of Investigations #3: Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, 21 p.

____, 1982, Hydrologic problems resulting from development upon karst terrain, Bowling Green, Kentucky: Guidebook prepared for U. S. Environmental Protection Agency karst hydrogeology workshop, Nashville, Tennessee, 34 p.

____, 1984, Toxic and explosive fumes rising from carbonate aquifers: a hazard for residents of sinkhole plains: in Beck, B. F. (ed.), Proceedings of the first Multidisciplinary Conference on Sinkholes, Rotterdam, Netherlands: A. A. Balkema, Publishers, pp. 297-304.

____, 1985a, Groundwater flow routes, Lost River Groundwater Basin, Warren County, Kentucky: Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, 1 pl.

____, 1985b, Exploratory and monitoring well logs: United States Environmental Protection Agency investigation of potentially hazardous fumes rising from caves beneath Bowling Green, Kentucky: Center for Cave and Karst Studies, Department of Geography and Geology, Western Kentucky University, 43 p.

Crawford, N. C., and C. G. Groves, 1984, Stormwater drainage wells in the karst areas of Kentucky and Tennessee: U. S. Environmental Protection Agency underground water source protection program grant report, 52 p.

Crawford, N. C., and C. G. Groves, 1987, Hydrogeology of the Lost River karst groundwater basin, Warren County, Kentucky: in Crawford, N. C. (ed.), Agricultural and urban nonpoint source pollution impacts on karst aquifers in the Pennyroyal Karst Region of Kentucky, Kentucky Division of Water and Barren River Area Development District, (in prep.)

Crawford, N. C., C. G. Groves, and others, 1984, Stormwater drainage wells in Kentucky: Bowling Green: U. S. Environmental Protection Agency underground water source protection program grant report, 1,422 p.

Cvijic, J., 1893, Das Karstphanomen: Geog. Abhandlung von A. Penck, v. 5, pp. 215-319.

Davies, W. E., 1960, Origin of caves in folded limestones: National Speleological Society Bulletin, v. 22, part 1, pp. 5-18.

Davis, W. M., 1899, The geographic cycle: Geographical Journal, v. 14, pp. 481-504.

———, 1930, Origin of limestone caverns: Geological Society of America Bulletin, v. 41, pp. 475-628.

Dilamarter, R. R., 1985, Oil wells in a Kentucky karst region: Annales de la Société Géologique de Belgique, v. 108, pp. 21-25.

Dwerryhouse, A. R., 1907, Limestone caverns and potholes and their mode of origin: Journal of the York Ramblers Club, v. 2, pp. 223-228.

Elrod, M., 1899, The geologic relations of some St. Louis Group caves and sinkholes: Indiana Academy of Science Proceedings for 1898, pp. 258-267.

Ferguson, C. C., and R. G. Stearns, 1967, Lost River Chert--a useful stratigraphic bed: in Smith, W. E. (ed.), A field guide to Mississippian sediments in northern Alabama and south-central Tennessee, University (Alabama): Alabama Geological Society, p. 61.

Ford, D. C., 1965, The origin of limestone caves, a model from the central Mendip Hills, England: National Speleological Society Bulletin, v. 27, pp. 109-132.

———, 1971, Geologic structure and a new explanation of limestone cavern genesis: Transactions of the Cave Research Group of Great Britain, v. 13, pp. 81-94.

Ford, D. C., and R. O. Ewers, 1978, The development of limestone cave systems in the dimensions of length and depth: Canadian Journal of Earth Science, v. 15, pp. 1783-1798.

Gardner, J. H., 1935, Origin and development of limestone caverns: Geological Society of America Bulletin, v. 46, pp. 1255-1274.

Groves, C. G., 1983, A potentiometric model of the shallow karst aquifer, City of Bowling Green, Warren County, Kentucky: Abstracts of the 14th Research Conference of the Western Kentucky University Club of Sigma Xi, Bowling Green, Kentucky, p. 12.

Groves, C. G., and N. C. Crawford, 1986a, Robinson Cave, Warren County, Kentucky: Central Kentucky Cave Survey Bulletin #2, (in press).

Groves, C. G., and N. C. Crawford, 1986b, Karst hydrology of the Sunken Spring Drainage Basin, Warren County, Kentucky (abs.): Geography Section Proceedings for 1985, Kentucky Academy of Science, (in press).

Grund, A., 1903, Die Karsthydrographie: Geog. Abhandlung, v. 7, pp. 1-200.

Hess, J. W., 1976, Review of the hydrology of the Central Kentucky Karst: National Speleological Society Bulletin, v. 38, pp. 99-103.

Howard, A. D., 1968, Stratigraphic and structural controls on landform development in the Central Kentucky Karst: National Speleological Society Bulletin, v. 30, pp. 94-114.

Integrated Software Systems Corporation, 1984, DISSPLA user's manual (version 10.0: San Diego: Integrated Software Systems Corporation.

Kissam, P., 1971, Surveying Practice (2nd ed.): New York: McGraw-Hill Book Company, 482 p.

Lambert, T. W., 1976, Water in a limestone terrane in the Bowling Green area, Warren County, Kentucky: Kentucky Geological Survey, Report of Investigations #17, 43 p.

Lavalle, P., 1967, Some aspects of linear karst depression development in south-central Kentucky: Association of American Geographers Annals, v. 50, pp. 49-71.

Maegerlein, S. D., and C. Dillon, 1980, Final report on the exploration and survey of the Lost River Rise at Bowling Green Kentucky: Report submitted to Nicholas Crawford, Hydrology Consultant, and G. Reynolds Watkins, Consulting Engineers, 4 p.

Malott, C. A., 1937, Invasion theory of cavern development: Geological Society of America Proceedings for 1937, p. 323.

McGrain, P., 1942, The Ste. Genevieve and St. Louis Limestone of Harrison

County, Indiana: unpublished master's thesis, Indiana University, Bloomington, 28 p.

, 1969, Extension of the Lost River Chert across parts of Kentucky: American Association of Petroleum Geologists Bulletin, v. 53, pp. 1506-1507.

McGrain, P., and D. G. Sutton, 1973, Economic geology of Warren County, Kentucky: Kentucky Geological Survey, series 10, county report 6, 28 p.

Miller, R. C., 1969, Geology of the Canmer quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-816.

Moore, S. L., 1963, Geology of the Drake quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-277.

Palmer, A. N., 1981, A geological guide to Mammoth Cave National Park: Teaneck, New Jersey: Zephyrus Press, Inc., 196 p.

Palmer, M. V., 1976, The Mitchell Plain of southern Indiana: National Speleological Society Bulletin, V. 38, pp. 74-79.

Petersen, A., 1983, Personal communication: Department of Geography and Geology, Western Kentucky University, Bowling Green.

Plebuch, R. O., R. J. Faust, and M. A. Townsend, 1985, Potentiometric surface and water quality in the principal aquifer, Mississippian Plateaus region, Kentucky: U. S. Geological Survey Water-Resources Investigations Report 85-4102, 45 p., 2 pl.

Piper, A. M., 1932, Groundwater in north-central Tennessee: U. S. Geological Survey Water-Supply Paper 640, pp. 69-89.

Pohl, E. R., 1970, Upper Mississippian deposits of south-central Kentucky: Kentucky Academy of Science Transactions, v. 31, pp. 1-15.

Pough, F. H., 1976, A field guide to rocks and minerals: Boston: Houghton Mifflin Company, 317 p.

Quinlan, J. F., and R. O. Ewers, 1981, Hydrogeology of the Mammoth Cave region, Kentucky: in Roberts, T. G. (ed.), G. S. A. Cincinnati '81 Field Trip Guidebooks, v. 3, pp. 457-506.

Quinlan, J. F., and Ray, J. A., 1981, Groundwater basins in the Mammoth Cave region, Kentucky: **Occasional** Publication #1, Friends of the Karst, 1 pl.

Rainey, H. C., 1964, Geology of the Rockfield quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-309.

Rauch, H., and W. B., White, 1970, Lithologic controls on the development of solution porosity in carbonate aquifers: Water Resources Research,

v. 6, pp. 1175-1192.

Sampson, R. J., 1978, SURFACE II graphics system (revision one): Lawrence: Kansas Geological Survey, 240 p.

Saunders, J., 1984, Fisher Ridge Cave System, Hart County, Kentucky: Central Kentucky Cave Survey Bulletin #1, pp. 188-191.

Schindel, G. M., 1984a, Carver Well Cave: Central Kentucky Cave Survey Bulletin #1, p. 183.

_ _ _, 1984b, Greenwood Cave: Central Kentucky Cave Survey Bulletin #1, pp. 194-195.

Shawe, F. R., 1963a, Geology of the Bowling Green North quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-234.

_ _ _, 1963b, Geology of the Bowling Green South quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-235.

_ _ _, 1963c, Geology of the Woodburn quadrangle, Kentucky: U. S. Geological Survey geologic quadrangle map GQ-280.

Smith, D. I., T. C. Atkinson, and D. P. Drew, 1976, The hydrology of limestone terrains: in Ford, T. D. and C. H. D. Cullingford, (eds.), The Science of Speleology, London: Academic Press, pp. 179-212.

Smith, W. S. T., and C. E. Siebenthal, 1907, Description of the Joplin District: U. S. Geological Folio 148, 18 p.

Swinnerton, A. C., 1932, Origin of limestone caverns: Geological Society of America Bulletin, v. 43, pp. 662-693.

Wells, S., 1976, Sinkhole Plain evolution in the Central Kentucky Karst: National Speleological Society Bulletin, v. 38, pp. 103-106.

White, W. B., 1960, Terminations of passages in Appalachian caves as evidence for shallow phreatic origin: National Speleological Society Bulletin, v. 22, pp. 43-53.

_ _ _, 1969, Conceptual models for carbonate aquifers: Ground Water, v. 7, pp. 15-21.

_ _ _, 1976, The geology of caves: in Geology and Biology of Pennsylvanian Caves, Bureau of Topographic and Geologic Survey General Geology Report 66, pp. 1-71.

