AN ABSTRACT OF THE THESIS OF

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Title: GIS Analysis of Dakota Flora Localities.

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The Cretaceous Dakota Flora from the Western Interior of North America is well known for its angiosperm diversity (435 nominal species). Paleobotanists find this anomalously high level of diversity significant considering the relatively low diversity found in other Cretaceous angiosperm floras, commonly containing 20-25 species. Although some paleobotanists argue that the high diversity is questionable, angiosperm species holotypes from the Dakota can be are still important, if they are restudied and reclassified.

Much of the Dakota Flora collection and study can be referred to as historical since it was performed from 1850 to 1920, when little was understood about stratigraphic relations within the Albian to Cenomanian allostratigraphic equivalents to the Kansas Dakota Formation. Further, precise records are not available for geographic locations and stratigraphic positions of Dakota angiosperm fossil collection sites. Some taxonomic questions can be resolved by

studying existing specimens from collections worldwide, but unless further fieldwork is conducted, resolution of all angiosperm diversity issues will be difficult. This thesis was undertaken to determine if historical collection sites could be more precisely relocated using geographic information systems (GIS) than using descriptions or using approximations drawn on a paper map, and if GIS analyses could help determine from which stratigraphic horizons the Dakota angiosperm specimens were collected.

There were four questions for this research: 1) Can existing location descriptions be used to create a GIS dataset that represents the collection sites as polygons of various shapes? 2) Can GIS analyses be used to refine these collection site polygon locations to smaller polygons that could be more useful for relocating specific historical collection sites? 3) Do spatial analyses of the relationships between the derived collection site polygon locations and other GIS datasets indicate that specimens were collected from a single well-defined geographic area or from a widespread geographic area? 4) After relocation, do analyses indicate that the collection sites are dispersed within similar enough stratigraphic units to indicate that they were extant contemporaneously?

Locations for historical collection sites were defined either as: 1) distances from a known location; 2) directional distances from a known location; or 3) legal descriptions. Legal descriptions were converted into polygon locations, whereas distance and directional distance locations were determined using a combination of buffers and directional indicators. The resulting locations were imprecise.

Comparisons with Dakota Formation outcrops helped increase the precision; however, results depended greatly on the quality of collection site descriptions and outcrop location data. Comparisons between the GIS-derived collection site locations and other GIS datasets (surface elevations, Dakota base, Cretaceous base) yielded mixed results. GIS analyses can be useful for planning further field research, but without more and better descriptive locational data or further fieldwork, questions about precise collection site relocation, species diversity, and species distribution cannot be entirely resolved.

GIS Analysis of Dakota Flora Localities

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Why Study Dakota Flora Collection Sites with GIS?

The Dakota Formation of the Cretaceous Western Interior of the United States is famous for its abundant well-preserved angiosperm leaves and for a history of debated stratigraphic correlations (Figure 1). The formation's most famous plant fossils were deposited, within sandy and clayey sediments. Most of the historical specimens come from the eastern margin of the Cretaceous Western Interior Seaway (CWIS), (Hamilton, 1989). Dakota strata, mainly those in Kansas, have yielded to collectors and researchers hundreds of these angiosperm, gymnosperm, and fern fossils. The Dakota Flora consists mainly of angiosperm leaf fossils representing some of the earliest and most-diverse (as characterized by Lesquereux) flowering plants known in the world. These Cretaceous leaves have been collected from Dakota outcrops in Kansas for over 130 years and were reported by Lesquereux (1874a; 1883; 1892 posthumously) as representing as many as 437 angiosperm species. This large number of species is surprising for the early evolution of angiosperms. C. H. Sternberg collected most of the historical (those of the 1800s and 1900s) Dakota Flora specimens in the late 1800s. These specimens were the basis for Lesquereux's monographic works.

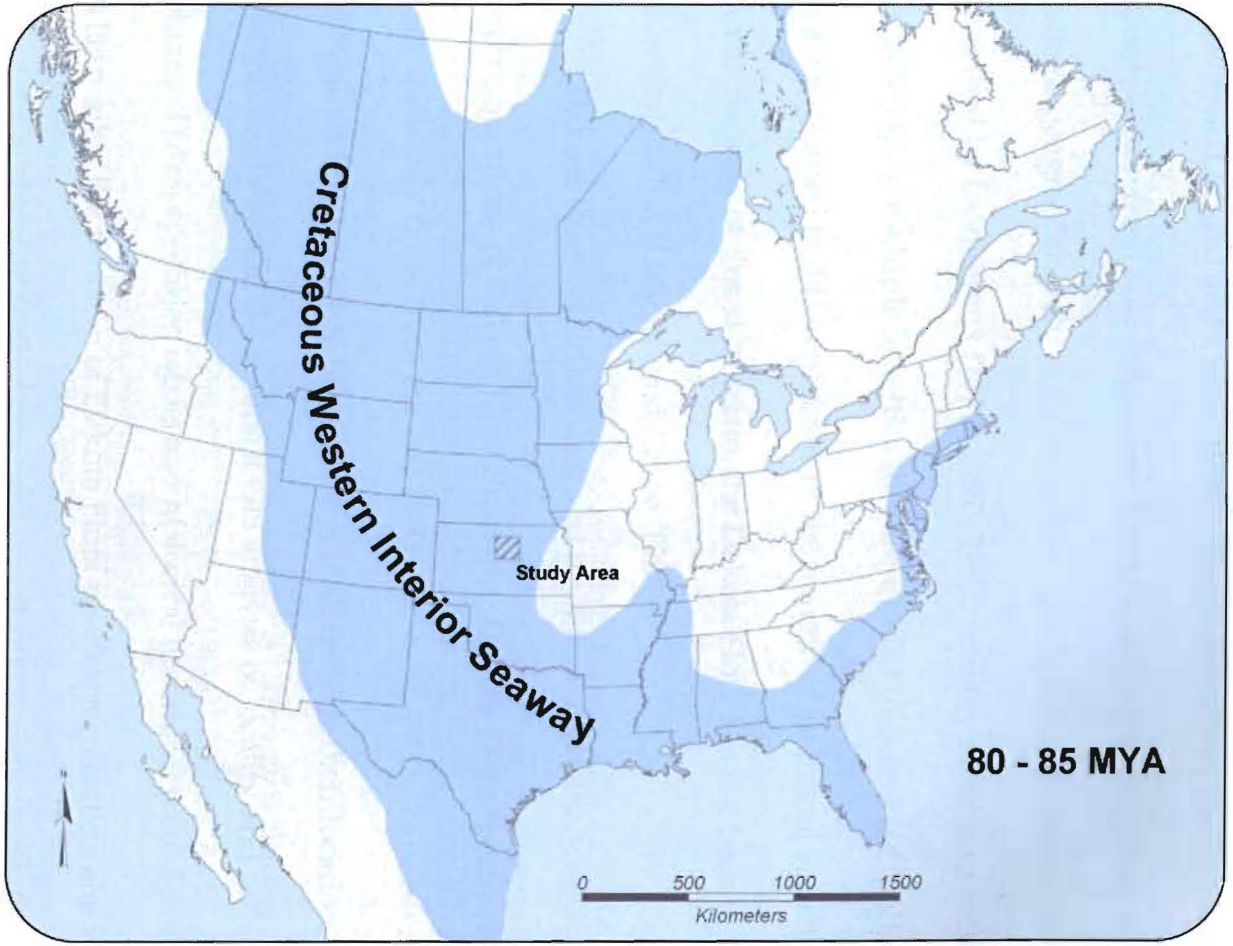

Figure 1: Map of Paleogeography Showing the Cretaceous Western Interior Seaway. Paleogeographical reconstruction of the Cretaceous Western Interior Seaway from about 80 to 85 million years ago depicts the location close to the time of Dakota strata deposition. Map created from coverages included with the ArcView program and the CWIS margin derived from Canadian Museum of Nature map of the CWIS (Botman, 2005).

The angiosperm species diversity (437 nominal species) reported for the Dakota Flora seems suspect when compared with the much lower angiosperm species diversity (20–25 species) of contemporaneous angiosperm floras collected elsewhere (Lidgard and Crane, 1988). Skepticism about the Dakota Flora has mainly arisen from how it has often been treated as coming from a single well-defined geographic area. An alternative view is that the Dakota Flora as described by Lesquereux (1874a; 1883; 1892) actually represents multiple floras collected from multiple localities that are smaller in extent (*i.e.*, collected from strata deposited at different times as the margin of an inland sea shifted through time). Because of this skepticism, the Dakota Flora has not been included in most diversity studies (Lidgard and Crane, 1988).

