An abstract of the thesis of
Bryan A. Bain for the Master of Science
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Title: SINKHOLES, CAVES, AND SPRINGS:
KARST DEVELOPMENT IN CENTRAL BUTLER COUNTY, KANSAS
Abstract approved: ______________________

## ABSTRACT

Research was conducted to study the geology and hydrology of sinkholes, springs, and caves formed in Lower Permian, Fort Riley Limestone, located in central Butler County, Kansas. This research project was undertaken to better understand the controlling factors of these karst features and the processes that produce them in a portion of Kansas that is undergoing rapid population growth and increased groundwater usage.

Research was conducted in seven phases: literature search, locating karst features, measuring bedrock fracture joint trends, surveying and mapping the major caves, determining an estimated discharge of the Spring Cave resurgence, dye tracing, and water chemistry analysis. Recognizable karst landforms within the defined study area were plotted onto a base map to demonstrate their geographic, geologic, and hydrologic relationships. Karst features

identified were 125 sinkholes, a major cave system composed of at least three enterable segments (Spring Cave, Smith Cave, and Windmill Cave), and one large spring.

The karst terrain found within the study area is clearly a system of interrelated features and processes. Long-term solution of the bedrock allows karst features to form, joints and bedding planes to enlarge, and creates an efficient network of subsurface drainage. Factors controlling karst development in the study area are lithology, thickness, and dip of the bedrock; presence of well-defined fracture joints and bedding planes; relatively level topography; nearby entrenched river valleys; lack of thick surficial cover; and climate. Of these influences, solutional activity at joints plays a major role in the formation of sinkholes and cave passages; however, a complex combination of all the controlling factors is responsible for the present, unique, and dynamic karst system consisting of sinkholes, caves, and springs.

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# SINKHOLES, CAVES, AND SPRINGS:
# KARST DEVELOPMENT IN CENTRAL BUTLER COUNTY, KANSAS

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A Thesis
Presented to
the Division of Physical Sciences
EMPORIA STATE UNIVERSITY

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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by
Bryan A. Bain
December 1992

James S Ager

Approved for the Major Division

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Approved for the Graduate Council

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Many thanks to my fellow cavers of the Kansas Speleological Society for their support, information, and assistance. I spent countless hours surveying, photographing, and dye tracing in the cold, muddy, wet, and wonderful Flint Hills underground assisted by Steve Allen, Jon Beard, Ron Flory, Gaylen Garinger, Omar Hodgens, Steve Kite, Wayne White, Janet Williams, and Jim Young.

Additionally, without the interest and cooperation of the landowners in the study area, I could not have completed my field research. I am grateful to these hard working people for allowing me access to their properties.

I would like to acknowledge the Kansas Department of Health and Environment for their cooperation with the groundwater quality portion of this thesis and the Kansas Geological Survey for providing supplemental information.

Finally, I wish to express appreciation to my graduate thesis committee of Prof. Johnston, Dr. Schroeder, and especially Dr. Aber for their assistance, encouragement, motivation, and patience. In fact, the entire Division of Physical Sciences staff at Emporia State University deserves recognition for their collective support.

# PREFACE

Caves were entered, explored, and surveyed during the course of this research project. At all times while underground, equipment and procedures were in accordance with standards established by the National Speleological Society, an organization dedicated to the study, exploration, and conservation of caves. The following list is a summary of the guidelines observed while caving:

1) Always wear a helmet or hardhat.
2) Always carry at least three sources of light.
3) Use lug-soled boots with ankle support.
4) Wear clothing that retains body heat when wet.
5) Never go caving alone.
6) Obtain landowner permission.
7) Tell someone where you are going and for how long.
8) Take nothing but pictures.
9) Leave nothing but footprints.
10) Kill nothing but time.

Additional caving information may be obtained by contacting:

National Speleological Society
Cave Avenue
Huntsville, AL 35810
(205) 852-1300

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# CHAPTER 1: INTRODUCTION, PURPOSE, AND SCOPE

Research was conducted to study the geology and hydrology of sinkholes, springs, and caves formed in Lower Permian, Fort Riley Limestone, located in central Butler County, Kansas. This research project was undertaken to better understand the controlling factors of these karst geomorphic landforms and the processes that produce them.

Karst is a German word which was derived from a Slav geographic name for limestone terrain in western Slovenia and has gained international usage (Jennings 1971). Karst is defined as landscape having distinctive features and drainage due to highly soluble bedrock and well-developed secondary porosity (Ford and Williams 1989). Karst regions are characterized by closed depressions, disrupted surface drainage, and underground drainage systems (White 1988).

The widespread geographic distribution of karst shows the importance of karst study. Soluble bedrock, mainly evaporites and carbonate rocks, represents up to 20 percent of the world's land surface (White 1988). Actual well-developed karst terrain covers less than this amount (Fig. 1), but is nevertheless a significant portion of the Earth's surface.

Approximately 25 percent of the Earth's population is dependent on karst waters (Ford and Williams 1989). Karst regions have rapid groundwater recharge and movement due to well-developed zones of secondary porosity and permeability. Thus, contamination has little, if any, chance for removal in karst systems. As human development increases in karst regions, groundwater quality frequently decreases. These environmental concerns are gaining public awareness.

Yet, until recently, little karst research had been conducted. The purpose of this investigation was to improve our understanding of karst terrain in a portion of Kansas, central Butler County, that is undergoing rapid population growth and increased groundwater usage.

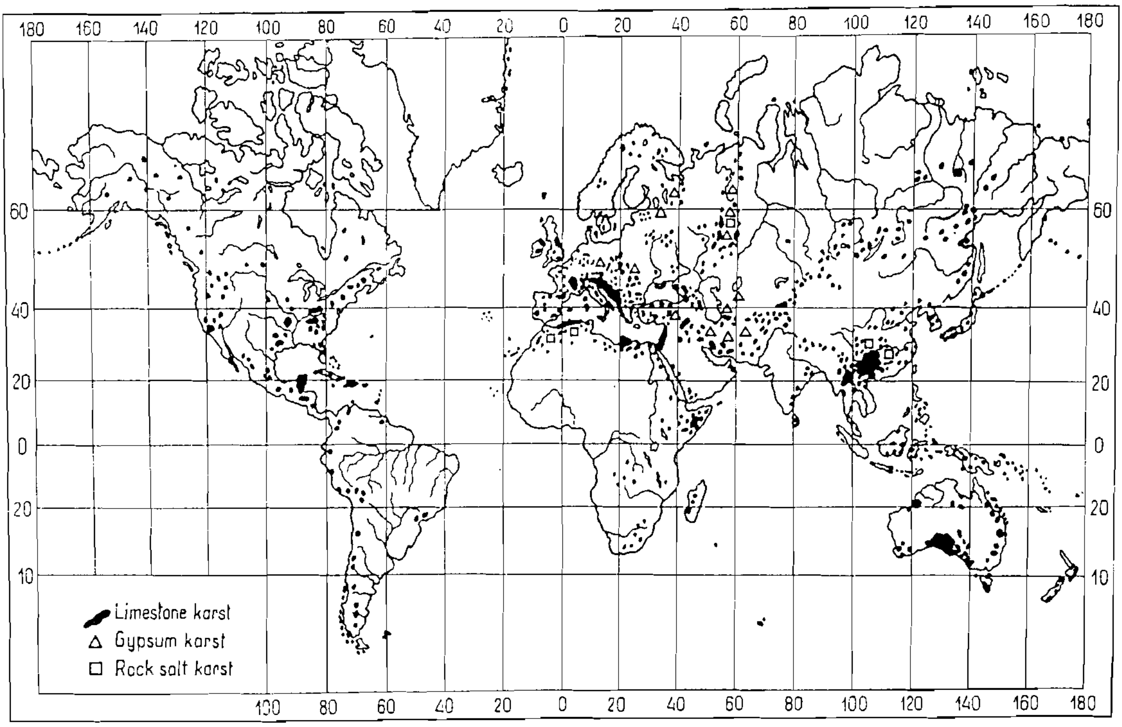

**Figure 1:** Karst regions of the world (Jakucs 1977).

# CHAPTER 2: KARST GEOMORPHOLOGY

Karst is "a type of landscape with distinctive landforms that arise primarily from abnormally high solubility of the bedrock" (Jennings 1971). Karst typically forms in carbonate and evaporite bedrock where the climate is humid enough for solution to occur. Limestone is the most common carbonate rock and the only karst-forming rock type that will be discussed in detail here.

Initially, dense limestone has a low permeability, which means water does not readily move through the rock. Even slight tectonic uplift or deformation may create fracture joints, thereby increasing secondary permeability (Bogli 1980). Bedding planes and faults, if present, offer additional avenues for water movement. Water seeps into these zones of weakness and solutional activity slowly enlarges the voids. Given enough time, subsurface conduits form with many input points, but only one or few outlets (Jennings 1971).

A host of karst geomorphic features has been described by various authors over the years. However, only three will be examined in detail: sinkholes, caves, and springs. Sinkholes, also referred to as dolines, are the input points of a karst system; caves are the groundwater conduits; and springs are the outlets or discharge points.

**Sinkholes:**

Sinkholes, the basic diagnostic feature of karst, are closed depressions usually ranging from 1-1000 meters in diameter (Ford and Williams 1989). The shape of sinkholes is frequently circular to oval in plan view, and funnel to cylindrical in profile. Water drains underground at the lowest point either by an open channel or by filtering through surficial sediment. Ponding can temporarily occur if the drain is plugged by clay or other debris.

Sinkholes are typically classified according to their origin: solution, collapse, alluvial/suffosion, or subsidence (Fig. 2). Solution sinkholes are formed by surface solution of the karst bedrock, often at joint intersections, and usually have a uniform conical shape (Jennings 1971). Collapse sinkholes are due to bedrock collapse into an existing void or cave and are initially vertical walled (Jennings 1971). Subsidence sinkholes are produced where thick soils or superficial deposits overlie karst bedrock, which allows continuous subsidence into solution pipes and open joints at depth (Jennings 1971). Upward stoping through nonsoluble beds by deep solution cavities will sometimes create deep subsidence pits (White 1988). Subsidence sinkholes are more common in karst terrain associated with evaporite bedrock (Ford and Williams 1989). In karst regions with a thick cover of glacial material, alluvial detritus or loess deposits, another type of sinkhole may form that is an intermediary cross between a pure solution and a subsidence sinkhole, called an alluvial sinkhole (Bogli 1980) or suffosion sinkhole (Ford and Williams 1989). Additionally, sinkholes may form using any combination of the above listed mechanisms.