White, W. B., R. A. Watson, E. R. Pohl, and R. Brucker, 1970, The Central Kentucky Karst: Geographical Review, v. 60, pp. 88-115.

Woodson, F. J., 1981, Lithologic and structural controls on karst landforms of the Mitchell Plain, Indiana, and Pennyroyal Plateau, Kentucky: unpublished master's thesis, Indiana State University, Terre Haute, Indiana, 132 p.

____, 1983, Uppermost St. Louis Limestone (Mississippian): The Horse Cave Member in Indiana: Proceedings of the Indiana Academy of Science, v. 91, pp. 419-427.

Woodward, H. P., 1961, A stream piracy theory of cave formation: National Speleological Society Bulletin, v. 22, part 2, pp. 39-58.

APPENDIX:

RECORDS OF GEOPHYSICAL WELL LOGGING

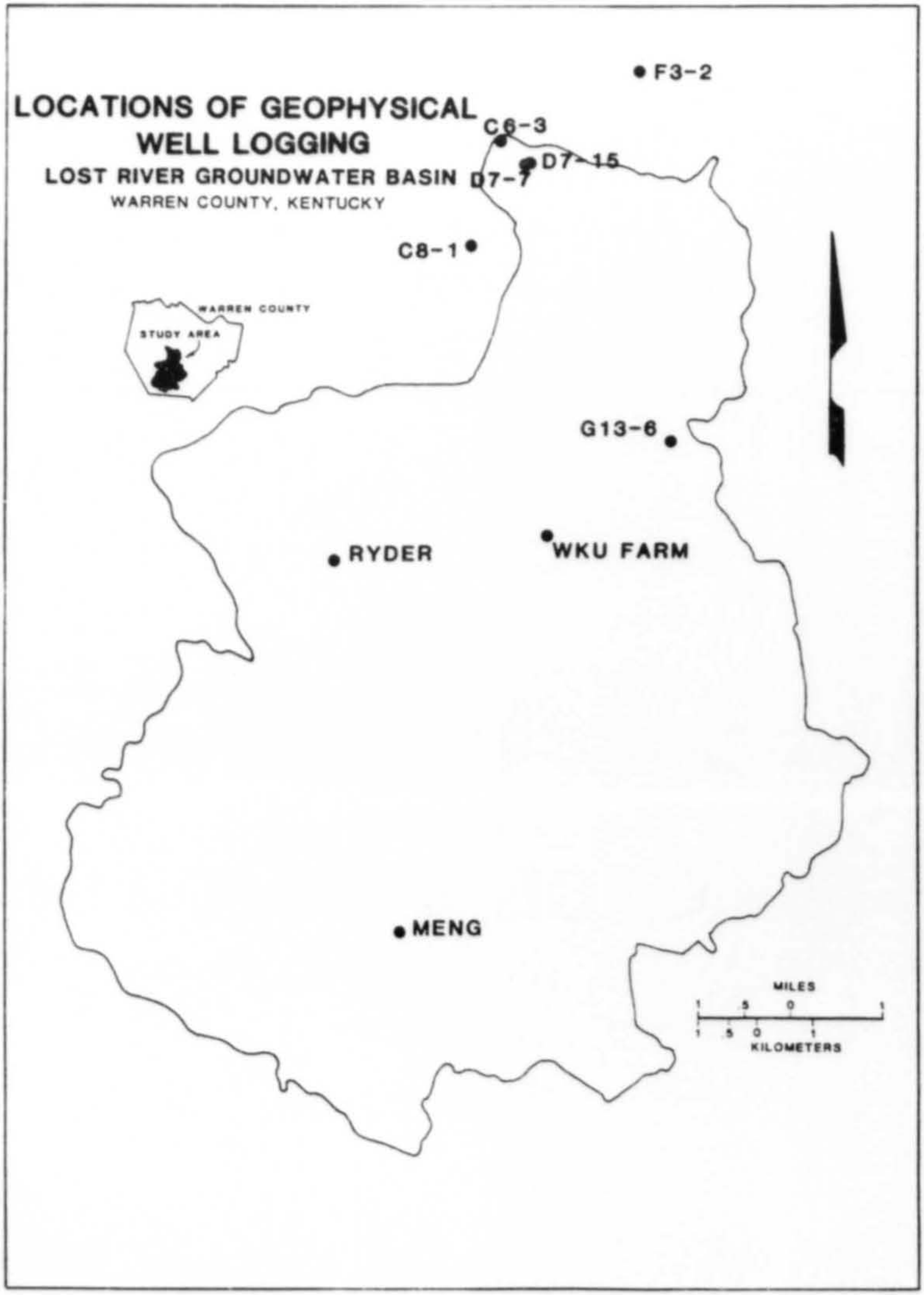


Figure 15. Locations of geophysical well logging.

Dresser Atlas

DRESSER

COMPENSATED
DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL SOUTH SUNRISE NO. 07-15

FIELD

COUNTY STATE Ky

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV.

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

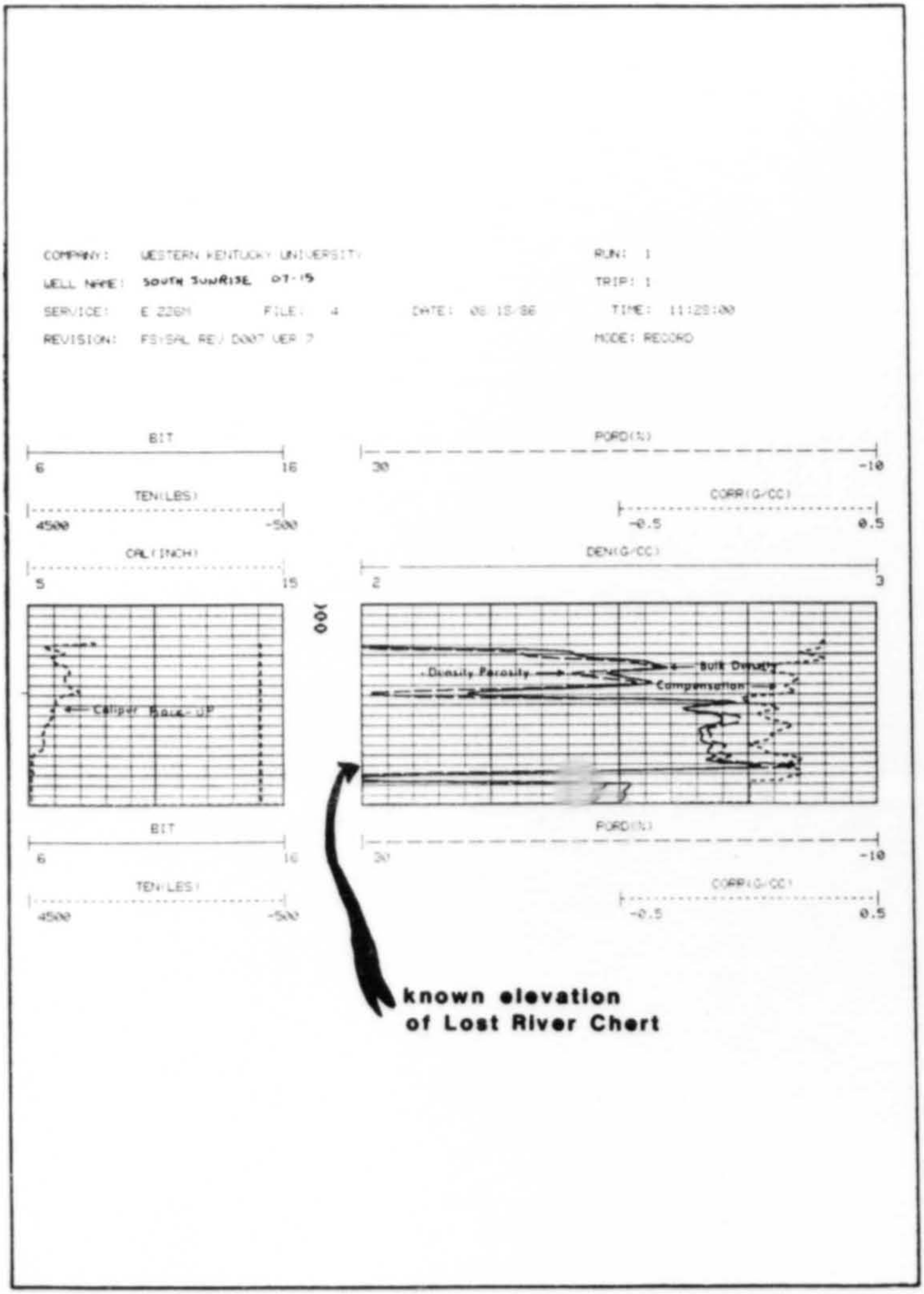
ELEVATIONS

KB

DF

GL

DATE	2 AUG 1986				
RUN	1				
SERVICE ORDER	130817				
DEPTH-DRILLER					
DEPTH-LOGGER	38′				
BOTTOM LOGGED INTERVAL	36′				
TOP LOGGED INTERVAL					
CASING - DRILLER		@		@	
CASING - LOGGER					
BIT SIZE					
TYPE FLUID IN HOLE					
DENSITY / VISCOSITY					
PH / FLUID LOSS					
SOURCE OF SAMPLE					
RM AT MEAS. TEMP.		@		@	
RMF AT MEAS. TEMP.		@		@	
RMC AT MEAS. TEMP.		@		@	
SOURCE OF RMF / RMC					
RM AT BHT		@		@	
TIME SINCE CIRCULATION					
MAX. REC. TEMP. DEG. F					
EQUIP. NO. / LOC.	HL 6375	HENDERSON			
RECORDED BY	LOWE				
WITNESSED BY	FRANK BOGLE				