Dakota Flora collection sites and localities need to be better understood to resolve questions of Dakota Flora diversity. Dakota Flora specimen collection sites, especially those from the late 1800s and early 1900s, have been considered ambiguous because it has been difficult to determine their location. It was hoped that this study would determine if GIS analysis of locality and collection site data (obtained from specimen labels and historical literature) would provide a means to help solve the problem of Dakota Flora specimen collection site ambiguity.

An additional desired outcome was that GIS analysis could help differentiate individual collection sites to aid in diversity studies. Diversity studies require the data to be separated into individual localities or collection sites so that analyses can be performed. Although separation of Dakota Flora specimens into their individual collection sites is a major problem there are others including checking species identifications by modern standards, that will still need worked out to appropriately use the flora in diversity studies.

Why Study Collection Sites with GIS?

In paleobotany natural history collections are important repositories for specimens, particularly those published in scientific research. Science depends on being able to verify the data and methods of other researchers. While discussing collection management and documentation systems in paleobiology, Crowther (1990: 517) comments that:

> "fossil collections and their associated data represent the primary material evidence...[and that] the survival and availability of such collections is crucial to the advancement of knowledge."

Documentation of specimens should include when and where the specimens were collected. Most natural history collections in museums contain at least a few specimens that were collected prior to 1970 that do not include this information. For these specimens researchers often need to relocate original collection sites, but accomplishing this may be difficult.

The locational information as observed in the descriptions associated with specimens must be interpreted. Murphey, *et. al.* (2004: 2) stated that there is "often [a] poor state of locality data associated with natural history museum specimens." Furthermore, they observed that locality data and therefore collection site data is often inadequate.

Additional factors are involved in creating uncertainty within the older collection site location data including revised or different geographic terminology and changing collection standards. Only complete locality and collection site descriptions are being entered into computer databases for newer materials (Murphey, *et. al.*, 2004). However, the most significant factor affecting the quality of collection site and locality information may be that "disassociation of detailed records of collecting events (text, maps, photographs, coordinates) from specimen labels and the collection catalogue" occurs (Murphey, *et. al.*, 2004: 2).

Attempts to relocate collection sites can be problematic. While problems differ from one study to another, there are some common similarities. Difficulties in relocating collection sites start with obtaining the descriptions of the collection sites from specimens, if these specimens reside in multiple museums, and each must be visited. Furthermore, the collection site data recorded on specimen labels varies among specimens. Often the specimen data are vague or incomplete with respect to the collection site location, making it difficult to convert into a format compatible with geographical information systems (GIS).

These incomplete collection site descriptions are present within the historically collected Dakota Flora specimen labels. In addition, GIS is increasingly used in current studies and analyses of fossil distributions however, the procedures used by collection curators and the format the records are kept in are often not compatible with GIS (Murphey, *et. al.*, 2004). While other methods exist for converting the records into a GIS compatible format, this study illustrates a method to convert vague collection site descriptions into a more useful location for relocating its position. Therefore, the research questions and methods I used in this study can have far-reaching impacts in the other natural history fields.

Purpose of This Study

A geologically emphasized geographical and historical study is required to gain a better understanding and appreciation of the spatial variability of the flora and strata of the Dakota. The history of the Dakota strata and flora is as important, if not more important, to the story of the Dakota as modern studies when using historically collected specimens. Additionally, if the history is better known and the value of some of the data it restores is recognized, then a greater appreciation of the geographic nature of the Dakota strata and flora might emerge from the current accumulated data, especially on collection sites.

The current allostratigraphic definition of the Dakota Formation is not always satisfactory when studying the spatial variability of the fossil bearing strata or field recognition of position within the strata. This makes determination of specific stratigraphic horizons from which the fossil plant specimens were collected difficult or impossible to determine in the field. Fossil bearing strata within the Dakota Formation are spatially variable due to temporal changes in deposition caused mainly by transgression of the CWIS. Field correlation and collection site relocation can therefore be very difficult. Walther's Law explains that correlative strata can contain different facies of sediment that vary in age depending on their location as well as their stratigraphic position. Boggs (1995: 501) points out that when unconformities are present Walther's Law cannot strictly be applied because it only applies to "facies that occur in conformable vertical successions of strata" with "laterally adjacent environments;" however, it does help aid in locating those unconformities if a depositional succession model (*e.g.*, transgressive sea) is known. Therefore, most of the time and space issues of the Dakota strata and flora can only be resolved if locations are properly classified in terms of spatial location, stratigraphic positions, and fossil content (paleontology). It was hoped that learning about the historical and geographical aspects of the Dakota strata and flora would lead toward a better understanding of the Dakota's nature. This could then lead to a better knowledge base of how spatial variability can be used in larger pictures studies to obtain a greater understanding of "well-known" or "significant" geologic assemblages.

There were four questions for this research: 1) Can existing location descriptions be used to create a GIS dataset that represents the collection sites as polygons of various shapes? 2) Can GIS analyses be used to refine these collection site polygon locations to smaller polygons that could be more useful for relocating specific historical collection sites? 3) Do spatial analyses of the relationships between the derived collection site polygon locations and other GIS datasets indicate that specimens were collected from a single well-defined geographic area or from a widespread geographic area? 4) After relocation, do analyses indicate that the collection sites are dispersed within similar enough stratigraphic units to indicate that they were extant contemporaneously?

Paleobotany Concepts Useful for Understanding This Study

Paleobotany incorporates both botanical and geological concepts; therefore, the paleobotanist ideally needs training that includes a background in both fields. However, the paleobotanist is typically trained either as a botanist with a few geology classes or as a geologist with a few botany classes. This leads to the paleobotanist being stronger in one of the sub-disciplines and weaker in the other sub-discipline—though the degree of weakness depends on the paleobotanist. Traditionally, paleobotanists have been trained as botanists who took a few geology classes—the amount of geology could be as few as a general geology class and a class on Earth history (Personal Communication Dilcher, 1999). This traditional background often leaves the paleobotanist without a true understanding of sedimentology and stratigraphy. Hughes (1976) indicates that paleobotanists for decades were lead by biological influences rather than geological influences. In fact, there have been comments in the literature dealing with stratigraphy, such as Hughes (1976: 11-12) comment:

> "Many investigators sink into speculation because of poor stratigraphic control, whose importance is not...appreciated by paleobotanists."

In addition, paleobotanists usually indicate that a flora comes from a particular formation in their published studies, but often provide little to no documentation of how stratigraphic position was determined. Paleobotany publications may include a section on geologic information, but often fail to contain documentation on the horizons from which specimens were collected. It is important therefore, that geologically trained paleobotanists research fossil floras as well as the strata in which these fossils are found. A greater understanding of the strata can provide greater insight useful in interpreting the significance of the fossils, the depositional environment conditions, and their age. It can also prevent misrepresentation or inaccurate interpretation of stratigraphy by paleobotanists with limited geologic background. From a practical point of view, adequate and accurate stratigraphic documentation are also essential to descriptions of fossil collecting sites so that they may be revisited and studied further in spatial and stratigraphic contexts.

Geologists and stratigraphers use fossils for a variety of purposes including correlation of strata and age estimation. Unless the fossils are being used to establish biozones, Macfarlane (Personal Communication 2005) suggests it would be best from a geological standpoint to discuss the stratigraphy separate from the fossils contained within the strata. In this study, the focus is on relocating sites where angiosperm fossils have been collected from the Dakota.

In that context, I will attempt to separate the stratigraphic discussion from the discussion of the fossil flora. However, the discussion of a fossil flora cannot occur without some references to stratigraphy. Avoiding discussion of the stratigraphy would leave out the history of the flora and explanation of why it has not been used in diversity studies. In older publications, paleobotanists used the available concepts about sedimentological architecture to determine if a particular specimen and flora was considered part of the Dakota Flora and not some other flora.

That said, consideration should also be given to what is or is not included in the term "Dakota Flora." A flora is a listing of the species of plants found in a specified area. While a modern flora consists of all parts of the plant—leaves, seeds, pollen, wood, flowers, etc.—belonging to a single species, paleobotanists rarely if ever find all the parts attached and therefore often have separate names for each part. They therefore think of the flora in terms of compilations of fossilized plant parts (megafossils, mesofossils, and microfossils) (Table 1).