Regardless of their origin, sinkholes channel surface runoff into the underlying caves and crevices. In some ways, sinkholes are similar to kitchen sinks, because they both will temporarily hold water until eventually the water goes down the drain. In the case of a karst sinkhole, the drain is an underground system of conduits or caves.

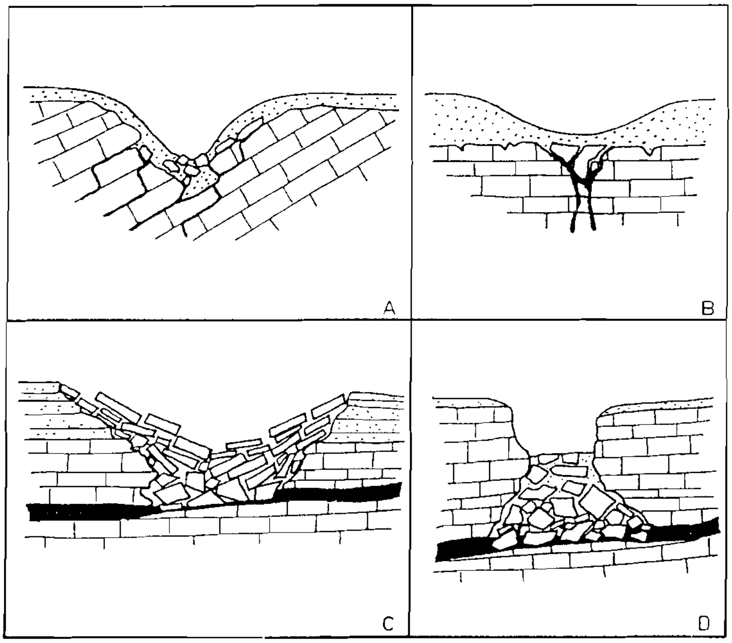

**Figure 2:** Types of sinkholes: (A) solution, (B) alluvial or suffosion, (C) subsidence, and (D) collapse (Bogli 1980). Note: black areas represent open passages or voids.

**Caves:**

Speleology, the study of caves, is an important part of karst research. To quote Palmer (1991), "An understanding of cave development is essential to the hydrologic or geomorphic interpretation of any karst region, and in assessing aquifer yield, contaminant migration, and soil and bedrock stability."

One method of classifying caves is by geologic control. In most cases, cave passages are bedding-plane controlled, fracture controlled, or both. Cave passages that are primarily bedding-plane influenced are sinuous and curvilinear, whereas cave passages consisting of solutionally enlarged fracture joints have sharp, angular bends (Palmer 1991).

Another classification method is by cave passage pattern. According to Palmer (1991), there are six different cave pattern categories:

1) Branchwork caves, the most common type, have a system of dendritic tributary passages that converge into higher-order passages in the downstream direction.
2) Network caves are a maze pattern of angular intersecting, joint-enlarged passages that resemble city streets.
3) Anastomotic caves consist of a braided pattern of curvilinear tubes with many closed loops.

4) Spongework caves are a three-dimensional series of interconnected, assorted-sized solution voids that resemble pores in a sponge.

5) Ramiform caves consist of random patterns of irregular shaped cavities and rooms that branch out from the main areas of development (network and spongework combined).

6) Single-passage caves are rudimentary forms or segments of the types described above, varying in size from small to large.

A simpler cave pattern classification system consists of only two types: branchwork caves and maze caves. Network, spongework, and ramiform caves are combined as maze caves and single-passage caves are ignored. Palmer (1991) surmised that the most important factor determining if a cave will develop into a branchwork or a maze pattern is the nature of the groundwater recharge. He further stated that "Branchwork caves are associated with discrete small-catchment sources (for example, sinkholes) typical of a karst surface." On the other hand, maze caves are usually due to surface streams sinking directly into soluble bedrock, diffuse recharge through overlying insoluble rock, or hypogenic recharge of deep-seated origin. "Branchwork caves exceed in number and aggregate length all other caves combined, and so it is not surprising that they are formed by the most common type of karst recharge" (Palmer 1991).

## Springs:

Normally in a karst system, water finds its way into subsurface conduits and then flows through the underground drainage system toward an outlet, which is often a spring. Karst springs are frequently much larger and more permanent than springs in other types of terrain (Jennings 1971). Karst springs may flow freely from open cave entrances or may well upwards through talus debris.

Springs are classified by various methods, commonly by the volume of water discharged. The principal factors that influence the amount of spring discharge are permeability of the bedrock, quantity of recharge, and the area contributing to the spring. One such accepted spring rating system is Meinzer's classification of spring discharge (Table 1).

**Table 1:** Meinzer's classification of spring discharge.

| MAGNITUDE | ENGLISH UNITS | METRIC UNITS |
|---|---|---|
| First | >100 $ft^3$/sec | >2.8 $m^3$/sec |
| Second | 10-100 $ft^3$/sec | 0.28-2.8 $m^3$/sec |
| Third | 1-10 $ft^3$/sec | 28.3-283 l/sec |
| Fourth | 100 gal/min-1 $ft^3$/sec | 6.3-28.3 l/sec |
| Fifth | 10-100 gal/min | 0.63-6.3 l/sec |
| Sixth | 1-10 gal/min | 63-630 ml/sec |
| Seventh | 1 pt/min-1 gal/min | 7.9-63 ml/sec |
| Eighth | <1 pt/min | <7.9 ml/sec |

# CHAPTER 3: KARST HYDROLOGY

"Hydrology is the study of how water precipitated on to the land surface is carried away. The natural landscape evolves a system of gutters and conduits, both on and below the surface, adjusted to evacuate surplus water most efficiently in the same way as the storm drains of a city" (Smith, Atkinson, and Drew 1976).

In karst terrains, the important segment in the hydrologic cycle is groundwater. Karst bedrock has high porosity and permeability, due to solution and secondary fractures, which allow a large percentage of its drainage to be subsurface. A basic understanding of the processes involved in limestone solution is necessary for karst hydrology.

Solution of calcite (calcium carbonate), the principal mineral of limestone, is a complex process. To simplify the chemistry as much as possible, precipitation ($H_2O$) obtains dissolved carbon dioxide ($CO_2$) from the atmosphere and sometimes from the soil to form carbonic acid ($H_2CO_3$). This slightly acidified, carbonated water comes into contact with limestone and reacts chemically with the calcium carbonate ($CaCO_3$), allowing calcium ions ($Ca^{2+}$) and bicarbonate ions ($HCO_3^-$) to go into solution until equilibrium is reached. Deposition of cave formations or speleothems occurs when carbon dioxide ($CO_2$) is lost from solution allowing calcium carbonate ($CaCO_3$) to precipitate until equilibrium is again attained. This sequence of chemical reactions is often summarized by the following equations:

1) $H_2O + CO_2 = H_2CO_3$

2) $CaCO_3 + H_2CO_3 = Ca^{2+} + 2HCO_3^-$

Continued chemical solution over geologic time results in the formation of karst features, such as sinkholes and caves. Controlling factors in the development of karstic aquifers are geological, geomorphological, climatic, and biological (Ford and Williams 1989). This hydrologic relationship is summarized in Figure 3.

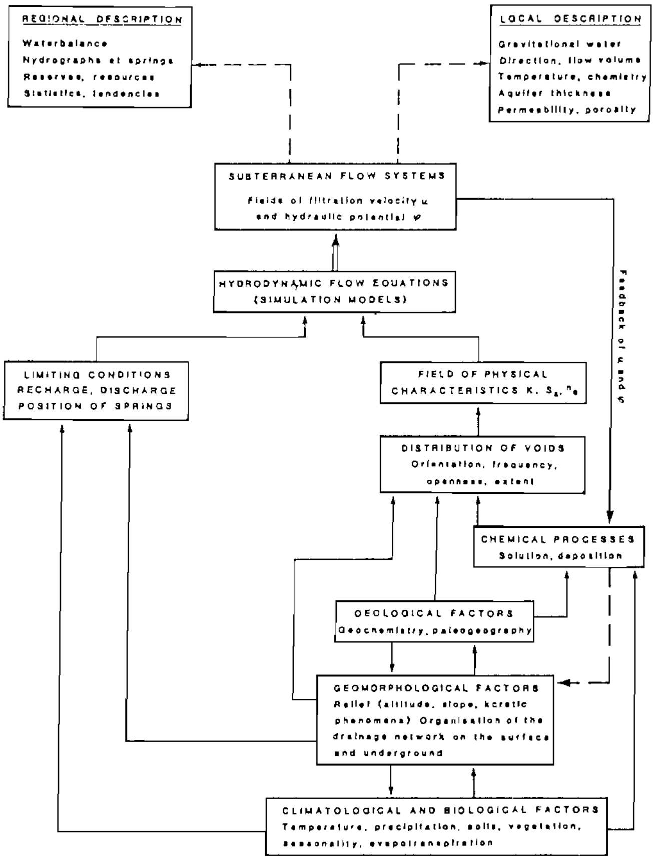

**Figure 3:** Relationship of hydrologic, geologic, and physical properties of karst aquifers (Ford and Williams 1989).

# CHAPTER 4: PREVIOUS KARST STUDIES IN KANSAS

Karst development in the Flint Hills study area has been previously investigated, but not in detail. Most of the intensive karst research has been in classic regions such as central Kentucky. However, karst features in Kansas have been described by several authors.

Fath (1921) described the Fort Riley Limestone in the El Dorado area and recognized that the upper massively bedded portion is especially porous and soluble. He observed that sinkholes are frequently found when this upper unit outcrops on nearly level ground "and through solution develops an efficient underground drainage." He concluded that "the depth of the sinks is probably controlled by the thickness of the upper member."