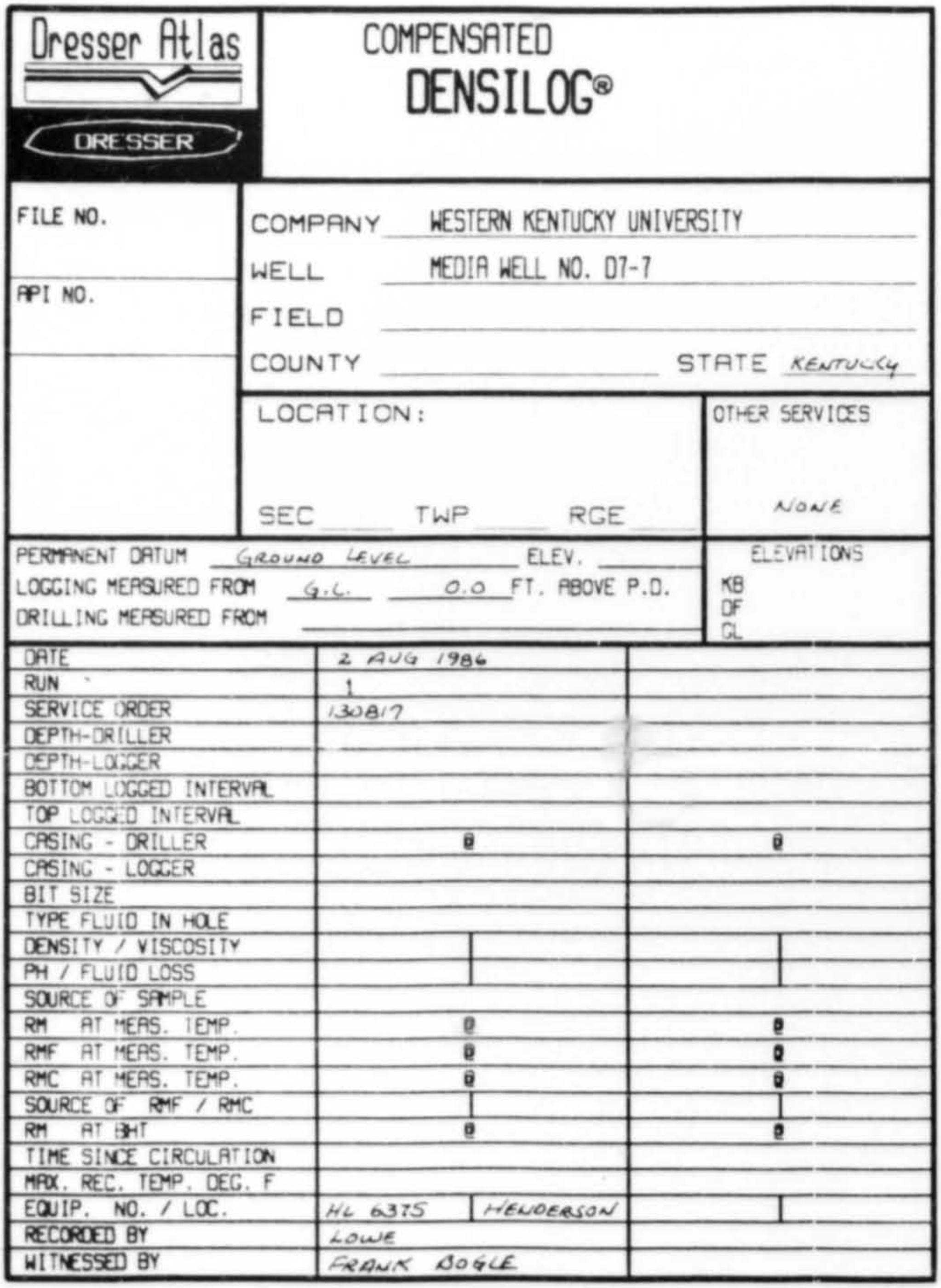


COMPANY: WESTERN KENTUCKY UNIVERSITY　　RUN: 1

WELL NAME: SOUTH SUNRISE 07-15　　TRIP: 1

SERVICE: E 226M　FILE: 4　DATE: 06/15/86　TIME: 11:28:00

REVISION: FS:SAL REV D007 VER 7　　MODE: RECORD



Dresser Atlas

DRESSER

COMPENSATED
DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY
WELL MEDIA WELL NO. D7-7
FIELD
COUNTY STATE KENTUCKY

LOCATION:
SEC TWP RGE

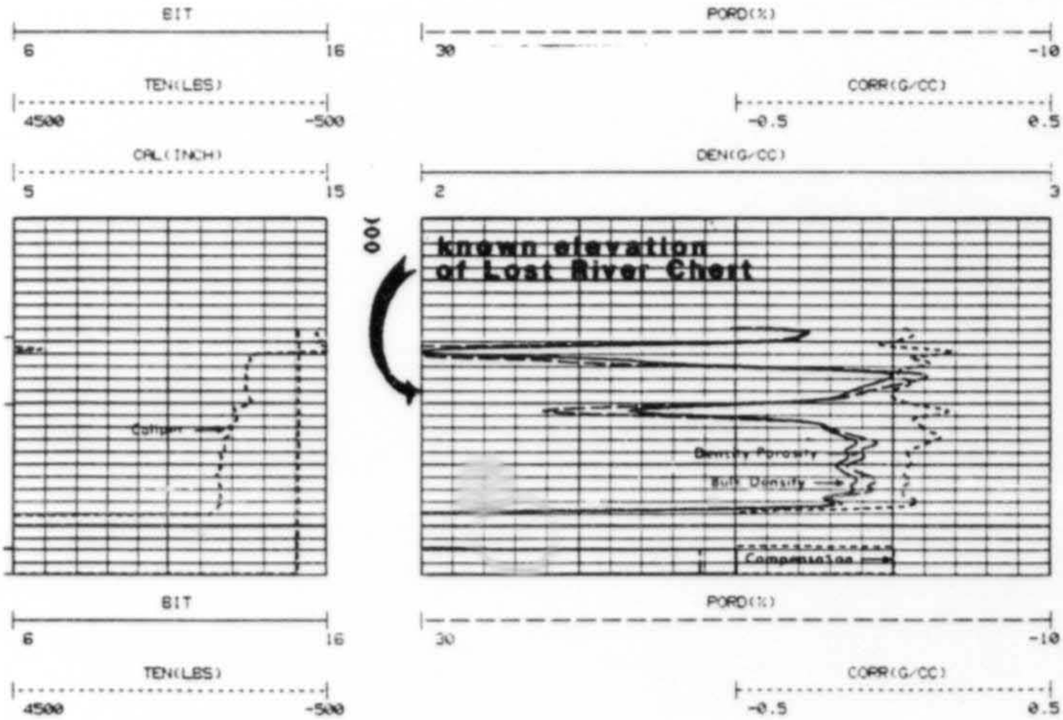
OTHER SERVICES
NONE

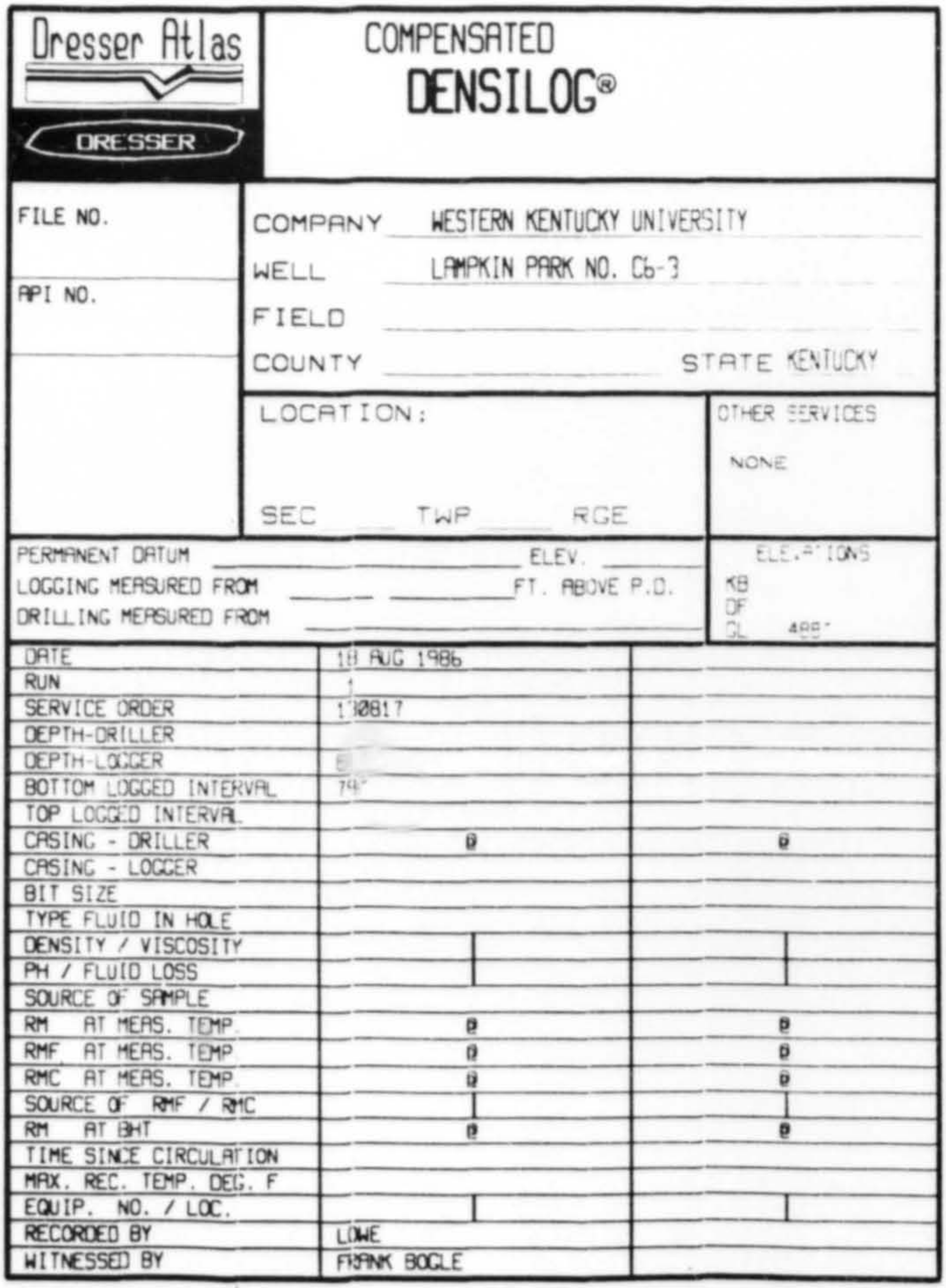
PERMANENT DATUM GROUND LEVEL ELEV.
LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.
DRILLING MEASURED FROM