The leaf megafossils, especially the angiosperms, are the most common specimens associated with the Dakota Flora. Leaf megafossils were being described when the term Dakota Flora was coined, and paleobotanists used a priority of publication in their terminology. In the years that followed initial publication, the leaf megaflora has been further studied and expanded from the leaves found in the sandstone to those in the surrounding Dakota shale.

Table 1: Fossil Size Terminology. Characteristic descriptions of fossil size terminology, and how they are studied as defined by Miller, *et. al.* (2002).

Term	Size Range	How Studied
Megafossil	At least 10 mm long	Usually with the naked eye or little-to-no magnification
Mesofossil*	1 mm to 10 mm long	Usually studied with only low-powered magnification
Microfossil	Smaller than 1 mm	Too small to see with the naked eye and must be studied using light, scanning electron, or tunneling electron microscopy

Term with an asterisk (*) next to it is a relatively new size classification to the field of paleontology.

In this expansion, the Dakota Flora has transitioned from the sandstone of old to the Dakota Formation. However, this expansion has lead to confusion when trying to properly define and describe the Dakota Flora. The Dakota Flora has become a flora associated with multiple sediment types in multiple depositional environments in multiple states. In addition, microfossil studies of the pollen and spores from the shales have been performed and results published as the microflora of the Dakota Flora. Few of these studies have focused on the areas that include the original collection sites because of an inability to precisely relocate them and because the historical specimens came from sandstone, which is less likely to preserve pollen and spores. More recently, mesofossil studies are being done (Wang and Dilcher, 2001) but these are also from the shale surrounding the sandstone and are being referred to as the mesoflora of the Dakota Flora.

Studies of the microflora and megaflora of the Dakota Formation will add to the understanding of the overall Dakota Flora. However, the historically collected leaves that Lesquereux (1874a; 1883; 1892) described in his monographs need to be restudied to truly understand the composition of the overall Dakota flora.

Dakota Nomenclature Through Time

Most geological and paleobotanical researchers working in the Cretaceous know about the Dakota; however, there have been a variety of terms used to describe various aspects of the Dakota strata and flora. The Dakota strata have been described as Formation # 1 (introduced in 1858 by Meek & Hayden), Dakota Group (introduced in 1862 by Meek & Hayden), Dakota Formation (introduced in 1894 by White according to Tester in 1931), Dakota Sandstone (introduced in 1897 by Haworth), and Dakota Flora (appears to have been introduced in 1892 by Lesquereux).

It is important to note that the nomenclature used to classify basal Cretaceous non-marine to marine clastic deposits has evolved since these units were described in the 19th century. Problems have arisen due to misunderstandings about modern stratigraphic concepts applied to the Dakota (lithostratigraphic versus allostratigraphic units). Though paleobotanists and stratigraphers should ideally share the same terminology on the strata, because of misunderstandings regarding both concepts and the needs of each field of study, they sometimes have not. Because of these misunderstandings, the terminology has been confusing for some time. For example, Tester 1931 described as the "Dakota Problem," having arisen from the paleobotanists and others using the historically collected fossil leaf specimens to view the strata as lithostratigraphic units; whereas, stratigraphers now view these basal Cretaceous strata as consisting of allostratigraphic and as unconformity-bounded sequences (Personal Communication Macfarlane, 2005). Therefore, an understanding of the history of the usage of the Dakota terminology (see "History of Dakota Strata and Flora Terminology" section for details) is helpful for interpreting the stratigraphic positions of Dakota plant fossils.

Terminology Used in This Study

It is necessary to define the terminology used in this study to ensure that the reader interprets the meanings of the terms correctly. A brief glossary of the most likely to be confused terms and abbreviations used in this study is included as "Appendix A: Glossary of Selected Terms" (starting on page 224).

Locational Terminology

Descriptions of the sites from which Dakota Flora specimens were collected, were found in the literature and on museum specimen labels. The collection site descriptions were from multiple specimens that had been collected from many field sites. I made the decision to define my use of locational terminology because of the variety of definitions that exist for locational terms; usually these definitions are dependent on the field of study for the scientists involved. For this description, unless it is in a direct quote, I will use the following locational terminology:

1. I use the term "collection site" to mean the actual position on the outcrop in the field from where the fossil specimen was obtained. In addition, it is important to note that the term "modern" associated with a collection site refers to recently (since about 1970) discovered collection sites. While, the term "historical" associated with a collection site refers to those collection sites from the late 1800s and early 1900s.
2. I use the term "locality" to mean the location of the outcrop that contains the collection site. However, a slight variation in terminology occurs in the sections on stratigraphy where "locality" has the same meaning as that used in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983; Salvador, 1994). The terms "type locality" and "type area" are used exactly as defined by stratigraphic codes.
3. I use the term "single, well-defined geographic area" to mean the overall geographic extent of the historically (late 1800s to early 1900s) collected and described Dakota Flora when taken as a whole. The overall extent consists mainly of the preserved Dakota outcrop belt within the eastern Great Plains. This term is necessary as discussion of the locations of the historically collected and described Dakota Flora specimens overall otherwise is difficult

because the term locality is usually reserved for more localized areas and needed when explaining the concept of how all the historically collected specimens are treated as coming from the same locality.

At this time, I will briefly introduce the terms I will use for my collection sites used in my study; however, their meanings and the differences between them will become clearer in the methods and results discussions.

1. I use the term "Distance Collection Site" to refer to a collection site that is described as a certain distance from a city that I represent as the distance around that city, even if the original locality description contained a directional component.
2. I use the term "Limited Distance Collection Site" to refer to a collection site that is described as within a certain distance from a city with a directional component, which I represent as a directional wedge from the city.
3. I use the term "PLSS Collection Site" to refer to a locality that is described by a legal description in public land survey format. However, at one point in the discussion I will use the term "Problematic PLSS Collection Site" when discussing those collection sites that have incomplete legal descriptions to differentiate them from those that have complete descriptions ("PLSS Collection Sites"). However, when referring to all the collection sites derived from legal descriptions, I simply refer to them as "PLSS Collection Sites" regardless of if they are complete and incomplete collection site descriptions.

Data Type Terminology

This study involves different types of qualitative and quantitative data. While some of the data type terms such as specimen label and map are self-explanatory, some terms need further explanation. I use "historical data" to refer to data or previous studies that I obtained from the literature published before 1994 or historical specimen labels—those labels that are not the current label or that were written before 1970. While it would be possible to consider anything done yesterday as historical data, I consider modern data to be any first-hand data I gathered, any data from studies published since 1994, and any modern specimen label—unless it was written before 1970. I use "current studies" to refer to this data.

Dakota Terminology

For this study, unless it is in a direct quote, I will use the following terminology for Dakota strata on the east side of the western interior seaway:

1. I use "Dakota sandstone" to mean any sandstone of the Dakota Formation especially if it contains fossils of the historically collected Dakota Flora.
2. I use the terms "Dakota Formation" and "Dakota strata" to mean both fossiliferous and non-fossiliferous Cretaceous sediments in Kansas that are older than the Graneros Shale and younger than the Kiowa Formation that encompasses the Dakota of Kansas (Zeller, 1968). This usage essentially

follows what the Kansas Geological Survey (KGS) and United States Geological Survey (USGS) lexicons imply (Baars and Maples, 1998; United States Geological Survey's National Geologic Mapping Program, 2000b).

3. I sparingly use the term "the Dakota strata and flora" when needing to discuss the Dakota in general. This term should be taken to include the Dakota Flora, the sediments the fossil flora comes from, and the Cretaceous sediments in Kansas assigned to the Dakota.
4. I use the term "Dakota Flora" to mean the primarily angiosperm leaf megafossil specimens that have been described in museums and the literature as coming from sandstones attributed to Dakota strata.

This study is concerned with the historical collection sites of the originally described Dakota Flora. The historical Dakota Flora specimens come mainly from the sandstone, while the formation as defined by the KGS today consists primarily of shales and siltstones (Zeller, 1968). I think of the Dakota Flora as only the megaflora component mainly collected from sandstone. Therefore, because the Dakota Formation consists of more than sandstone a term referring to the sediments that the fossils come from is necessary for discussing the Dakota Flora. I use the term Dakota sandstone, where the lower case "s" in sandstone is used deliberately to show that while Dakota sandstone is not nor should it be used as a formation name, it is useful only when referring to the sediments that the leaf fossils come from unless it is in a direct quote. While the need for a specialized term for the sediments that the fossil flora comes from may not be apparent, I feel it simplifies the discussion and makes the older paleobotanical literature more sensible.