Merriam and Mann (1957) discussed the physical characteristics, distribution, origins, and ages of sinkholes throughout the state. They listed the following conditions as necessary for sinkhole formation: soluble beds, water, and time. "Other factors also to be considered are: type of rock, thickness of soluble beds, depth of burial of soluble beds, amount of rainfall and its distribution, and available ground water." They mentioned that sinkholes and caves are fairly common in the Fort Riley Limestone of the Flint Hills including Butler County. They stated that the

the origin of Flint Hills sinkholes is due to solutional processes with development beginning in the Pliocene and still continuing today.

Merriam (1963) suggested that sinkholes are "formed either by solution-subsidence or solution-collapse" and that development can be influenced by folds and faults. He advised that in areas where sinkholes were numerous, groundwater quality could be adversely affected.

Reams (1965) investigated the origin of domepits (vertical shafts) in caves located in central Kentucky, central and southern Missouri, and south-central Kansas. He observed that the Fort Riley Member in Kansas is thinner than most karst forming limestones, but "is very cavernous and contains caves of several kilometers in length." He also stated that the cave passages and domepits within the Fort Riley Limestone are good examples of joint control.

Ward (1968) conducted a joint-pattern study which concentrated on Butler County. He proposed that jointing controls the karst topography found in the study area. He noted that solution produces open joints and large caves in some cases. He also theorized that "with advanced solution, the roofs of these caverns collapse, forming sinkholes."

Buchanan and McCauley (1987) mentioned that "south of El Dorado is one of the longest known caves in Kansas, extending at least a mile into a thick ledge of limestone, although it has not been completely explored and is on private property that is currently off-limits to the public."

Young (1987) described caves in the study area. He noted that most of the Spring Cave passages follow the major local joint trends and head mainly northeast toward the center of a large sinkhole plain. However, the Smith Cave passages appear to meander beneath the sinkhole plain without a distinctive pattern. Smith Cave and Spring Cave were thought to be hydrologically connected. "A local rancher relates that when a wooden windmill was chopped up and thrown into the Smith entrance pit, the wooden splinters were later observed floating out the Spring entrance."

Aber (1991, 1992) recognized several zones of high sinkhole density in Butler County, one of which includes the study area (Figs. 4 and 5). He suggested that the development of sinkholes and other related karst features was the result of several structural and topographic conditions that enhanced vertical drainage into highly fractured, soluble bedrock:

1) Near structural crests of anticlines.
2) Level to gently sloping upland drainage divides.
3) Nearby entrenched river valleys.
4) Lack of thick surficial cover.

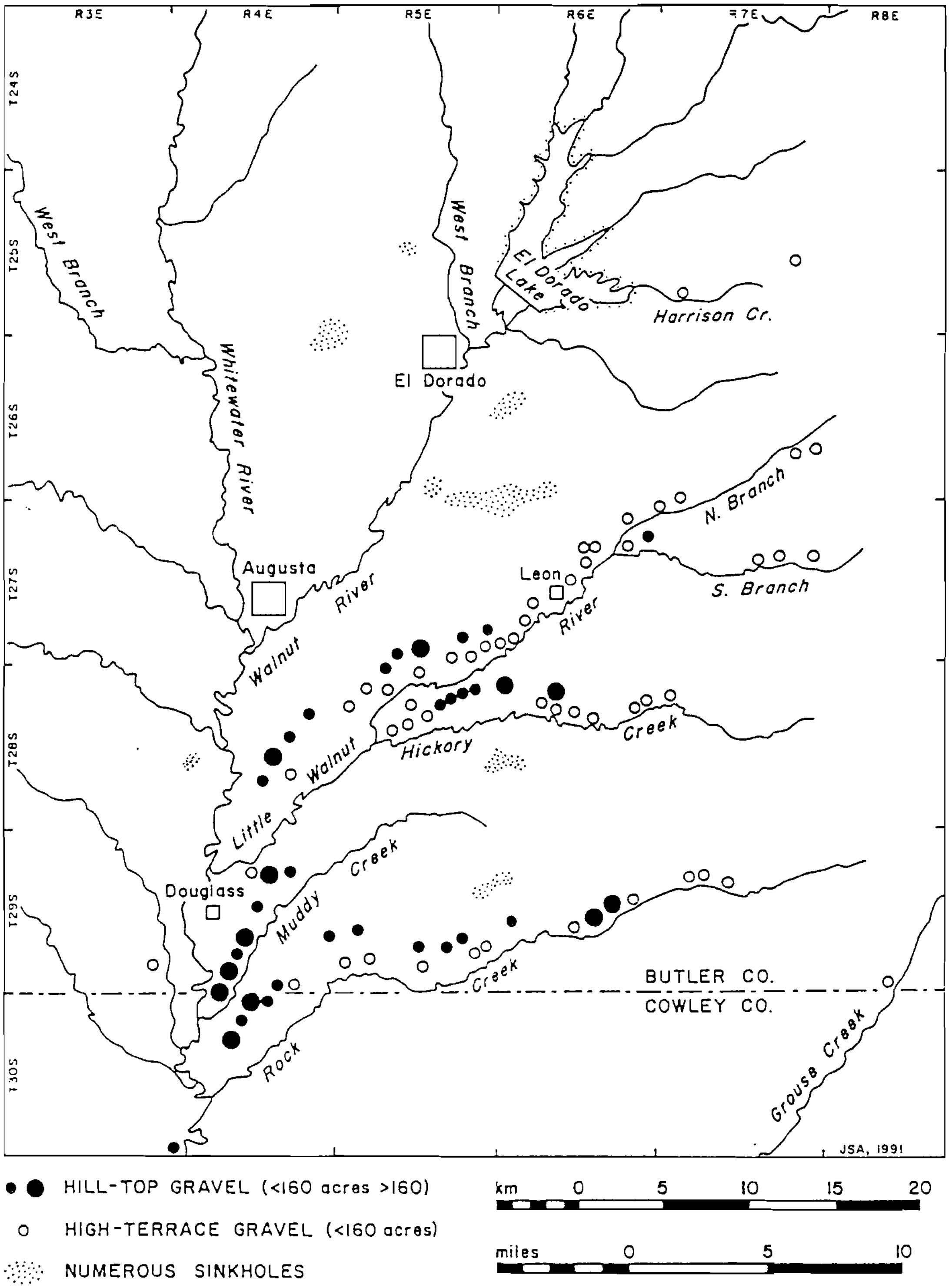

**Figure 4:** Zones of sinkholes in Butler County (Aber 1992).

Regarding the age of sinkholes, Aber (1992) stated that "sinkholes probably began to develop after erosion had removed the apron of Neogene sediment that had covered the western flanks of the Flint Hills."

Young and Beard (1992) noted that the Fort Riley Limestone contains the majority of the known Flint Hills caves (approximately 70 caves) mainly in Butler and Cowley counties. Additionally, many of the longest mapped caves in Kansas are within the Fort Riley Limestone of Butler County, most notably Spring Cave and Smith Cave. They also observed that while some ranchers used to fill sinkholes (with old appliances, barbed wire, tires, trash, etc.) to prevent cattle from stumbling into them, a few positioned windmills above sinkholes leading to cave streams in order to obtain livestock drinking water.

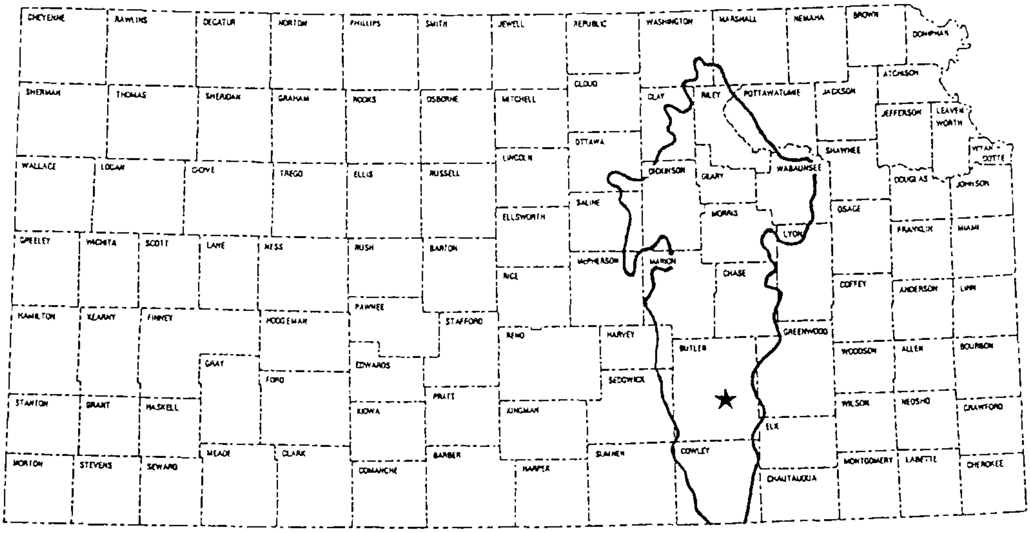

**Figure 5:** Flint Hills region of Kansas (star = study area).

## CHAPTER 5: DESCRIPTION OF STUDY AREA

The study area is located in the south-central Flint Hills physiographic region of Kansas (Fig. 5), consisting of 15.5 $km^2$ (6 $miles^2$) situated approximately 10 km (6 miles) southeast of El Dorado in Butler County. Legal description of the study area is: section 1, T27S, R5E; sections 5 and 6, T27S, R6E; sections 30 and 31, T26S, R6E; and section 36, T26S, R5E (Fig. 6).

Topography of the study area consists of a nearly level to gently sloping upland drainage divide that contains numerous sinkholes and nearby entrenched stream valleys. Turkey Creek is located to the northwest, and a smaller spring-fed tributary stream is to the southwest. These surface streams are part of the Walnut River drainage basin. Elevation varies from approximately 395 meters (1290 feet) in the west to 425 meters (1400 feet) in the east (Fig. 7).