ELEVATIONS
KB
DF
GL

DATE	2 AUG 1986			
RUN	1			
SERVICE ORDER	130817			
DEPTH-DRILLER				
DEPTH-LOGGER				
BOTTOM LOGGED INTERVAL				
TOP LOGGED INTERVAL				
CASING - DRILLER	@		@	
CASING - LOGGER				
BIT SIZE				
TYPE FLUID IN HOLE				
DENSITY / VISCOSITY				
PH / FLUID LOSS				
SOURCE OF SAMPLE				
RM AT MEAS. TEMP.	@		@	
RMF AT MEAS. TEMP.	@		@	
RMC AT MEAS. TEMP.	@		@	
SOURCE OF RMF / RMC				
RM AT BHT	@		@	
TIME SINCE CIRCULATION				
MAX. REC. TEMP. DEG. F				
EQUIP. NO. / LOC.	HL 6375	HENDERSON		
RECORDED BY	LOWE			
WITNESSED BY	FRANK BOGLE			

COMPANY: WESTERN KENTUCKY UNIVERSITY
RUN: 1
WELL NAME: MEDIA WELL
TRIP: 1
SERVICE: E 226M FILE: 2 DATE: 08/18/86 TIME: 10:13:33
REVISION: FSYSAL REV D007 VER 7
MODE: RECORD





Dresser Atlas

DRESSER

COMPENSATED
DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY
WELL LAMPKIN PARK NO. Cb-3
FIELD
COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES
NONE

PERMANENT DATUM ELEV.
LOGGING MEASURED FROM FT. ABOVE P.D.
DRILLING MEASURED FROM

ELEVATIONS
KB
DF
GL 488'

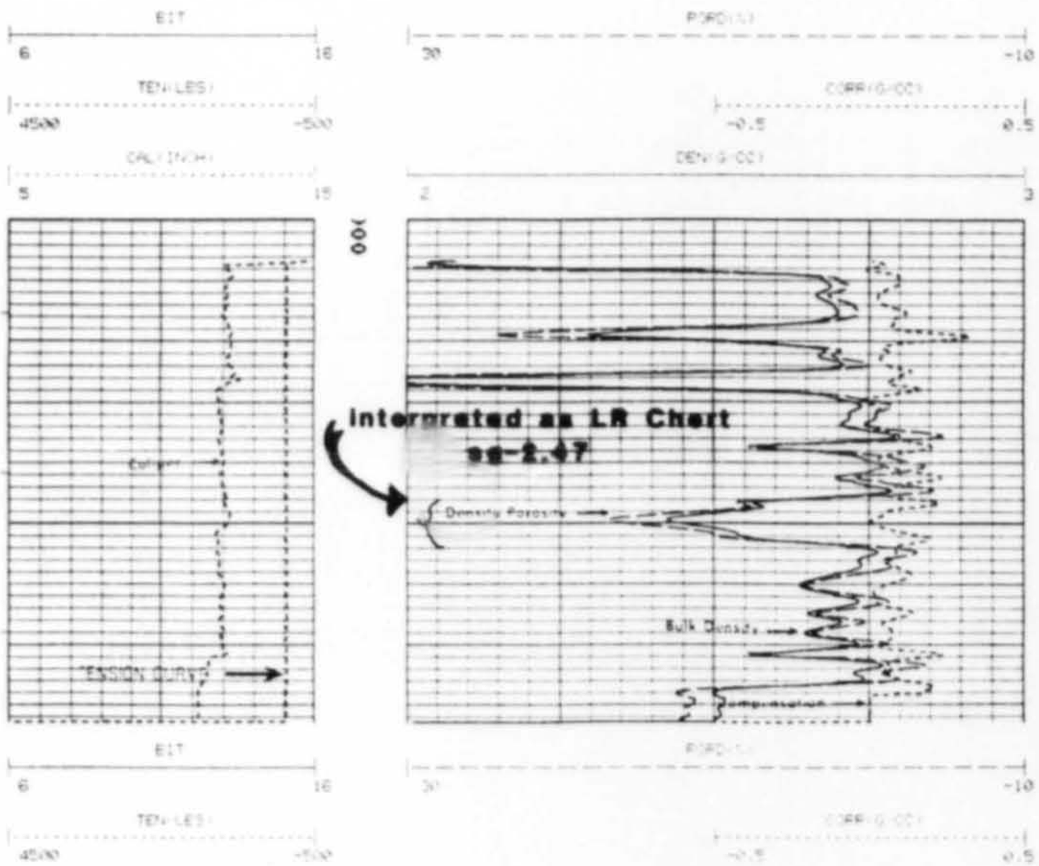
DATE	18 AUG 1986	
RUN	1	
SERVICE ORDER	130817	
DEPTH-DRILLER		
DEPTH-LOGGER	[illegible]	
BOTTOM LOGGED INTERVAL	79'	
TOP LOGGED INTERVAL		
CASING - DRILLER	0	0
CASING - LOGGER		
BIT SIZE		
TYPE FLUID IN HOLE		
DENSITY / VISCOSITY		
PH / FLUID LOSS		
SOURCE OF SAMPLE		
RM AT MEAS. TEMP.	0	0
RMF AT MEAS. TEMP.	0	0
RMC AT MEAS. TEMP.	0	0
SOURCE OF RMF / RMC		
RM AT BHT	0	0
TIME SINCE CIRCULATION		
MAX. REC. TEMP. DEG. F		
EQUIP. NO. / LOC.		
RECORDED BY	LOWE	
WITNESSED BY	FRANK BOGLE	

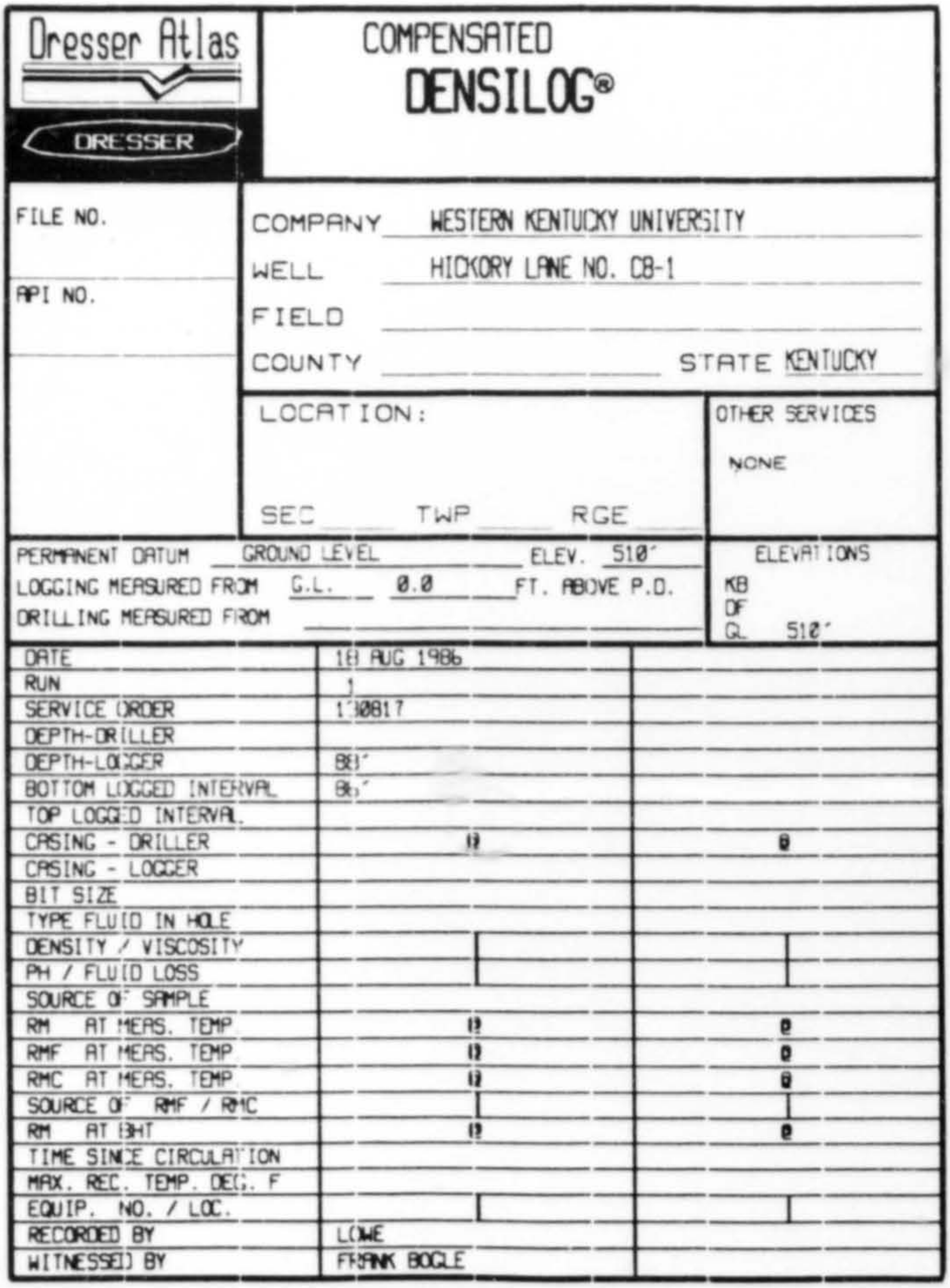
COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1