History of Dakota Strata and Flora Terminology

Dakota strata and flora have been described and studied by numerous investigators (Tables 2 and 3). The terminology used to describe the Dakota flora and strata have changed over the years as concepts in paleobotany, geology, and stratigraphy have evolved. Terminology in use when the specimens were collected has been helpful in determining where and when the specimens were collected. Therefore, two tables were constructed to summarize terminology in the following section "Early Investigators of the Dakota Flora and Strata" (Tables 2 and 3). Table 2 was constructed to summarize Dakota strata descriptions. Table 3 was constructed to summarize the Dakota Flora descriptions.

Early Investigators of the Dakota Flora and Strata

The early investigators included explorers (*e.g.*, Meek and Hayden), botanists (*e.g.*, Heer, Newberry, and Lesquereux), collectors (*e.g.*, Sternberg family), and a few geologists (*e.g.*, Hayden and Capellini).

Table 2: Summary of Dakota Strata Descriptions Through Time. Dakota strata descriptions, terminology, and work that pertain to Kansas and this study are highlighted. It is not intended to be a comprehensive list.

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(Strata now considered to be sandstone in Dakota Formation)	1804 (1931)*	Meriwether Lewis & William Clark (Allen C. Tester)	Along Missouri River in Nebraska	Observed "'yellow, soft sandstone' in the bluffs of the west side of the Missouri River near the place of the Mahar (Omaha) Indian Chief Blackbird burial mound" according to Tester's interpretation of their journals (1931: 204)	Tester, 1931
Formation #1	1858	Fielding Brown Meek & Ferdinand Vandiveer Hayden	In hills near Dakota City, Nebraska	Coined term and described as "yellowish, reddish, and occasionally white sandstone with rather thick beds with interstratified alterations of various yellow and ash-colored beds and seams of impure lignite. Also, silicified wood, and great numbers of leaves of higher types of dicotyledonous trees," plus they list several genera of brachiopods, considered Cretaceous in age(1858)	Meek and Hayden, 1858

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Dakota Group	1862	Fielding Brown Meek & Ferdinand Vandiveer Hayden	In hills near Dakota City, Nebraska	Re-named Formation #1 as the Dakota Group using same description, (1862: 419) considered Cretaceous in age	Meek and Hayden, 1862
Woodbury Sandstone Nishnabotany Sandstone	1870 (1931)*	C. A. White (A. C. Tester)	Iowa	Tester (1931) claimed White coined the terms Woodbury Sandstone and Nishnabotany Sandstone to subdivide the Dakota in light of a transgressive series	Tester, 1931
Dakota Formation	1894 (1931)*	C. A. White (A. C. Tester)	Iowa?	Tester (1931) claimed White was the first to use the term Dakota Formation in a 1894 publication, though he was beginning to suggest [orally?] the Dakota should be a formation in the 1870s	Tester, 1931
Dakota Sandstone	1897	Erasmus Haworth	Kansas	Coined the term Dakota Sandstone in publication as "this formation is so largely composed of sandstone that it is frequently spoken of as the Dakota Sandstone" (1897: 201)	Haworth and Logan, 1897
Dakota Sandstone	1912	George Willis Stose	Colorado?	Dakota Sandstone described as massive gray sandstone	Stose, 1912
"Dakota Problem"	1922	Timothy W. Stanton	General	First addressed the complex nature of the "Dakota Problem"	Stanton, 1922

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Dakota Group	1925	Willis T. Lee	General	Dakota Group informally divided into 5 informal formations <3 sandstones, 2 shales>	Lee, 1925
Dakota Sandstone "Dakota Problem"	1925	Willis T. Lee	General	"There is no single, definite, persistent, easily recognized sandstone, such as was formerly supposed to exist and was termed the Dakota Sandstone" (1925: 6)	Lee, 1925
Rocktown channel sandstone member	1925	W. W. Rubey and N. W. Bass	Kansas	Coined and described Rocktown channel sandstone member, occurs as exposures along streams in Russell Co, KS	Rubey and Bass, 1925
Dakota Stage (type section)	1931	Allen C. Tester	Vicinity of Sioux City, Iowa	Describe a type locality in which he described a composite type section around Sioux City, Iowa	Tester, 1931
Ellsworth Formation Terra Cotta	1935	Raymond Cecil Moore	Kansas	Lower Dakota of Ellsworth Formation is Terra Cotta	Moore, 1935
Dakota Group Solomon Formation Ellsworth Formation	1937	Raymond Cecil Moore & K. K. Landes	Kansas	Dakota Group mapped and includes Solomon Formation & Ellsworth Formation	Moore and Landes, 1937
Dakota Group Cheyenne Sandstone Kiowa Shale Cockrum Sandstone	1941	Bruce F. Latta	Kansas	Dakota Group includes Cheyenne Sandstone, Kiowa Shale, Cockrum Sandstone	Latta, 1941

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Janssen Clay Member Terra Cotta Clay Member	1942	Norman V. Plummer	Kansas	Subdivided Dakota into two newly named members: Terra Cotta clay member at the bottom, and Janssen clay member at the top; measured section; provided cross-section; said Cretaceous age	Plummer, 1942
Dakota Formation	1942	Norman V. Plummer and John F. Romary	Kansas	Restricted in Kansas to include only continental and littoral beds occurring above the Kiowa shale and below Graneros shale and occurs [in this report] in central and north-central KS on the Central Kansas uplift; consists of sandstone and clay; contains siderite and limonite pellets and "quartzite" underlying "iron" concretions; Mushroom Rock Dakota strata.	Plummer and Romary, 1942
(type section)	1943	G. E. Condra & E. C. Reed	Nebraska	Established first type section by then current stratigraphic code standards; "type locality" designated in Missouri River Bluffs, 1 mi southeast of Homer, NE/4 sec. 13, T. 27 N., R. 4 E., Dakota Co., NE	Condra and Reed, 1943

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Omadi Sandstone	1943	G. E. Condra & E. C. Reed	Nebraska	Named top formation of Dakota Group Omadi Sandstone; type section in the Missouri River Bluffs extending through Omadi township in southeastern Dakota Co, NE; in northeastern Salina basin proposed as substitute for Dakota sandstone because use of name "Dakota" both for a formation and a group leads to confusion; measured section in vicinity of NE 1/4 sec 13, T 27 N, R 4 E; Cretaceous age	Condra and Reed, 1943
Dakota Formation	1944	Raymond Cecil Moore, J.C. Frye, & John Mark Jewett	Kansas	Dakota Formation consists of clay, shales, siltstones, and sandstones interbedded with lenticular concretions of hematite/limonite and locally quartzitic sandstones	Moore, *et. al.*, 1944

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
"Dakota Problem"	1952	William A. Cobban & John B. Reeside, Jr.	Western Interior of the United States	Claimed, "The relation of the sandstone designated 'Dakota' in this [Western Margin of the Cretaceous Interior Seaway] and many areas to the typical Dakota Sandstone on the Missouri River near Sioux City, Iowa are not well understood. Such usage of the name may cover beds of both Early and Late Cretaceous ages, though it was apparently the intent originally to include in the Dakota beds no older than European Cenomanian" (1952: 1028)	Cobban and Reeside, 1952
Cruise Member Gunley Member Huntsman Formation Omadi Formation	1954	M. J. Borling	Kansas?	Cites Charles W. Sternberg & A. J. Crowley unpublished data which divides into Cruise Member, Omadi Formation (lower), Huntsman Formation (middle), & Gunley Member (upper)	Borling, 1954
"Dakota Problem" Dakota Group	1955	Karl M. Waage	General?	Dakota Problem described in detail; stated Dakota Group strictly rock-term & does not imply on age	Waage, 1955