The land in the study area is used primarily for cattle grazing. A small percentage is cultivated, but the soil is normally too thin and rocky to plow. The majority of the vegetation is grasses with a few isolated trees and an occasional shelter belt. The study area overlies a petroleum producing reservoir; therefore, active and abandoned oil wells are scattered throughout the landscape.

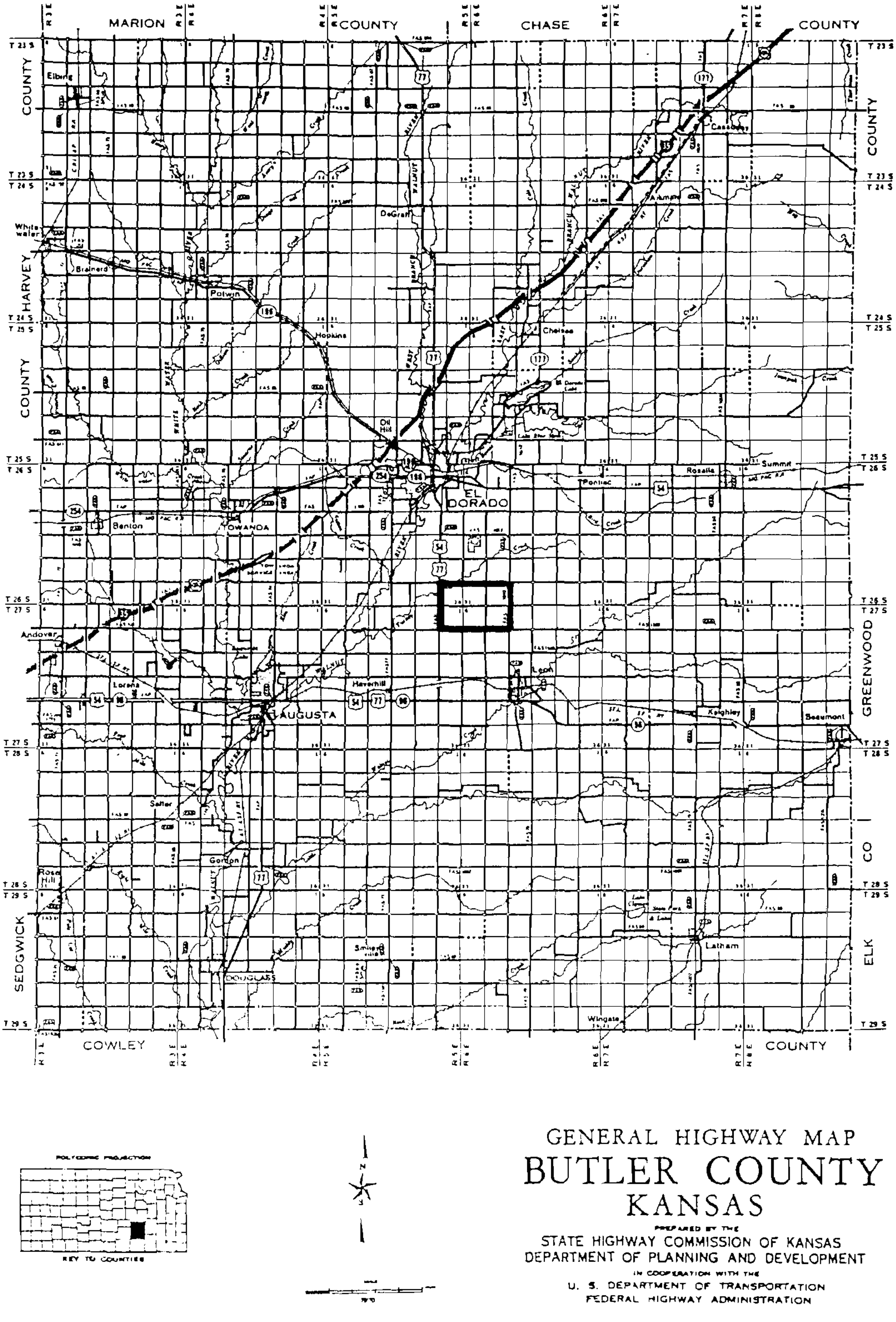

**Figure 6:** Map of Butler County, Kansas (box = study area).

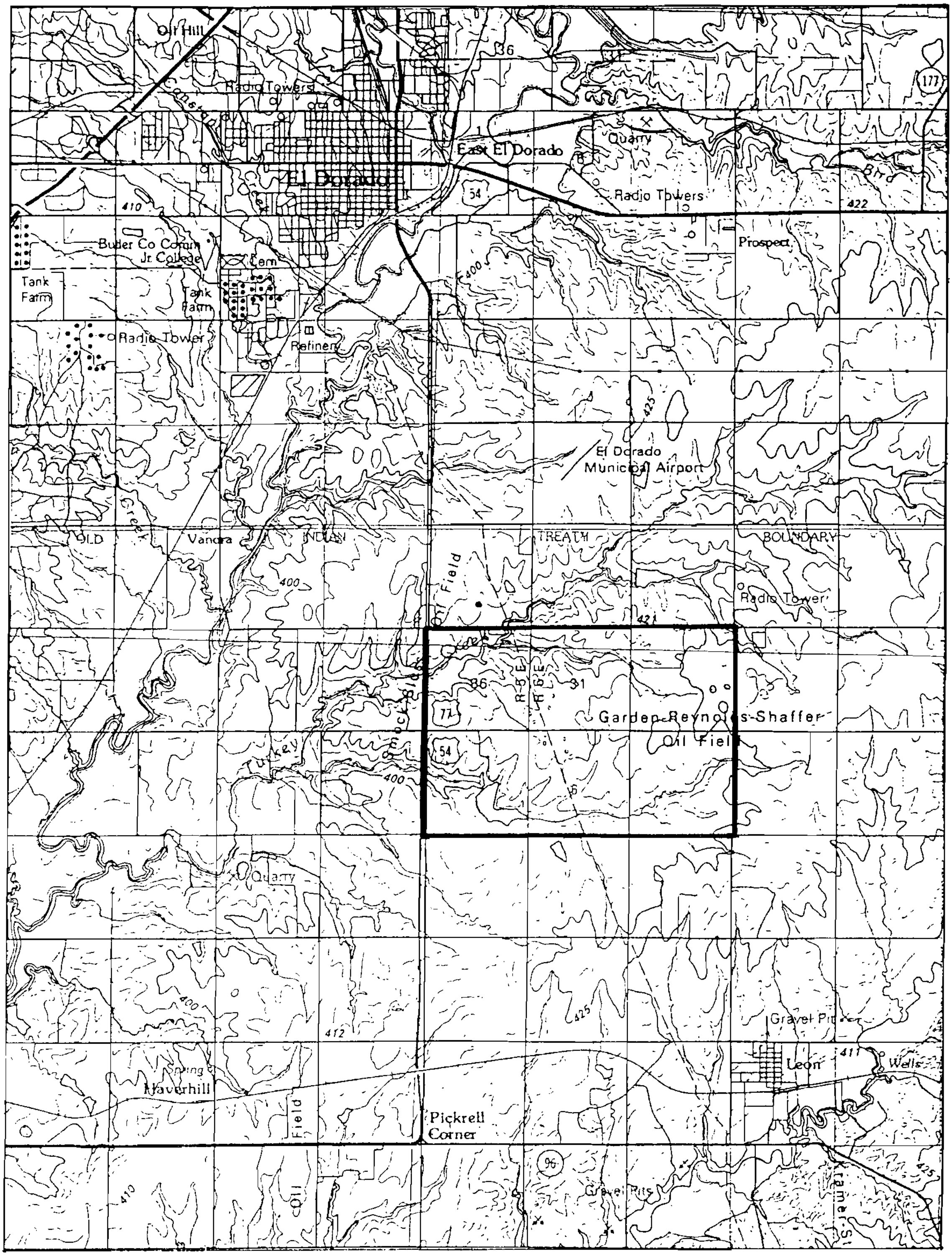

**Figure 7:** Topography of study area (box) and vicinity. Scale = 1:100,000 and contour interval = 5 meters (16 ft.).

The study area is within easy commuting distance of El Dorado, so the land is gradually being subdivided and developed for residential use. Construction of new homes in this area, each with a septic sewer system, will undoubtedly continue into the future.

Karst features in the study area consist of surface solution of the exposed bedrock, sinkholes, open joints, enterable cave passages, and springs. Surface boulders and bedrock outcrops frequently exhibit small solutional pits and holes giving the rock a honeycomb texture. Sinkholes are common with the greatest density of these depressions existing along the central east-west axis of the study area. Several minor wet-weather seeps exist along the stream valleys, in addition to one relatively large, well-known karst spring (Spring Cave) near the west-central boundary of the study area. Subsurface features consist of a major cave system, as well as other smaller caves that are probably hydrologically related. The major cave system, presently the longest known in Kansas, is composed of three main enterable segments, Spring Cave, Smith Cave, and Windmill Cave.

* * *

# CHAPTER 6: LOCAL GEOLOGY

The surface bedrock of the study area is composed entirely of Permian limestone from the Fort Riley Member of the Barneston Formation (Fig. 8). Fath (1921) described the thickness of the Fort Riley Limestone in the El Dorado region as varying from approximately 13.5 to 17 meters (44-56 feet).

The Fort Riley Limestone in the study area has three distinctive subdivisions:

1) Lower unit that is fine textured, medium to dark gray, fossiliferous, and massively bedded.
2) Middle unit that is gray, fossiliferous, and thinly bedded with some shale interbeds.
3) Upper unit that is light gray, locally oolitic and cross bedded, porous, fossiliferous, and massively bedded.

Probably due to the porous nature of the upper massively bedded unit of the Fort Riley, sinkholes are a common surface feature, but are rarely present in the middle and lower subdivisions. The Fort Riley Limestone displays the best examples of karst development throughout the entire Flint Hills region.

Subsurface structures, such as anticlines, synclines, joints, and faults, often influence karst development by fracturing and tilting the bedrock. Aber (1991) documented the existence of these features in Butler County (Fig. 9). The study area is on the eastern flank of a syncline, with the bedrock dipping towards the west at approximately 4 to 6 meters per kilometer (about 20-30 feet/mile). These observations agree with previous county-wide bedrock dip studies done by Ward (1968) and Aber (1991).