WELL NAME: LAMPKIN PARK NO. CE-3 TRIP: 1

SERVICE: E 220M FILE: 6 DATE: [illegible] TIME: 12:44:46

REVISION: PSYSAL REV D007 VER 7 MODE: RECORD





Dresser Atlas

DRESSER

COMPENSATED

DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL HICKORY LANE NO. CB-1

FIELD

COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 510'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

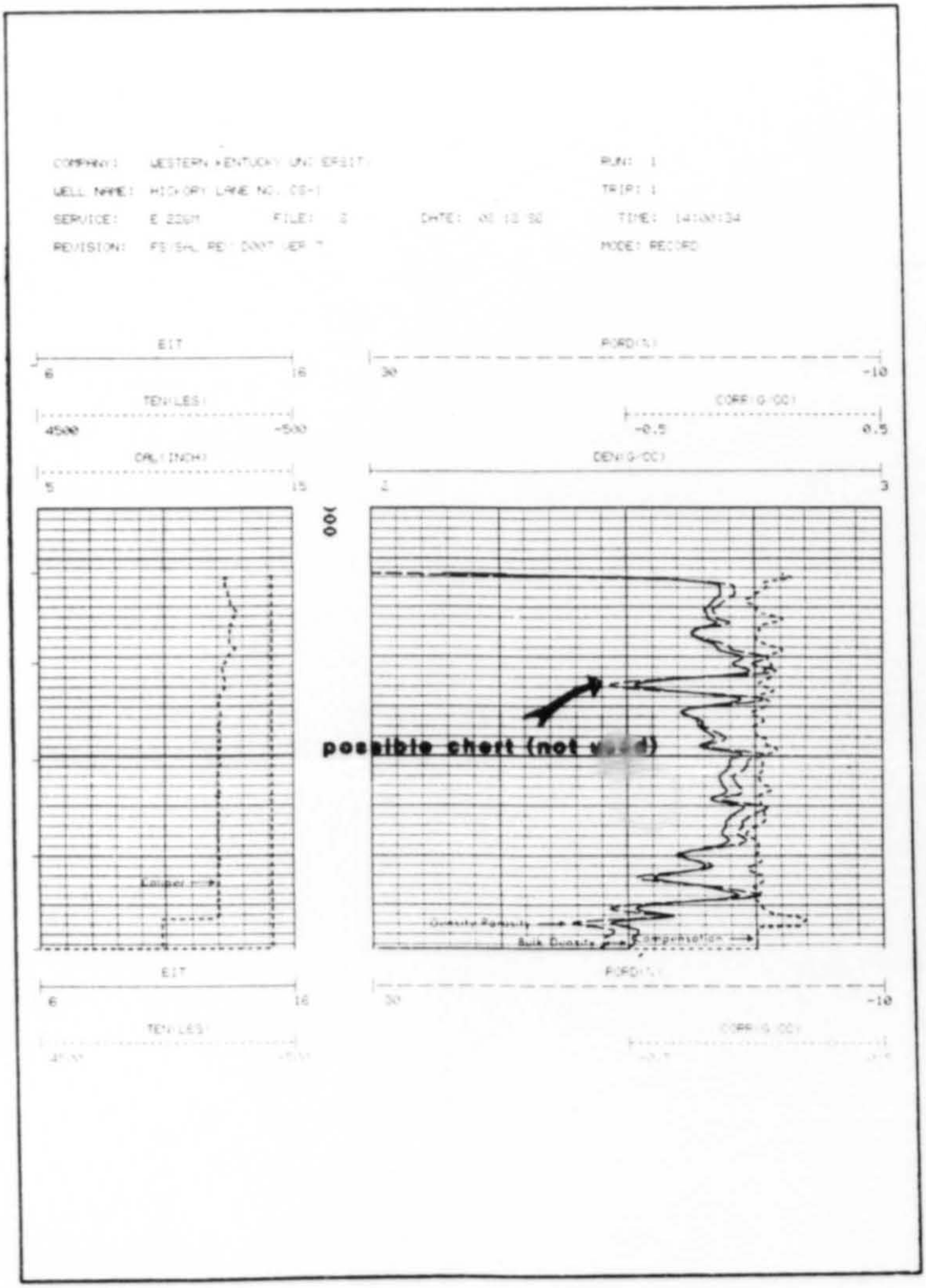
ELEVATIONS

KB

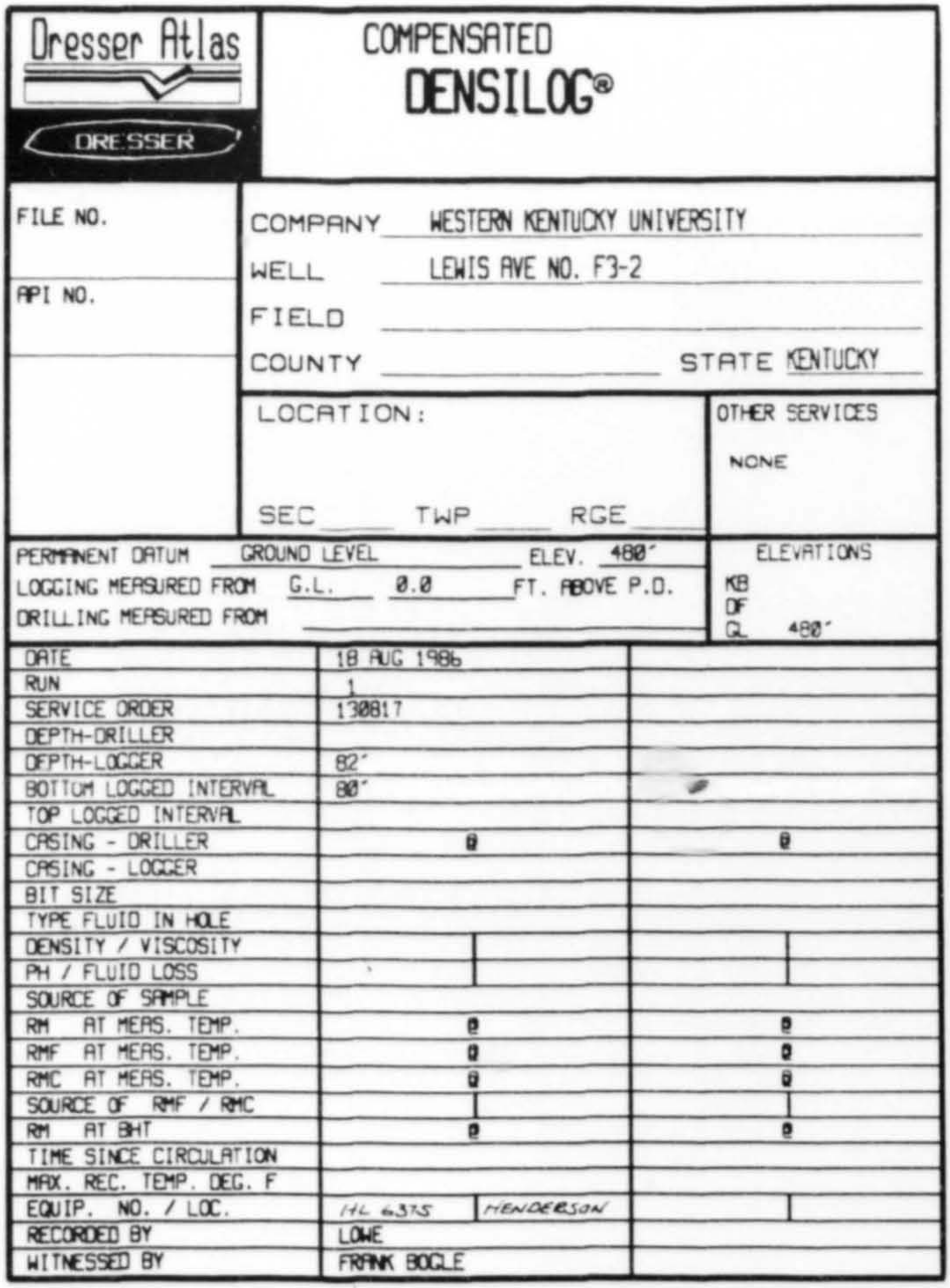
DF

GL 510'

DATE	18 AUG 1986	
RUN	1	
SERVICE ORDER	130817	
DEPTH-DRILLER		
DEPTH-LOGGER	88'	
BOTTOM LOGGED INTERVAL	86'	
TOP LOGGED INTERVAL		
CASING - DRILLER	@	@
CASING - LOGGER		
BIT SIZE		
TYPE FLUID IN HOLE		
DENSITY / VISCOSITY		
PH / FLUID LOSS		
SOURCE OF SAMPLE		
RM AT MEAS. TEMP	@	@
RMF AT MEAS. TEMP	@	@
RMC AT MEAS. TEMP	@	@
SOURCE OF RMF / RMC		
RM AT BHT	@	@
TIME SINCE CIRCULATION		
MAX. REC. TEMP. DEG. F		
EQUIP. NO. / LOC.		
RECORDED BY	LOWE	
WITNESSED BY	FRANK BOGLE	



COMPANY: WESTERN KENTUCKY UNIVERSITY
WELL NAME: HICKORY LANE NO. CS-1
SERVICE: E 226M FILE: 3 DATE: [illegible]
REVISION: [illegible]
RUN: 1
TRIP: 1
TIME: 14:00:34
MODE: RECORD



Dresser Atlas

DRESSER

COMPENSATED
DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL LEWIS AVE NO. F3-2

FIELD

COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 480'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