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Omadi Sandstone of the Dakota Group, Cruise Sandstone Member of Omadi Formation of Dakota Group, Huntsman Shale Member of Omadi Formation of Dakota Group, Gurley Sandstone Member of Omadi Formation of Dakota Group	1957	Daniel F. Merriam	Kansas	Subdivided the Dakota in Kansas and introduced the Omadi Sandstone of the Dakota Group, Cruise Sandstone Member of Omadi Formation of Dakota Group, Huntsman Shale Member of Omadi Formation of Dakota Group, and Gurley Sandstone Member of Omadi Formation of Dakota Group rock units instead	Merriam, 1957
Omadi Formation of Dakota Group	1959	Daniel F. Merriam	Kansas	Mainly sandstones, siltstones, shales, clay, conglomerates, and coal	Merriam, 1959
Dakota Formation	1968	Howard G. O'Conner	Kansas	Thickness 200-300 ft in north-central & Western Kansas though lower and upper Cretaceous boundary was not located & therefore placed in Dakota Formation; Dakota described as having lenticular sandstones, siderite pellets, and concretions of iron-oxide near its base	O'Conner, 1968

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Dakota Formation Janssen Clay Member Terra Cotta Clay Member	1975	Paul C. Franks	Kansas	Sediments of Dakota Formation deposited by south flowing streams in prograding alluvial plain & delta complex that grade laterally and vertically into Graneros Shale and states that Terra Cotta and Janssen Clay Members are unmappable	Franks, 1975
"Dakota Problem"	1976	Philip B. King & Helen M. Beikman	Western Interior of the United States	Summarized the "Dakota Problem" as the use of the term Dakota to designate many Cretaceous strata in the Western Interior of the United States	King and Beikman, 1976
Terra Cotta Clay Member, Janssen Clay Member, "D" Sandstone, "J" Sandstone	1989	Vincent J. Hamilton	Kansas	Used Terra Cotta Clay Member, Janssen Clay Member, "D" Sandstone, and "J" Sandstone of Colorado to discuss the Dakota of Kansas	Hamilton, 1989
"J" Unconformity "D" Unconformity Cheyenne- Kiowa Unconformity	1989	Vincent J. Hamilton	Kansas	Lower and upper Cretaceous strata of Cheyenne Sandstone, Kiowa Formation, and Dakota Formation divided into 3 unconformity-bounded sequences Cheyenne-Kiowa, J & D; unconformities traced westward to basin center	Hamilton, 1989

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
"J" Sandstone Huntsman Shale "D" Sandstone	1989	Vincent J. Hamilton	Kansas	Huntsman Shale is between "J" Sandstone & "D" Sandstone	Hamilton, 1989
(strata of type Dakota)	1994	Robert L. Ravn & Brian J. Witzke	General	Noted numerous problems with all previously published type sections in the literature, including not being able to relocate them in the field	Ravn and Witzke, 1994
"Dakota Problem"	1994	Robert L. Ravn & Brian J. Witzke	Eastern Margin of the Cretaceous Western Interior Seaway	Suggested that the Dakota be confined to describe only "a body of rock of eastern provenance, primarily non-marine fluvial to marginal marine deltaic deposits, that were deposited during the transgressive phases of the Greenhorn marine cyclothem" (1994: 72)	Ravn and Witzke, 1994
Dakota Formation Janssen Clay Member Terra Cotta Clay Member CWIS	1998	Robert W. Scott, Paul C. Franks, Michael J. Evetts, James A. Bergen, & Jeffery A. Stein	Cretaceous Western Interior Seaway	Timing of depositional events in the CWIS using chronostratigraphy and biostratigraphy, includes Dakota Formation and Terra Cotta & Janssen Members	Scott, *et. al.*, 1998

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Dakota Formation Kiowa Formation	2000	Robert L. Brenner, Greg A. Ludvigson, Brian J. Witzke, A. N. Zawistoski, E. P. Kvale, Robert L. Ravn, & R. M. Joeckel	Kansas, Nebraska, Iowa, South Dakota	Paleoclimate and paleogeography project that established a temporal framework for Dakota and Kiowa Formations using palynostratigraphy and sedimentology as well as sequence stratigraphy	Brenner, *et. al.*, 2000
Dakota sandstone	2005	Margaret Landis	Kansas, Iowa, Nebraska, and Minnesota	Defined Dakota sandstone as any sandstone of the Dakota Formation, especially if they contain fossils of the historically collected Dakota Flora (see my discussion on pg 16)	This Study
Dakota Formation	2005	Margaret Landis	Kansas	Defined Dakota Formation as both the fossiliferous and non-fossiliferous Cretaceous sediments in Kansas that are older than the Graneros Shale and younger than the Kiowa Formation (see my discussion on pg 16)	This Study

Table 2 (continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
"Dakota Problem"	2005	Margaret Landis	Kansas, Iowa, Nebraska, and Minnesota	Defined "Dakota Problem" as paleobotanists using the historically collected fossil leaf specimens to view the strata as a lithostratigraphic unit; while, stratigraphers view the strata by using modern stratigraphic concepts as an allostratigraphic unit (see my discussion on pg 13)	This Study

Years with an asterisk (*) next to them indicate the source of the information, as some original references have not been relocated. Therefore, the primary references that have not been relocated do not appear in the reference column.

Table 3: Summary of Dakota Flora Descriptions Through Time. Dakota flora descriptions, terminology, and work that pertain to Kansas and this study are highlighted. It is not intended to be a comprehensive list. Publications from 1970 to present often include the Dakota Flora general discussions or specific species from the Dakota Flora that are also in other flora descriptions but are not included here.

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil leaves)	1858	Fielding Brown Meek & Ferdinand Vandiveer Hayden	In hills near Dakota City, Nebraska	First mentioned fossil leaves (in association with Formation #1, mainly in Nebraska)	Meek and Hayden, 1858
(fossil leaves)	1858	Oswald Heer	In hills near Dakota City, Nebraska	Among the first descriptions of paleobotany fossils (Dakota); considered them Miocene in age; no figures	Heer, 1858 in Meek and Hayden, 1858
(fossil leaves)	1858/1859	John Strong Newberry	In hills near Dakota City, Nebraska	Among the first descriptions of paleobotany fossils (Dakota); considered them Cretaceous in age; no figures	Newberry, 1859 but first mention of his involvement in Meek and Hayden, 1858

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(using fossil leaves to determine age)	1858-1864? (1901)	Fielding Brown Meek, Ferdinand Vandiveer Hayden, John Strong Newberry, Leo Lesquereux, Oswald Heer, G. C. Swallow, F. Hawn, & Jules Marcou (Charles N. Gould)	General	Controversy amongst them with many published "letters" concerning age of Dakota based on plant fossils	Gould, 1901
(fossil leaves and some geology)	1866	J. Capellini & Oswald Heer	Nebraska	First publication on paleobotany fossils (Dakota) that included figures and complete descriptions, includes some geology discussion	Capellini and Heer, 1866
(fossil leaves and collecting)	1866 (2001)*	Benjamin Franklin Mudge (Mike Everhart)	Kansas	Collected fossil leaves and invertebrates around Ft. Harker	Everhart, 2001

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil leaves)	1866 (2001)*	Benjamin Franklin Mudge (Mike Everhart)	Kansas	First to note and publish on the leaves in Kansas, though he was unsure of age and provenance	Everhart, 2001
(fossil leaves)	1867 (2001)*	John LeConte (Mike Everhart)	Kansas	Described sandstone around Ft. Harker as containing leaves and indicated that specimens had been collected and sent to Lesquereux to study	Everhart, 2001
(fossil leaves)	1867 (1901)*	C. A. White (Charles N. Gould)	Iowa	Published on fossil leaves from Dakota strata in Iowa	Gould, 1901
(collected specimens of the flora of the Dakota)	1867–1875	Charles H. Sternberg	Primarily Kansas	Main collecting period of Dakota Flora specimens	Sternberg, 1990 (reprint from 1909)
(fossil leaves)	1868	Leo Lesquereux	General?	First publication on angiosperm fossils (Dakota) by primary descriptive worker	Lesquereux, 1868
(fossil leaves)	1868 (1901)*	John Strong Newberry (Charles N. Gould)	General?	Published on new species from Cretaceous, some from Dakota strata	Gould, 1901

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil leaves)	1869	Leo Lesquereux (Charles N. Gould)	Kansas, although publication claims Nebraska	Published on fossil leaves from Fort Ellsworth	Gould, 1901
(fossil leaves)	1870	John Strong Newberry (Charles N. Gould)	Kansas	Published on fossil leaves from Fort Harker	Gould, 1901
(fossil leaves and identifications)	1872 (2001)*	Benjamin Franklin Mudge & Leo Lesquereux (Mike Everhart)	Kansas	Lesquereux visited Mudge and observed new species in leaves collected form Dakota strata	Everhart, 2001
(fossil plants & collecting)	1872	Leo Lesquereux (Mike Everhart)	Kansas	Lesquereux studied plant fossils and where they came from during the summer	Everhart, 2001
(fossil plants & collecting)	1872 (1990 reprint of 1901)* (2001)*	Leo Lesquereux & Charles H. Sternberg (Mike Everhart)	Kansas	Lesquereux and Sternberg met at Ft. Harker and discussed Sternberg's collection of fossil leaves from the Dakota, thereafter Sternberg sent all his plant material to Lesquereux	Lesquereux, 1874 Sternberg, 1990 (reprint from 1909) Everhart, 2001