The Fort Riley Limestone is well jointed in Butler County, producing the needed secondary porosity for karst to develop. The joint pattern consists of a primary set trending NE-SW (50-70 degrees), a secondary set trending NW-SE (310-340 degrees), and several other minor sets (Ward 1968; Aber 1991, 1992).

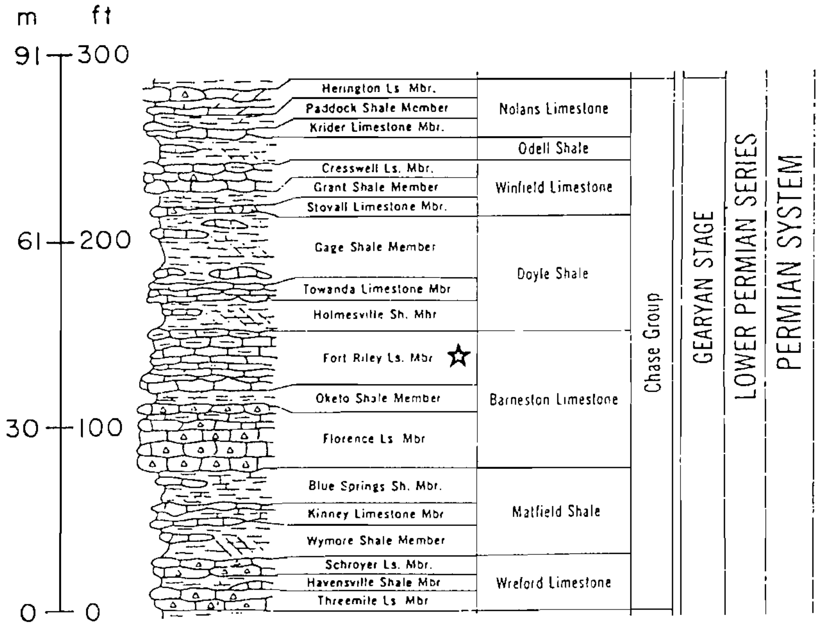

**Figure 8:** Stratigraphic section showing the position of the Fort Riley Limestone Member (Twiss and Underwood 1988).

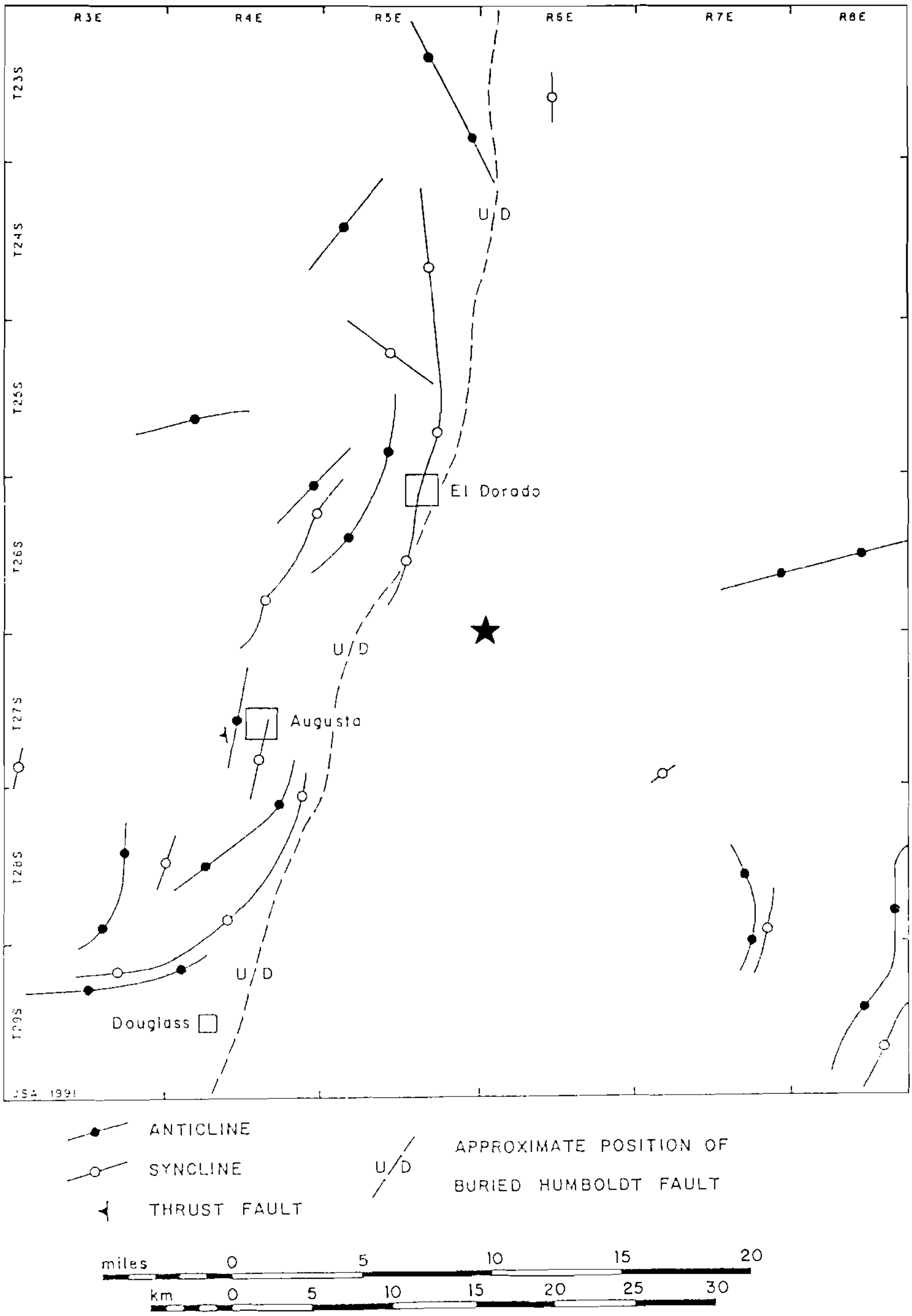

**Figure 9:** Surficial geologic structures of Butler County, Kansas (Aber 1991). Note: star = study area.

# CHAPTER 7: RESEARCH METHODS AND PROCEDURES

Research was conducted in seven phases: literature search, locating karst features, measuring bedrock fracture joint trends, surveying and mapping the major caves, determining an estimated discharge of the Spring Cave resurgence, dye tracing, and water chemistry analysis.

A literature search was initiated by examining Kansas Geological Survey, United States Geological Survey, and other library resources. The literature review was limited to previous studies of the area (chapter 4) and other karst studies relating to this particular geologic setting.

Locating the karst features was accomplished by a combination of examining topographic maps and air photographs, in addition to extensive field checking. The features were identified and recorded onto a base map.

Joints are often exposed at the surface in sinkholes and were measured using a hand-held compass. The resulting trend data were grouped in ten-degree intervals and plotted using rose diagrams.

Cave exploration was conducted, keeping safety and conservation in mind, by utilizing equipment and techniques recommended by the National Speleological Society (summarized in the preface). Cave passages were surveyed by experienced cavers following procedures outlined by Thomson and Taylor (1981). Distances were measured using fiberglass surveying tapes to the nearest 3 cm (0.1 ft.). Horizontal and vertical angles were measured, using either Suunto or Sisteco hand-held instruments, to the nearest 1 degree.

Discharge of the Spring Cave resurgence was roughly estimated by measuring how much time the water took to fill a 11.4 liter (3 gallon) bucket.

Three dye traces were conducted using fluorescein dye to determine hydrological flow characteristics of the study area and the relationship between various karst features. The dye traces were conducted using materials and procedures outlined by Aley and Fletcher (1976). Approximately 150 grams (5.3 ounces) of fluorescein dye were utilized during the first dye trace. However, that amount was reduced to approximately 50 grams (1.8 ounces) for each of the two subsequent dye traces.

Water chemistry was determined by direct sampling of the cave stream at the Spring Cave resurgence located in the west-central part of the study area (NW 1/4, SW 1/4, NW 1/4, Sec. 1, T27S, R5E). The following water samples were collected and analyzed as part of the Kansas Groundwater Quality Monitoring Program operated by the Kansas Department of Health and Environment (KDHE):

1) liter (quart) plastic "cubtainer" for minerals.
2) 175 mL Nalgene bottle for nutrients.
3) 250 mL Nalgene bottle for heavy metals.

4) 3.8 liter (gallon) dark glass bottle with teflon seal for pesticides.
5) 40 mL glass vial with teflon seal for volatile organic compounds (VOC).
6) 3.8 liter (gallon) plastic bottle for radionuclides.
7) A 20 mL plastic vial for total dissolved solids.

To preserve the samples in the field, the large bottle for radionuclides and the Nalgene bottles for nutrients and heavy metals were pre-acidified by KDHE laboratory staff. Care was taken to prevent overfilling the acidified containers when sampling. The VOC sample vial was filled to the top without aeration and checked to ensure it was free of air bubbles. The pesticide and VOC samples were placed in a cooler and packed with ice.

Temperature, pH, and conductivity were analyzed in the field and noted as the samples were being collected. The instrument probes were rinsed with distilled water before and after use. All sample containers were labeled for easy identification and lab submission forms were completed.

All samples were handled and stored to minimize contamination, leakage, or damage during transportation. Maximum holding or storage times imposed by departmental protocol were strictly observed. Finally, a chain of custody record was completed and samples were submitted to the appropriate KDHE laboratories.

# CHAPTER 8: RESULTS AND INTERPRETATIONS

## Karst features:

Recognizable karst features (sinkholes, caves, and springs) within the defined study area were plotted onto a base map to demonstrate their geographic, geologic, and hydrologic relationships (Fig. 10). These karst features were identified by utilizing U.S.G.S. topographic maps, air photographs, and extensive field checking.