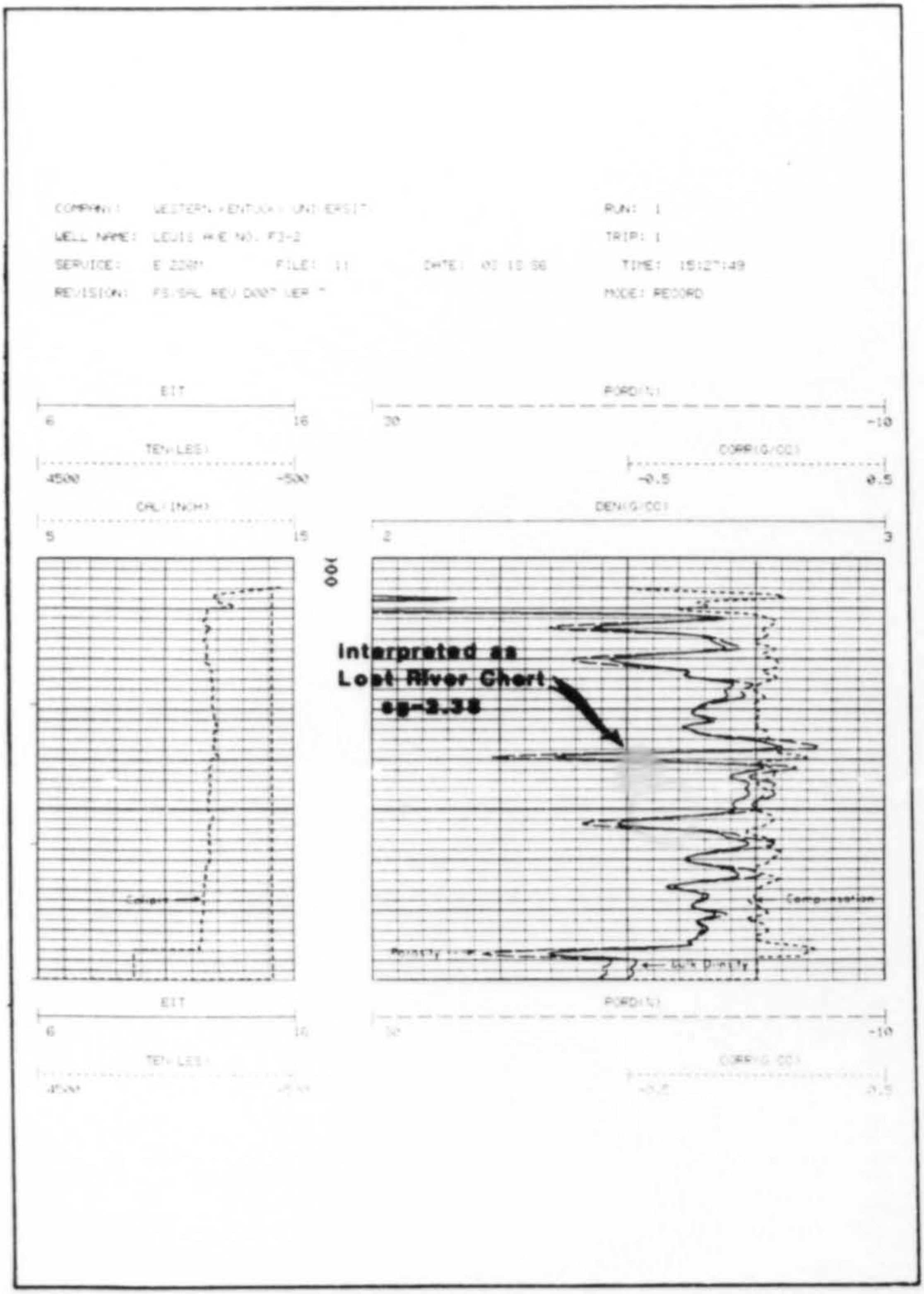
ELEVATIONS

KB

DF

GL 480'

DATE	18 AUG 1986	
RUN	1	
SERVICE ORDER	130817	
DEPTH-DRILLER		
DEPTH-LOGGER	82'	
BOTTOM LOGGED INTERVAL	80'	
TOP LOGGED INTERVAL		
CASING - DRILLER	@	@
CASING - LOGGER		
BIT SIZE		
TYPE FLUID IN HOLE		
DENSITY / VISCOSITY		
PH / FLUID LOSS		
SOURCE OF SAMPLE		
RM AT MEAS. TEMP.	@	@
RMF AT MEAS. TEMP.	@	@
RMC AT MEAS. TEMP.	@	@
SOURCE OF RMF / RMC		
RM AT BHT	@	@
TIME SINCE CIRCULATION		
MAX. REC. TEMP. DEG. F		
EQUIP. NO. / LOC.	HL 6375 HENDERSON	
RECORDED BY	LOWE	
WITNESSED BY	FRANK BOGLE	



COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1

WELL NAME: LEWIS AVE NO. F3-2 TRIP: 1

SERVICE: E 2200 FILE: 11 DATE: 03 10 96 TIME: 15:27:49

REVISION: FS/SAL REV DOOT VER 7 MODE: RECORD

Interpreted as
Lost River Chert
sg=2.38

Dresser Atlas

DRESSER

COMPENSATED

DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL CAVE MILL ROAD NO. C13-6

FIELD

COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 565'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

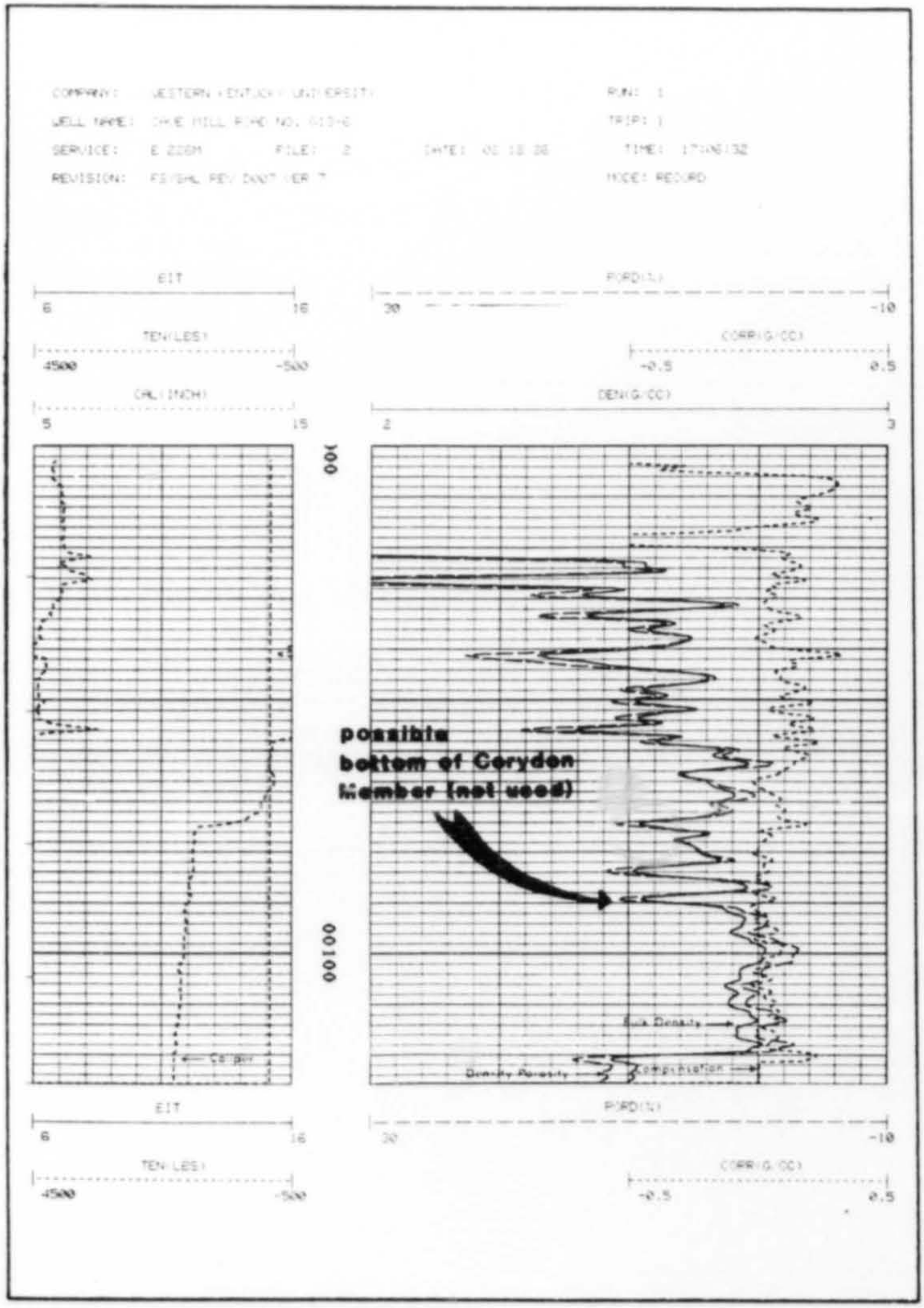
ELEVATIONS

KB

DF

GL 565'

DATE	18 AUG. 1986	
RUN	1	
SERVICE ORDER	130817	
DEPTH-DRILLER		
DEPTH-LOGGER	123'	
BOTTOM LOGGED INTERVAL	121'	
TOP LOGGED INTERVAL		
CASING - DRILLER	@	@
CASING - LOGGER		
BIT SIZE		
TYPE FLUID IN HOLE		
DENSITY / VISCOSITY		
PH / FLUID LOSS		
SOURCE OF SAMPLE		
RM AT MEAS. TEMP.	@	@
RMF AT MEAS. TEMP.	@	@
RMC AT MEAS. TEMP.	@	@
SOURCE OF RMF / RMC		
RM AT BHT	@	@
TIME SINCE CIRCULATION		
MAX. REC. TEMP. DEG. F		
EQUIP. NO. / LOC.	HL 6375 HEDERSON	
RECORDED BY	LOWE	
WITNESSED BY	FRANK BOGLE	