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil plants)	1874	Leo Lesquereux	Kansas, Nebraska, Iowa, and Minnesota	First comprehensive and detailed survey of plant fossils (Dakota) published	Lesquereux, 1874
(fossil leaves)	1877 (2001)*	Benjamin Franklin Mudge (Mike Everhart)	Kansas	Published on the fossil leaves of Kansas	Everhart, 2001
(fossil leaves prints: Dakota Sandstone)	1877 (2001)*	H. C. Towner (Mike Everhart)	Kansas	Published on leaf prints in Dakota Sandstone	Everhart, 2001
(fossil leaves)	1878 (2001)*	Benjamin Franklin Mudge (Mike Everhart)	Kansas	Published on the cretaceous fossil leaves of Kansas	Everhart, 2001
(fossil leaves)	1881	Charles H. Sternberg	Kansas	Published on the fossil flora of the Cretaceous Dakota Group in Kansas	Sternberg, 1881
(fossil leaves and determining age of strata)	1882 (2001)*	Leo Lesquereux (Mike Everhart)	General?	Can not use flora to obtain age of strata but can compare with other floras of known ages to derive at it; 170 species from Dakota known; compared to other "contemporaneous" floras	Everhart, 2001

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil plants)	1883	Leo Lesquereux	Kansas, Nebraska, Iowa, and Minnesota	Second comprehensive and detailed survey of plant fossils (Dakota) published	Lesquereux, 1883
(fossil plants)	1889 (1901)*	Lester F. Ward (Charles N. Gould)	Kansas & Nebraska	Published on the distribution of fossil plants in Kansas and Nebraska, including those of the Dakota	Gould, 1901
Dakota Flora	1892	Leo Lesquereux	Kansas, Nebraska, Iowa, and Minnesota	This seems to be the first use of the term in an official way; most comprehensive and detailed survey of plant fossils published	Lesquereux, 1892 (posthumously)
(fossil leaves—specific species)	1894 (1901)*	Arthur Hollick (Charles N. Gould)	General	Published detailed look at *Lirophyllum populoides* Lesq. & *Lirodendron alatum* Newb. whose type is from Dakota strata	Gould, 1901
(fossil leaves)	1895	Arthur Hollick	Kansas	Published description of new leaves from the Cretaceous (Dakota Group) of Kansas	Hollick, 1895

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil leaves—specific species)	1897 (1901)*	Lester F. Ward (Charles N. Gould)	Kansas	Published on new species of *Eucalyptus* from Kansas Dakota strata	Gould, 1901
(fossil leaves & collecting)	1897–1898	Charles N. Gould & Lester F. Ward	Kansas	Collected fossil leaves in Kansas from Dakota strata that reside (in 1901 at least) in the University of Nebraska museum	Gould, 1901
(fossil leaves & collecting)	1899	Charles N. Gould	Nebraska	Collected fossil leaves in Nebraska from Dakota strata that reside (in 1901 at least) in the University of Nebraska museum	Gould, 1901
(fossil leaves)	1899	Francis Huntington Snow	General	Published on the discovery and significance of stipules in leaves of the Dakota strata	Snow, 1889
(fossil plants)	1898	John S. Newberry	General	Additional large-scale survey of plant fossils (Dakota) by another describer	Newberry, 1898 (posthumously)

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(fossil flower & fossil fruit)	1903	Arthur Hollick	Kansas	Described and published on a fossil petal (the first and only discovered so far?) and fruit from the Cretaceous (Dakota Group) of Kansas	Hollick, 1903
(fossil leaves)	1918	E. M. Gress	General	Presented critical study of fossil leaves from the Dakota Sandstone at Geological Society of America meeting	Gress, 1918
Dakota Flora specimens	1922	E. M. Gress	General	Created and published an annotated list of the fossil plants of the Dakota Formation in the collections at the Carnegie Museum, that included descriptions of new species	Gress, 1922
(fossil plants)	1925	A. C. Noe	Oklahoma	Described and published about Dakota Sandstone plants from Cimarron County, Oklahoma	Noe, 1925

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
Dakota Flora specimens	1954	Robert W. Baxter	General	Cataloged and published all Dakota Sandstone Flora specimens in University of Kansas collection of fossil plants	Baxter, 1954
(megaspores)	1963	John W. Hall	Iowa	Described/Published on megaspores and other fossils in the Dakota Formation	Hall, 1963
(expanding Dakota Flora)	1971	Samuel R. Rushforth	Utah	Described/published on flora from the Dakota Sandstone Formation near Westwater, Grand County, Utah	Rushforth, 1971
(specific species)	1981	Gregory J. Retallack & David L. Dilcher	General?	Described/published on *Prisca reynoldsii* gen. et. sp. nov.—an early angiosperm reproductive material	Retallack and Dilcher, 1981
(specific species)	1984	David L. Dilcher & Peter R. Crane	General?	Published detailed look at *Archaeanthus* from Dakota strata	Dilcher and Crane, 1984
(specific species)	1984	David L. Dilcher & Peter R. Crane	General?	Published detailed look at *Lesqueria*—an early angiosperm fruiting axis	Crane and Dilcher, 1984

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(problems with historically described fossil flora)	1986	Robert Nathan Schwarzwalder Jr.	General	Stated that historically described specimens were incorrectly done, including those for the Dakota Flora	Schwarzwalder, 1986
(miospores & depositional environments)	1986	Martin Birtell Farley & David L. Dilcher	Kansas & Nebraska	Correlated miospores and depositional environments of the Dakota Formation	Farley and Dilcher, 1986
(Dakota flora diversity)	1988	Scott Lidgard & Peter Crane	General	Did not include the Dakota Flora in their diversity study because of anomalies with contemporaneous (Cretaceous) floras	Lidgard and Crane, 1988
(fossil leaves)	1990	Garland R Upchurch Jr. & David L. Dilcher	Nebraska	Described/Published on fossil angiosperm leaves from Dakota Formation in Jefferson County, Nebraska – Rose Creek Locality	Upchurch and Dilcher, 1990
Dakota Flora/(fossil plants)	1994	Judith E. Skog & David L. Dilcher	Kansas & Nebraska	Described/published on the lower vascular plants of the Dakota Formation in Kansas and Nebraska	Skog and Dilcher, 1994
Dakota Flora specimens	2000	Tim Northcutt	General	Showed that some Dakota Flora type specimens were lost	Northcutt, 2000

Table 3 (Continued)

Dakota Term	Year	By Whom	Where	Description	Literature Reference
(Dakota flora diversity and leaf fossils)	2002	Hongshan Wang	Kansas, Nebraska, and Minnesota	Found an angiosperm diversity of about 20-25 species per Dakota floral locality for modern collection sites	Wang, 2002
Sediments containing Dakota Flora	2005	Margaret Landis	Kansas, Iowa, Nebraska, and Minnesota	Defined Dakota sandstone as any sandstone of the Dakota Formation, especially if they contain fossils of the historically collected Dakota Flora (discussion on pg 16)	This Study

Years with an asterisk (*) next to them indicate the source of the information, as some original references have not been relocated. Therefore, the primary references that have not been relocated do not appear in the reference column.

The most notable among these early investigators were Meek (Meek and Hayden, 1858, 1862), Hayden (Meek and Hayden, 1858, 1862), C. H. Sternberg (1990 reprint of 1909 original), Heer (Capellini and Heer, 1866; Heer, 1858), Newberry (Meek and Hayden, 1858; Newberry, 1898), and Lesquereux (1874a; 1883; 1892 posthumously). Meek and Hayden did the primary fieldwork and originally named the formation, while C. H. Sternberg was the major collector, especially of fossiliferous nodules. The early floristic determinations were made by Newberry (1859), Heer (1858), and Lesquereux (1874a). Lesquereux published not only the early, but also the majority, of the monographic studies of Dakota Flora (1892), especially those from sediments of the Dakota Sandstone.