Approximately 125 sinkholes were mapped, although the actual quantity is probably greater. Some were undoubtedly overlooked, while others were reportedly filled by natural or human activity. At first glance, the sinkholes appear to be randomly scattered about the landscape. However, a closer inspection reveals that many are aligned along the primary joint trends. Several are either in close proximity to or directly over surveyed cave passages.

The vast majority of these sinkholes are solutional in origin with most forming at joint intersections. Continued solutional action slowly enlarges the sinkholes which increases recharge into the subsurface. Greater available groundwater allows cave development to progress, particularly at the joints and bedding planes. There are a few sinkholes that have collapsed into existing cave passages. The entrances of Smith Cave and Windmill Cave are examples of sinkholes formed by collapse. However, this appears to

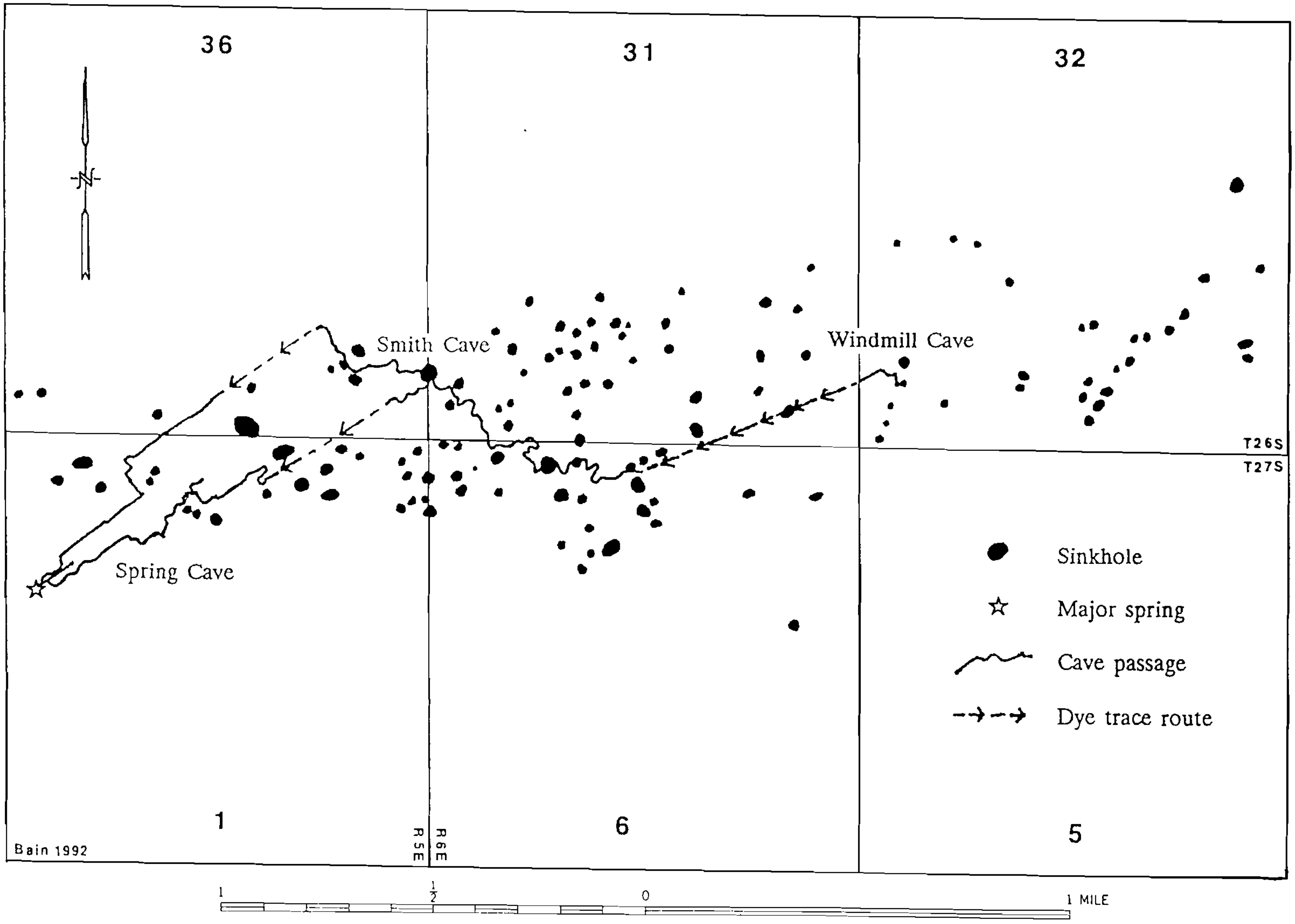

Figure 10: Karst features within the study area.

be more of the exception than the rule and there is usually evidence of both solution and collapse in these cases.

The major cave system in the area is composed of at least three enterable segments that are hydrologically connected by sumped (water-filled) passages. The surveyed length of Spring Cave is 2,593 meters (8,508 feet), Smith Cave is 2,210 meters (7,249 feet), and Windmill Cave is 205 meters (671 feet) for a combined total cave system length of 5 kilometers (3.1 miles). The Right Passage in Spring Cave (Fig. 11) had previously been mapped, however, all of the remaining 3.4 kilometers (2.1 miles) of cave passages were surveyed during the course of the research project (Plate 1). Actual length is much longer if all unsurveyed side-passages and sumped passages are considered. Three dye traces positively established the hydrologic connections among the three main cave segments.

Groundwater recharge into this karst cave system is by direct runoff via the numerous sinkholes and by diffuse percolation through the soil and bedrock. This allows the cave stream underlying the sinkhole plain to be perennially active. The primary groundwater movement is in the dip direction or basically east to west. The cave system is a branchwork cave with small dendritic tributary passages that converge into larger passages in the downstream direction. The one exception is the "Y Passage" of Smith Cave, which pirates approximately 25 to 35 percent of the main

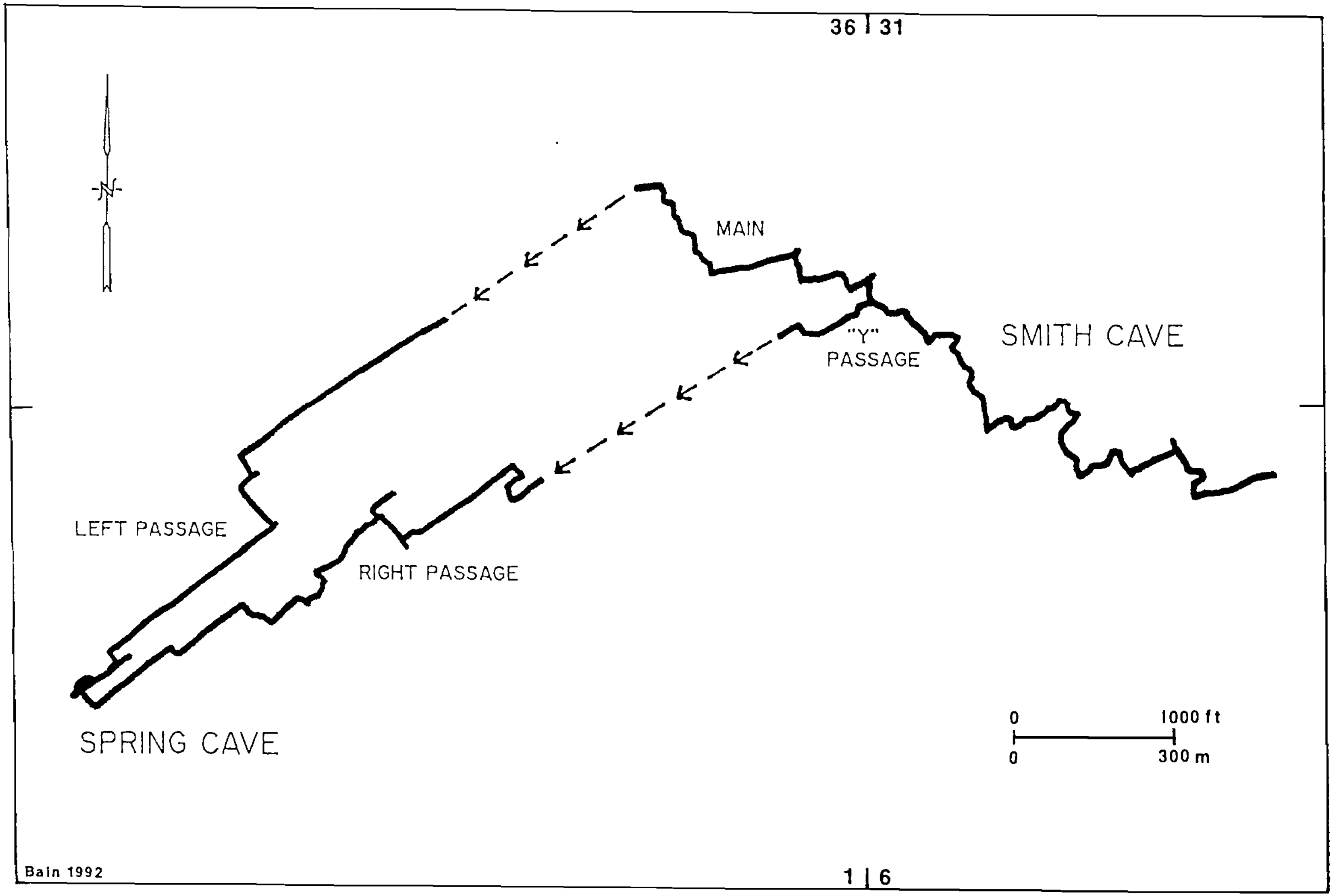

**Figure 11:** Line map of Spring Cave and Smith Cave.

flow into the right (southern) passage of Spring Cave. The rest of the Smith Cave stream flows into the left (northern) passage of Spring Cave (Fig. 11). It appears that the "Y Passage" was once a tributary passage of Smith Cave until continued solution action caused it to intersect a tributary passage in Spring Cave, creating a flood by-pass route during high flow conditions. Eventually, through solution and erosion, the passage penetrated the drainage divide enough to reverse its original flow.