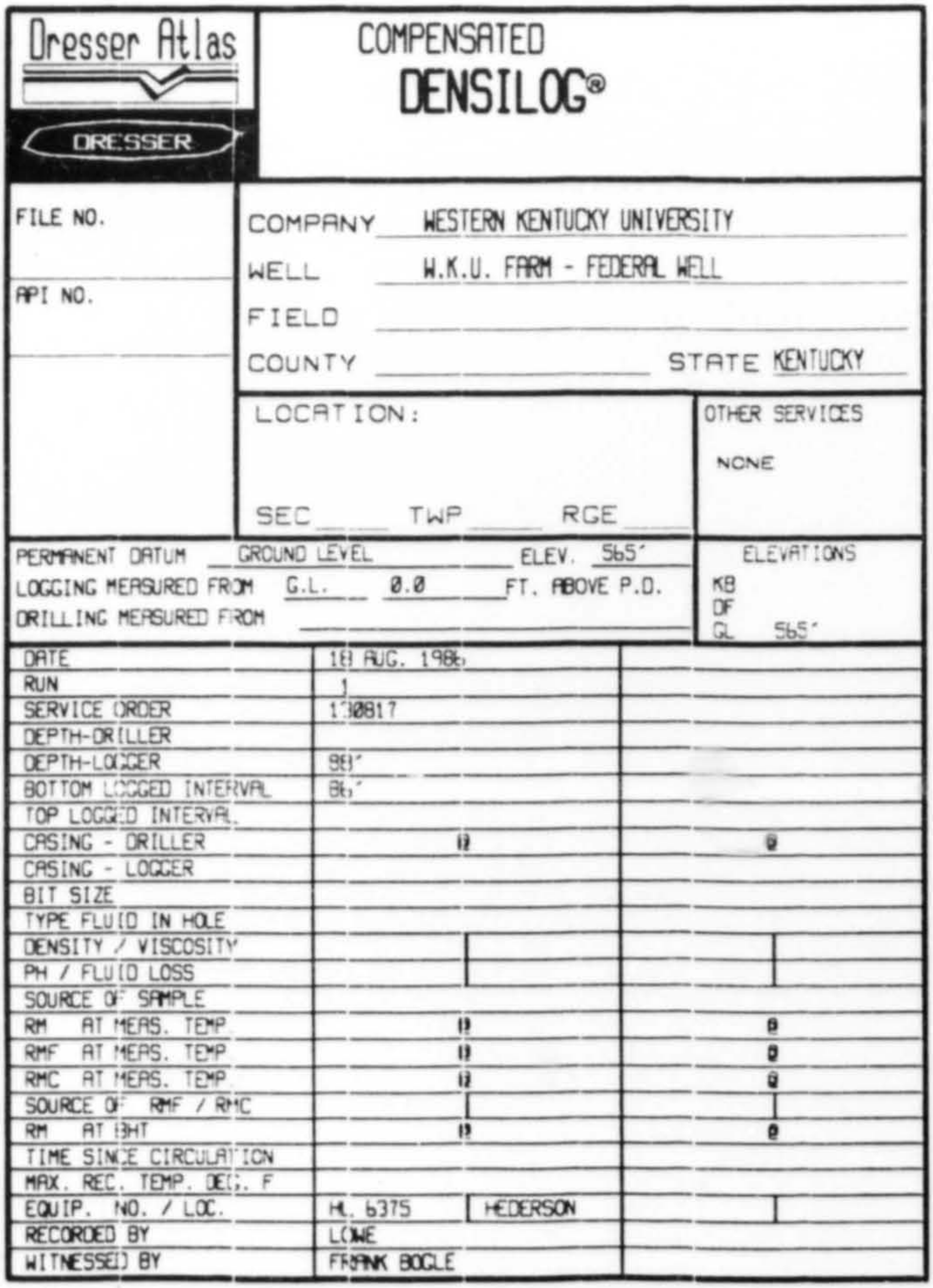
COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1

WELL NAME: [illegible] NO. [illegible] TRIP: 1

SERVICE: E 220M FILE: 2 DATE: [illegible] TIME: [illegible]

REVISION: [illegible] MODE: RECORD

possible bottom of Corydon Member (not used)



Dresser Atlas

DRESSER

COMPENSATED

DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL W.K.U. FARM - FEDERAL WELL

FIELD

COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 565'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

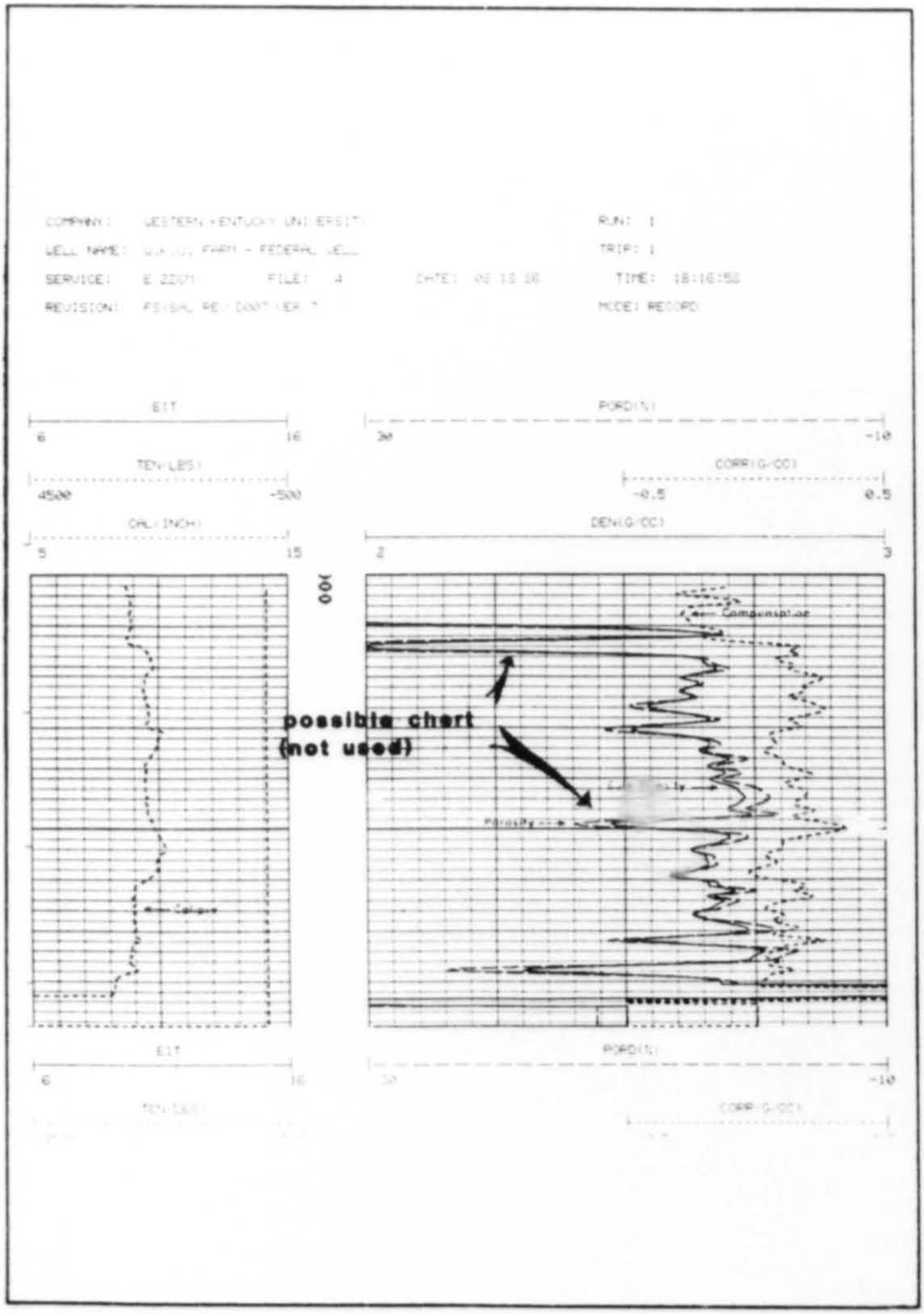
ELEVATIONS

KB

DF

GL 565'

DATE	18 AUG. 1986			
RUN	1			
SERVICE ORDER	130817			
DEPTH-DRILLER				
DEPTH-LOGGER	88'			
BOTTOM LOGGED INTERVAL	86'			
TOP LOGGED INTERVAL				
CASING - DRILLER	@		@	
CASING - LOGGER				
BIT SIZE				
TYPE FLUID IN HOLE				
DENSITY / VISCOSITY				
PH / FLUID LOSS				
SOURCE OF SAMPLE				
RM AT MEAS. TEMP	@		@	
RMF AT MEAS. TEMP	@		@	
RMC AT MEAS. TEMP	@		@	
SOURCE OF RMF / RMC				
RM AT BHT	@		@	
TIME SINCE CIRCULATION				
MAX. REC. TEMP. DEG. F				
EQUIP. NO. / LOC.	HL. 6375	HEDERSON		
RECORDED BY	LOWE			
WITNESSED BY	FRANK BOGLE			



COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1
WELL NAME: W.K.U. FARM - FEDERAL WELL TRIP: 1
SERVICE: E 2201 FILE: 4 DATE: 02 18 88 TIME: 18:16:58
REVISION: FS:SAL REV DDOT VER 7 MODE: RECORD

Dresser Atlas

DRESSER

COMPENSATED

DENSILOG®

FILE NO.	COMPANY WESTERN KENTUCKY UNIVERSITY
API NO.	WELL RYDER WELL
	FIELD
	COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 593'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