Previous Dakota Flora Investigations

Lewis and Clark first saw the sandstones of the Dakota in 1804. It was not until 1858, when Meek, Hayden, Newberry, and Heer mentioned finding fossil leaves in "Formation #1" strata, mainly in Nebraska. However, the most comprehensive and detailed surveys of these fossils were published by Lesquereux (1874a; 1883; 1892) describing 437 angiosperm species mainly from Dakota sandstone exposed in Kansas. Swineford (1947: 61) stated, "The resistant, most conspicuous beds of the Dakota are the dark-brown sandstone cemented with iron oxide which cap the hills and produce the irregular topography so common in the Dakota outcrop area." Swineford (1947) suggested it was this irregular topography and sandstone outcrop style that gave rise to the surficial material that was collected to provide the basis for the studies of Dakota Flora (Figures 2 and 3).

In all probability, the angiosperm leaf impressions were preserved in the case-hardened Dakota sandstone nodules that weathered out of the surrounding rocks. It appears that the fossil-bearing nodules were strewn about the surface in such a manner that anyone who passed by could gather them by the hundreds. Several specimens in museums possess evidence of having had lichens growing on them. The nodules were well indurated, which allowed them to be shipped easily with minimal damage.

Early Collection of the Dakota Flora

C. H. Sternberg collected most of the Dakota fossil leaf specimens, especially those in sandstone, distributed them to museums during the late 1800s. He claimed the years 1867–1875 as the main collecting times for Dakota sandstone. He revisited the collection sites later in his life (as did his sons who were also well-known collectors), doing some minor collecting (Rodgers, 1999; Sternberg, 1990). Just before this time, C. H. Sternberg traveled in Ellsworth County to deliver food to Fort Harker from his family farm (see "Processing Location of Fort Harker" on page 111, for specific location of Fort Harker and "Processing Location of Sternberg Ranch" on page 113, for specific location of Sternberg Ranch).

Figure 2: Relationship of Central Kansas Terrain to Generalized Surface Geology. The enhanced shaded relief map depicts the relation of the Dakota Formation (green color) to the surrounding generalized geology (strata below the Dakota are a pink color while strata above the Dakota are a brown color) and sediments (tan color). Lakes/reservoirs are depicted as a blue color. Created from NED and surficial geology GIS datasets downloaded from DASC.

Figure 3: Dakota-capped Hills in Central Kansas. Dakota Formation sandstone outcrops along the hilltops in Central Kansas as viewed in the field.

During these travels, he observed the geology around him and began collecting some nodules. Because of his early successes in locating fossils, Sternberg mainly made surface collections of Dakota leaf fossils (Figure 4).

Figure 4: Charles H. Sternberg at Sassafras Hollow. C. H. Sternberg and his sons collected some Dakota Flora specimens from this collection site thought to be in Central Kansas. Figure from (Rodgers, 1999: 21).

C. H. Sternberg's Dakota Flora collections appear to have come entirely from localities and collection sites in Kansas. These Kansas localities include, but are not limited to Ellsworth County, Fort Harker, Churchill, Sassafras Hollow, and Thompson Creek. The collections he made were occasionally given to friends or more often were sold and distributed to museums worldwide. The railroad, which had just been built through Kansas in the 1800s, provided a ready means for shipping thousands of the Dakota sandstone leaf fossils to researchers and purchasing museums worldwide. Today, major Sternberg collections of Dakota Flora reside at The University of Kansas Natural History Museum (KU NHM), The Sternberg Museum of Natural History (Sternberg Museum), The Natural History Museum of the Smithsonian Institute

(Smithsonian), and at Cambridge Museum of Comparative Zoology (Cambridge Museum) at Harvard University (Harvard); as well as other famous and not-so-famous museums.

Lesser-known collectors obtained the specimens on record from other localities in Kansas and in other States. All these collected specimens provided the basis for the early studies on the Dakota Flora.

Early Studies of Dakota Flora

Heer (1858) was among the first to describe the fossil leaves from the Dakota strata, after Meek and Hayden sent sketches to him to determine the age of the specimens. Meek and Hayden also sent Newberry duplicate sketches to examine. In 1858, Heer responded to Meek and Hayden stating that he believed the specimens to be Miocene in age because of their angiosperm nature (Meek and Hayden, 1858). This response contradicted Meek and Hayden's ideas as well as those given by Newberry (Meek and Hayden, 1858). This was just the beginning of Heer's involvement in Dakota Flora studies and age debates. In the next few years there were published "notes" in various journals (though most were in *The American Journal of Science*) by Heer, Newberry, or one of their supporters (including Lesquereux) offering criticism of both sides of the age debates (Lesquereux, 1859; Meek and Hayden, 1858; Newberry, 1859, 1860a, 1860b). However, Capellini published along with Heer the first full paleobotanical analyses of fossil leaves (including figures) found in the Nebraska type area in 1866, where they state that the Dakota Flora was Cretaceous in age.

Newberry (1858 with Meek and Hayden, though 1859 himself) was an early describer of leaves from the Dakota strata because Meek and Hayden did eventually send their drawings and fieldnotes to him as well. Based on the sketches and fieldnotes, he agreed that the age must be Cretaceous just as Meek and Hayden claimed. Most of his descriptions are included in his *Later Extinct Cretaceous Floras* publication, which was not completed and published until much later (Gress, 1922; Newberry, 1898). However, Newberry kept a stake in the age debates at least until 1868.

Lesquereux is perhaps the most famous of the investigators of the Dakota Flora albeit not the first, though he first published on the Dakota Flora in the American Journal of Science in 1868. After that, he worked for the USGS (formerly the United States Geological and Geographical Survey) from 1870 to 1889 where he published major monographs (1874a; 1883; 1892 posthumously) of detailed Dakota sandstone descriptions and illustrations, describing 437 angiosperm species. His *Cretaceous Floras* of 1874 and *Dakota Flora* of 1892 were the most famous. C. H. Sternberg collected the majority of the specimens of fossil angiosperm leaves from the Dakota sandstone that Lesquereux described in preparing the well-known monographic works (1874a; 1883; 1892) on the Dakota Flora.

The Dakota Flora Itself

The mid-Cretaceous record is well represented by a number of well-known floras (Lidgard and Crane, 1988). Most Cretaceous fossil localities contain about 15–20 angiosperm species, with the notable exception of the Dakota Flora's single well-defined geographic area. As published by Lesquereux (1874a; 1883; 1892), the Dakota Flora when treated as single well-defined geographic area is composed of 460 species of vascular plants, of which 437 are angiosperms. Recently published studies of early Cretaceous angiosperm diversity (Lidgard and Crane, 1988) have excluded the historical data of the Dakota Flora diversity compiled by Lesquereux (1874a; 1883; 1892). Lesquereux's 437 species of angiosperms exhibit an unusually greater diversity compared to contemporaneous Cretaceous diversities of 20–25 species from other localities (Lidgard and Crane, 1988; Upchurch and Dilcher, 1990) (Figure 5). Lidgard and Crane (1988) stated that they excluded the flora of the Dakota from their inventory because they considered this flora anomalous. However, they implied that if more was understood about the Dakota Flora and a reexamination of morphology and systematics of angiosperm leaf megafossils from the Dakota was undertaken it could be included in a future study.

Interpretations of Dakota Flora diversity in recent years have varied dramatically from those of the last century as expressed by many workers (Upchurch and Dilcher, 1990).