**Structural control:**

Spring Cave is almost entirely fracture joint controlled. The passages are tall, narrow, solutionally enlarged joints that have sharp, angular bends at joint intersections. The joints are visible in the cave most of the time as fractures in the ceiling.

The sinkhole joint trends (Fig. 12) closely correspond with the Spring Cave passage trends (Fig. 13). The joint pattern observed in sinkholes and in Spring Cave passages has a primary set of 50 to 70 degrees and a secondary set of 300 to 320 degrees. This suggests that Spring Cave is almost entirely composed of joint controlled passages. Cave passage trends can often be used to help determine the local fracture joint system (Deike 1969). Smith Cave (Fig. 14) and Windmill Cave (Fig. 15) exhibit some joint control in their passage trends, but not as much as Spring Cave.

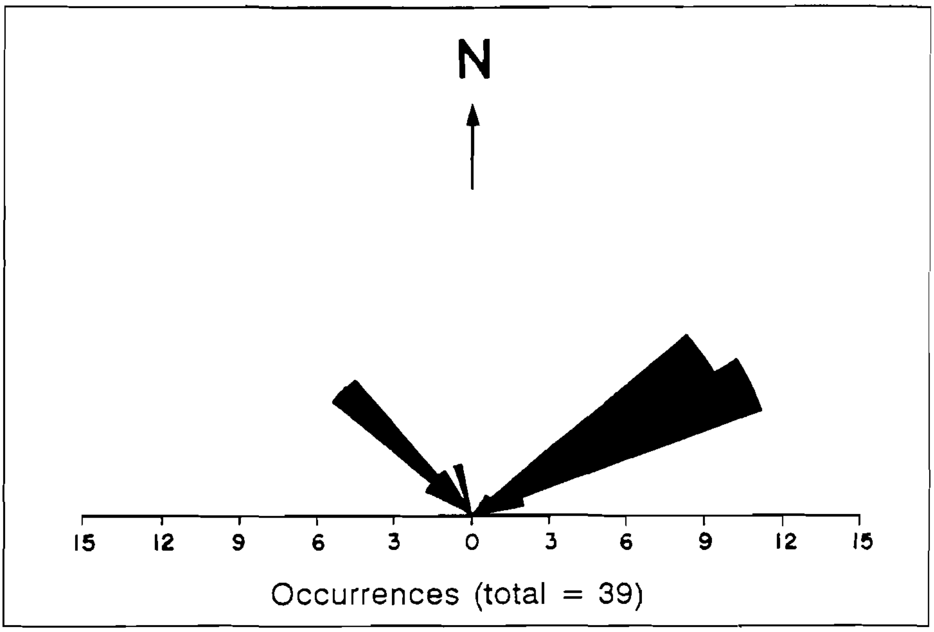

Figure 12: Rose diagram of sinkhole joint trends.

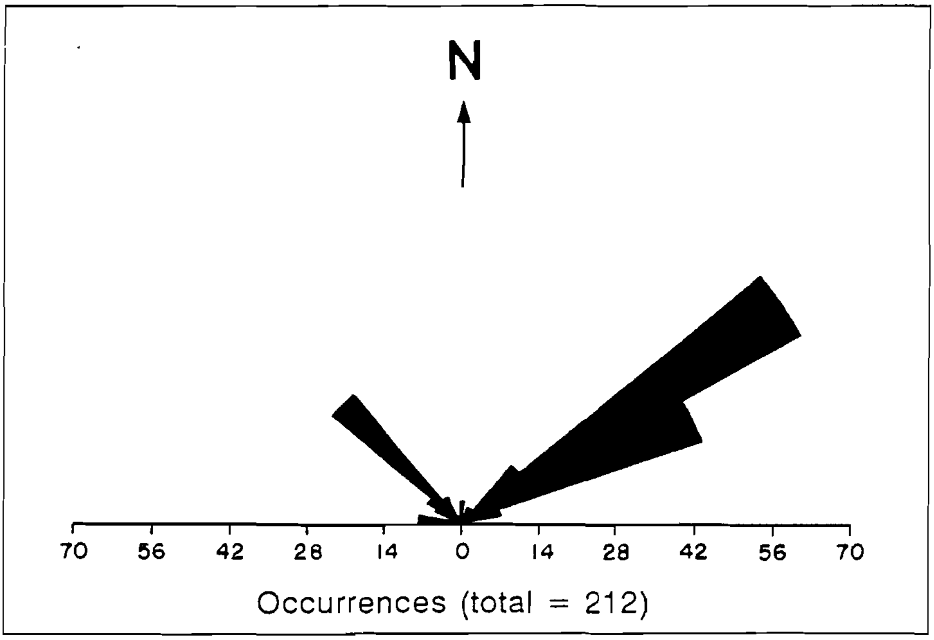

Figure 13: Rose diagram of Spring Cave passage trends.

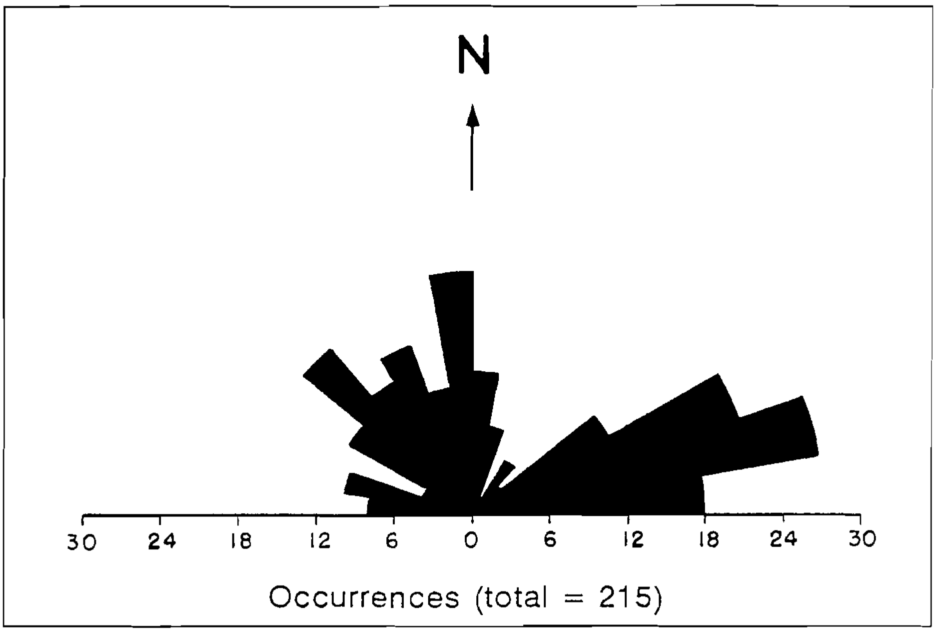

**Figure 14:** Rose diagram of Smith Cave passage trends.

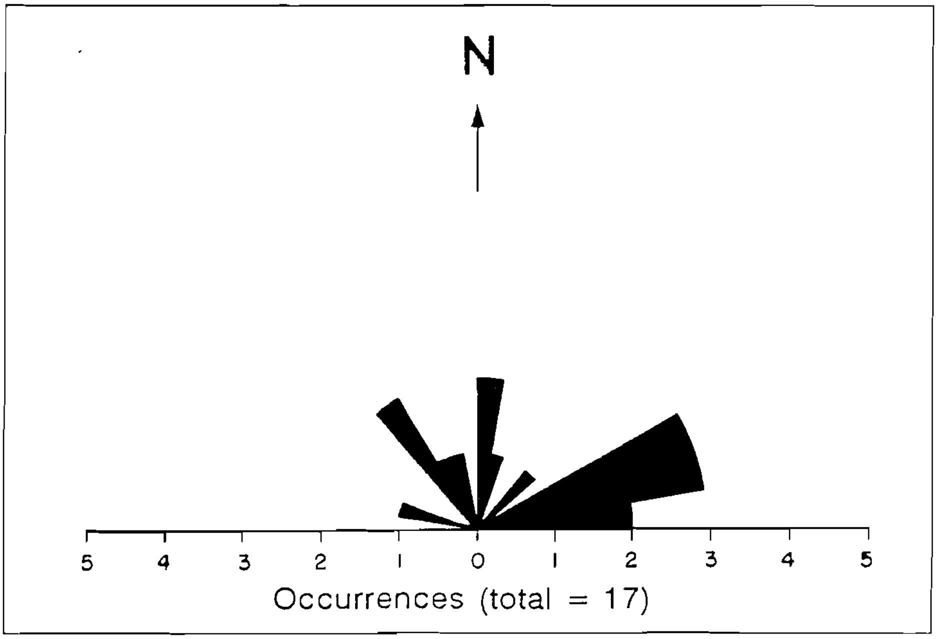

**Figure 15:** Rose diagram of Windmill Cave passage trends.

In Smith Cave, especially in the eastern and central surveyed sections, the passages often display bedding-plane control. The passages are sinuous and have an elliptical shape at the top with a relatively flat ceiling and a vadose canyon at the bottom where the cave stream is now actively down-cutting. In at least three different places, the bedding-plane controlled passages end in a sediment fill with the water now following a joint controlled passage. The downstream (western) passages of Smith Cave show the best joint control and resemble Spring Cave passage characteristics.

### Hydrology:

Geologic factors, such as jointing and bedding, control both sinkhole and cavern development in the study area. Nevertheless, groundwater hydraulics also exert forces that preferentially favor certain joints or bedding planes; otherwise, all zones of weakness would uniformly enlarge into an interconnecting network of conduits. This particular karst system has only one known outlet (spring); therefore, the groundwater flow is constantly seeking the most efficient route toward this outlet.

The spring flowing from the entrance of Spring Cave has been known historically since the late eighteen hundreds and probably long before that by Indians of the region. During a period of normal (low) flow, the spring discharge was roughly estimated to be 12.6 liters/second (200 gal/min). Utilizing Meinzer's classification of spring discharge (p. 8), Spring Cave would rank as a fourth magnitude spring.

As with many karst springs, Spring Cave is extremely flashy (flood prone) during or directly after high precipitation events. At one point during the period of research, the spring was observed immediately after several days of heavy thunderstorms and rains. The discharge was a raging torrent several times that of normal flow. During flood conditions, sediment movement and mechanical erosion within the cave system is greatly increased.