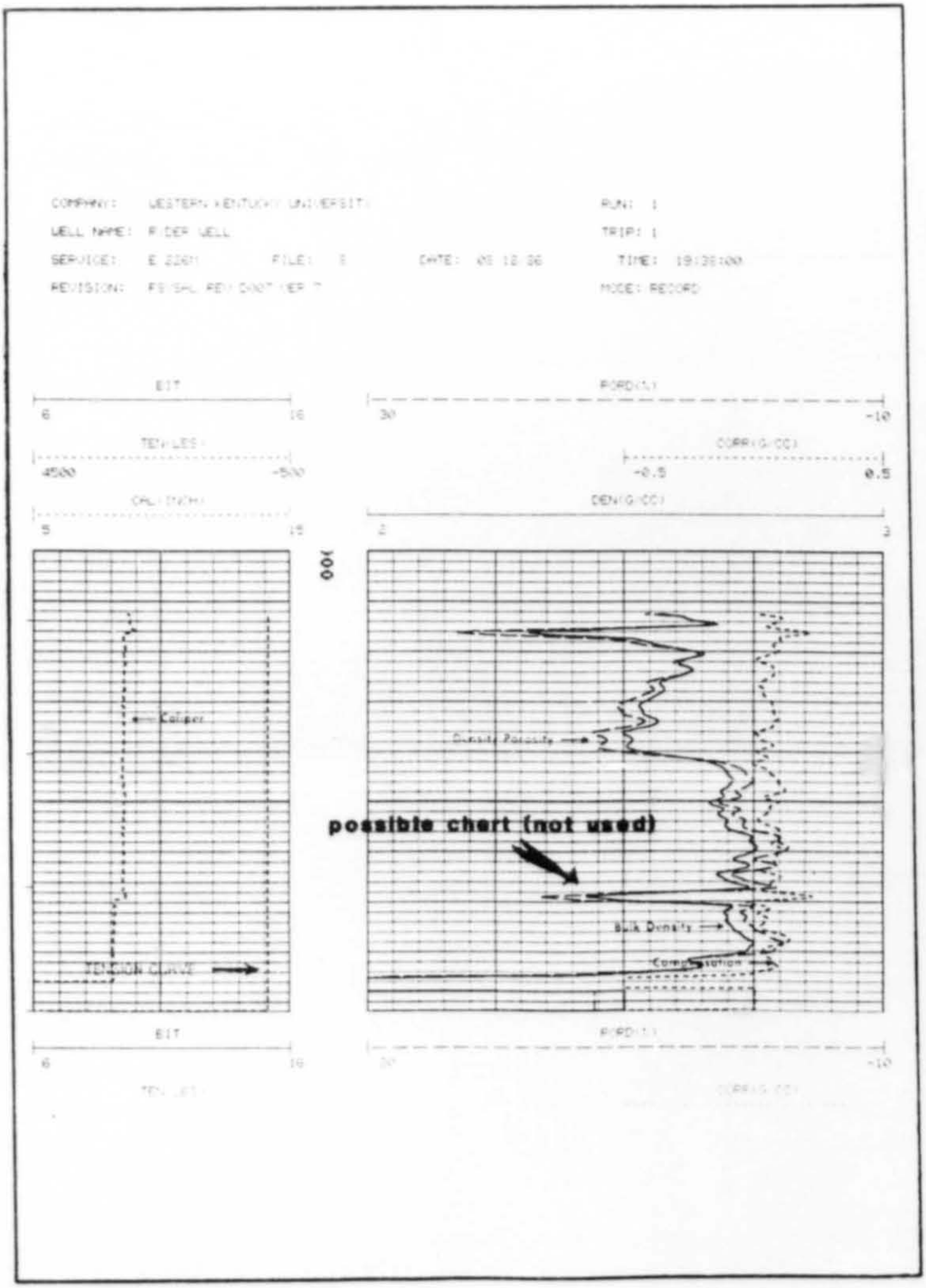
ELEVATIONS

KB

DF

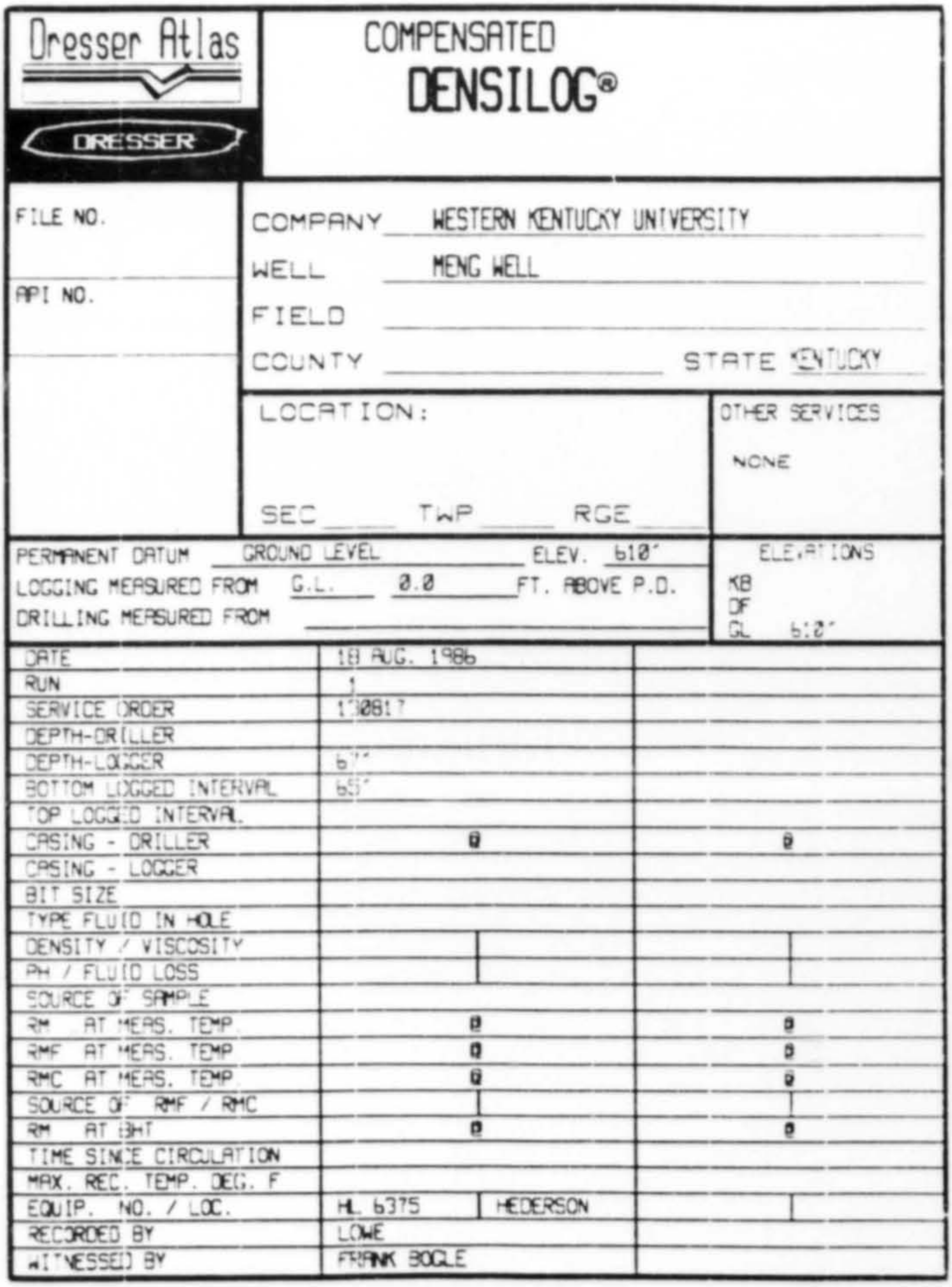
GL 593'

DATE	18 AUG. 1986	
RUN	1	
SERVICE ORDER	130817	
DEPTH-DRILLER		
DEPTH-LOGGER	91'	
BOTTOM LOGGED INTERVAL	89'	
TOP LOGGED INTERVAL		
CASING - DRILLER	@	@
CASING - LOGGER		
BIT SIZE		
TYPE FLUID IN HOLE		
DENSITY / VISCOSITY		
PH / FLUID LOSS		
SOURCE OF SAMPLE		
RM AT MEAS. TEMP	@	@
RMF AT MEAS. TEMP	@	@
RMC AT MEAS. TEMP	@	@
SOURCE OF RMF / RMC		
RM AT BHT	@	@
TIME SINCE CIRCULATION		
MAX. REC. TEMP. DEG. F		
EQUIP. NO. / LOC.	HL 6375 HEDERSON	
RECORDED BY	LOWE	
WITNESSED BY	FRANK BOGLE	



COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1
WELL NAME: RIDER WELL TRIP: 1
SERVICE: E 2201 FILE: 3 DATE: 03 12 86 TIME: 19:38:00
REVISION: [illegible] MODE: RECORD

possible chart (not used)



Dresser Atlas

DRESSER

COMPENSATED

DENSILOG®

FILE NO.

API NO.

COMPANY WESTERN KENTUCKY UNIVERSITY

WELL MENG WELL

FIELD

COUNTY STATE KENTUCKY

LOCATION:

SEC TWP RGE

OTHER SERVICES

NONE

PERMANENT DATUM GROUND LEVEL ELEV. 610'

LOGGING MEASURED FROM G.L. 0.0 FT. ABOVE P.D.

DRILLING MEASURED FROM

ELEVATIONS

KB

DF

GL 610'

DATE	18 AUG. 1986			
RUN	1			
SERVICE ORDER	130817			
DEPTH-DRILLER				
DEPTH-LOGGER	67'			
BOTTOM LOGGED INTERVAL	65'			
TOP LOGGED INTERVAL				
CASING - DRILLER		@		@
CASING - LOGGER				
BIT SIZE				
TYPE FLUID IN HOLE				
DENSITY / VISCOSITY				
PH / FLUID LOSS				
SOURCE OF SAMPLE				
RM AT MEAS. TEMP.		@		@
RMF AT MEAS. TEMP		@		@
RMC AT MEAS. TEMP.		@		@
SOURCE OF RMF / RMC				
RM AT BHT		@		@
TIME SINCE CIRCULATION				
MAX. REC. TEMP. DEG. F				
EQUIP. NO. / LOC.	HL 6375	HEDERSON		
RECORDED BY	LOWE			
WITNESSED BY	FRANK BOGLE			

COMPANY: WESTERN KENTUCKY UNIVERSITY RUN: 1
WELL NAME: [illegible] WELL TRIP: 1
SERVICE: E 2201 FILE: 10 DATE: [illegible] TIME: 21:09:26
REVISION: [illegible] MODE: RECORD