Even at low flow, movement within the cave system is fairly rapid. The first dye trace demonstrated that water takes only 2-3 days to flow from the sinkhole entrance of Smith Cave to the entrance of Spring Cave, a straight line distance of about 2 kilometers (1.25 miles).

## Water chemistry and cave organisms:

The chemical content of karst groundwater, due to rapid recharge and movement, is variable depending on seasonal and climatic fluctuations. On September 16, 1992, water samples were collected by the Groundwater Quality Monitoring Network of the Kansas Department of Health and Environment. Inorganic, pesticide, volatile organic compound (VOC), and radiological samples were collected at the entrance of Spring Cave as the water emerged from underground. The laboratory results (Appendix) indicate that the cave water is quite hard and contains a concentration of iron (0.53 mg/L) that is above the Secondary Drinking Water Standard (0.30 mg/L). No pesticides or volatile organic compounds (VOC) were detected. Overall, the quality of the water at the time of sampling was relatively good.

Biologically, the cave stream is inhabited by a fairly abundant population of albino isopods, amphipods, crayfish, and catfish. This diverse faunal assemblage not only suggests water-quality stability, but also that these species have probably thrived for many generations in the cave environment.

According to personal communications with Dr. W. Busby of the Kansas Biological Survey, the following observations were made concerning the cave organisms of Smith Cave. The catfish were identified as black bullheads (_Ictalurus melas_) and the predominant amphipod species appears to be Clanton's cave amphipod (_Stygobromus clantoni_). The isopods and the crayfish have yet to be identified, although they are probably similar to those commonly found throughout eastern Kansas.

* * *

# CHAPTER 9: CONCLUSIONS

The research project was successful in obtaining valuable knowledge regarding one karst system within the south-central Flint Hills of Kansas. The information gained here may be applied to other karst terrains developed in similar geologic and climatic settings. One fact that became clearly obvious is that this karst region is a system of interrelated features and processes. Solutional action throughout geologic time is the primary agent of karst development. Solution of the bedrock allows karst features to form, joints and bedding planes to enlarge, and creates an efficient network of subsurface drainage.

Factors controlling karst development in the study area are lithology, thickness, and dip of the bedrock; presence of well-defined fracture joints and bedding planes; relatively level surface topography; nearby entrenched river valleys; lack of thick surficial cover; and climate. Of these influences, joints have a major role in the formation of sinkholes and cave passages; however, a complex combination of all the controlling factors is responsible for the present, unique, and dynamic karst system consisting of sinkholes, caves, and springs.

* * *

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* * *

# APPENDIX

Part 1

SPRING CAVE WATER ANALYSES RESULTS
INORGANIC CHEMISTRY PARAMETERS
SAMPLE COLLECTED ON 9-16-92

| CONSTITUENT OR PHYSICAL PROPERTY | ANALYSIS RESULT | REPORTING UNIT |
|---|---|---|
| Temperature | 13 | degrees celsius |
| Specific conductance | 600 | micromhos/cm |
| pH | 7.3 | pH units |
| Total Hardness | 238 | milligrams/liter |
| Calcium | 73.307 | milligrams/liter |
| Magnesium | 13.314 | milligrams/liter |
| Sodium | 59.125 | milligrams/liter |
| Potassium | 5.45 | milligrams/liter |
| Total Alkalinity | 170 | milligrams/liter |
| Chloride | 121 | milligrams/liter |
| Sulfate | 18 | milligrams/liter |
| Nitrate | 1.07 | milligrams/liter |
| Fluoride | 0.22 | milligrams/liter |
| Total dissolved solids | 411 | milligrams/liter |
| Total phosphorus | 0.05 | milligrams/liter |
| Silica | 13.393 | milligrams/liter |
| Boron | 0.08 | milligrams/liter |
| Ammonia | <0.05 | milligrams/liter |
| Aluminum | 0.85 | milligrams/liter |
| Antimony | 0.01 | milligrams/liter |
| Arsenic | <0.021 | milligrams/liter |
| Barium | 0.18 | milligrams/liter |
| Beryllium | <0.001 | milligrams/liter |
| Cadmium | <0.002 | milligrams/liter |
| Chromium | 0.005 | milligrams/liter |
| Cobalt | <0.004 | milligrams/liter |
| Copper | 0.018 | milligrams/liter |
| Iron | 0.53 | milligrams/liter |
| Lead | <0.02 | milligrams/liter |
| Manganese | 0.009 | milligrams/liter |
| Mercury | <0.0005 | milligrams/liter |
| Molybdenum | <0.001 | milligrams/liter |
| Nickel | <0.007 | milligrams/liter |
| Selenium | <0.03 | milligrams/liter |
| Silver | <0.004 | milligrams/liter |
| Thallium | <0.015 | milligrams/liter |
| Vanadium | 0.004 | milligrams/liter |
| Zinc | 0.031 | milligrams/liter |

# APPENDIX

Part 2

SPRING CAVE WATER ANALYSES RESULTS
VOLATILE ORGANIC COMPOUND PARAMETERS
SAMPLE COLLECTED ON 9-16-92

| CONSTITUENT OR PHYSICAL PROPERTY | ANALYSIS RESULT | REPORTING UNIT |
|---|---|---|
| Chloromethane | Not detected | micrograms/liter |
| Bromomethane | Not detected | micrograms/liter |
| Vinyl Chloride | Not detected | micrograms/liter |
| Chloroethane | Not detected | micrograms/liter |
| Dichloromethane | Not detected | micrograms/liter |
| 1,1-Dichloroethylene | Not detected | micrograms/liter |
| 1,1-Dichloroethane | Not detected | micrograms/liter |
| Trans and/or Cis 1,2-Dichloroethylene | Not detected | micrograms/liter |
| Trichloromethane | Not detected | micrograms/liter |
| 1,2-Dichloroethane | Not detected | micrograms/liter |
| 1,1,1-Trichloroethane | Not detected | micrograms/liter |
| Tetrachloromethane | Not detected | micrograms/liter |
| Bromodichloromethane | Not detected | micrograms/liter |
| 1,2-Dichloropropane | Not detected | micrograms/liter |
| Trans 1,3-Dichloropropene | Not detected | micrograms/liter |
| Trichloroethylene | Not detected | micrograms/liter |
| Benzene | Not detected | micrograms/liter |
| Dibromochloromethane | Not detected | micrograms/liter |
| Cis 1,3-Dichloropropene | Not detected | micrograms/liter |
| 1,1,2-Trichloroethane | Not detected | micrograms/liter |
| Bromoform | Not detected | micrograms/liter |
| 1,1,2,2-Tetrachloroethane | Not detected | micrograms/liter |
| Tetrachloroethene | Not detected | micrograms/liter |
| Toluene | Not detected | micrograms/liter |
| Chlorobenzene | Not detected | micrograms/liter |
| Ethylbenzene | Not detected | micrograms/liter |
| Meta-Xylene | Not detected | micrograms/liter |
| Ortho and/or Para-Xylene | Not detected | micrograms/liter |
| 1,2-Dichlorobenzene | Not detected | micrograms/liter |
| 1,3-Dichlorobenzene | Not detected | micrograms/liter |
| 1,4-Dichlorobenzene | Not detected | micrograms/liter |

# APPENDIX

Part 3

| SPRING CAVE WATER ANALYSES RESULTS<br>PESTICIDE PARAMETERS<br>SAMPLE COLLECTED ON 9-16-92 | | |
|---|---|---|
| CONSTITUENT OR PHYSICAL PROPERTY | ANALYSIS RESULT | REPORTING UNIT |
| Alachlor | Not detected | micrograms/liter |
| Aldrin | Not detected | micrograms/liter |
| Atrazine | Not detected | micrograms/liter |
| Cyanazine (Bladex) | Not detected | micrograms/liter |
| Chlordane | Not detected | micrograms/liter |
| DCPA (Dacthal) | Not detected | micrograms/liter |
| Dieldrin | Not detected | micrograms/liter |
| Metolachlor (Dual) | Not detected | micrograms/liter |
| Heptachlor | Not detected | micrograms/liter |
| Heptachlor Epoxide | Not detected | micrograms/liter |
| PCB-1016 | Not detected | micrograms/liter |
| PCB-1221 | Not detected | micrograms/liter |
| PCB-1232 | Not detected | micrograms/liter |
| PCB-1242 | Not detected | micrograms/liter |
| PCB-1248 | Not detected | micrograms/liter |
| PCB-1254 | Not detected | micrograms/liter |
| PCB-1260 | Not detected | micrograms/liter |
| Propazine | Not detected | micrograms/liter |
| Propachlor (Ramrod) | Not detected | micrograms/liter |
| Metribuzin (Sencor) | Not detected | micrograms/liter |
| Endrin | Not detected | micrograms/liter |
| Gamma BHC (Lindane) | Not detected | micrograms/liter |
| Methoxychlor | Not detected | micrograms/liter |
| Toxaphene | Not detected | micrograms/liter |
| 2,4-D as acid | Not detected | micrograms/liter |
| Silvex as acid | Not detected | micrograms/liter |
| 2,4,5-T as acid | Not detected | micrograms/liter |
| Picloram (Tordon) | Not detected | micrograms/liter |

| SPRING CAVE WATER ANALYSES RESULTS<br>RADIOLOGICAL PARAMETRS<br>SAMPLE COLLECTED ON 9-16-92 | | |
|---|---|---|
| CONSTITUENT OR PHYSICAL PROPERTY | ANALYSIS RESULT | REPORTING UNIT |
| Gross Alpha | 1 | picocuries/liter |
| Gross Uranium | Not analyzed | picocuries/liter |
| Radium-226 | Not analyzed | picocuries/liter |
| Radium-228 | Not analyzed | picocuries/liter |

# PLATES

**Plate 1:** Cavers surveying in Smith Cave.

**Plate 2:** Bedding-plane controlled passage in Smith Cave.

**Plate 3:** Sediment filled paleo-passage in Smith Cave.

**Plate 4:** Joint controlled passage in Smith Cave.

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