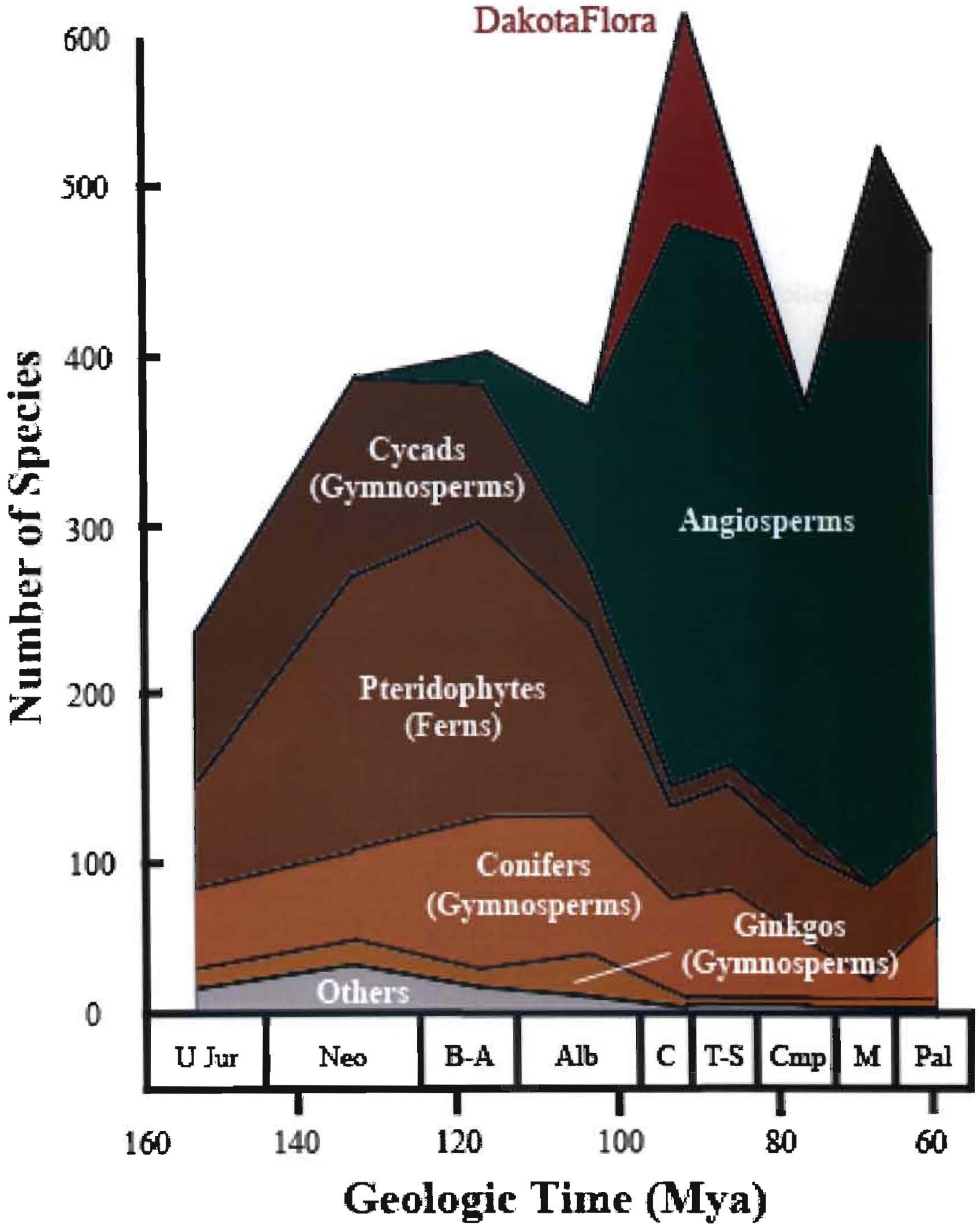

Figure 5: Number of Documented Species in the Mesozoic. Number of plant species over time (each interval has been averaged and plotted as a point) showing how the Dakota Flora (as described by Lesquereux) is anomalous in relationship to data obtained from other fossil floras. Graph derived from (Lidgard and Crane, 1988; Wang, 2002).

Some effort has been made to assess diversity variation among different collection sites of the Dakota Formation (Farley and Dilcher, 1986; Kovach and Dilcher, 1988; Skog and Dilcher, 1994; Wang, 2002). However, an all-inclusive evaluation of the flora as contained in Lesquereux's monographs (1874a; 1883; 1892) has yet to be completed and published on the individual collection sites within the single well-defined geographic area comparing such diversity variation among the individual collection sites, especially those historically collected sites that contained Lesquereux's type specimens in the late 1800s.

Dakota Stratigraphy

The Dakota Formation and its stratigraphic equivalents are well-known in the Western Interior of the United States. Meek and Hayden (1862: 419) described the "Dakota Group" in the "hills back of the town Dakota [City]" in Dakota County, Nebraska, after originally referring to it as Formation #1 in 1858 (pg 269). Since that time, similar basal Cretaceous strata have been described in Nebraska, Iowa, Kansas, Minnesota, Oklahoma, North Dakota, South Dakota, Texas, Colorado, New Mexico, Arizona, Utah, Wyoming, Montana, and parts of Canada (Figure 6).

The Dakota strata were deposited mainly during the transgressive phase of the Greenhorn cycle in the Cretaceous Western Interior Seaway that covered a large part of the Western United States and Canada (Hattin, *et. al.*, 1987) (Figure 1).

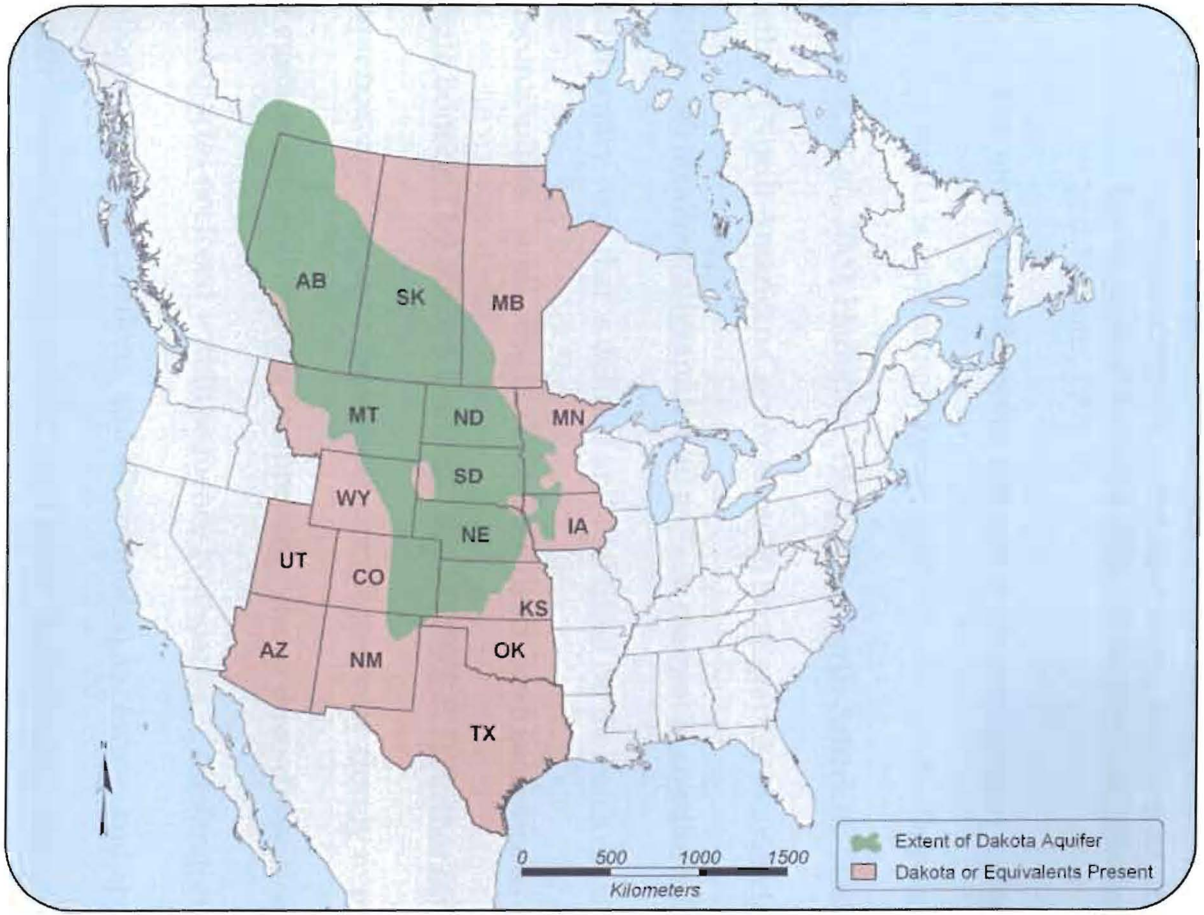

Figure 6: States and Providences Containing Dakota Formation or Correlated Cretaceous Strata. The mauve-shaded 14 States (AZ=Arizona, CO=Colorado, IA=Iowa, KS=Kansas, MN=Minnesota, MT=Montana, ND=North Dakota, NE=Nebraska, NM=New Mexico, OK=Oklahoma, SD=South Dakota, TX=Texas, UT=Utah, WY=Wyoming) and 3 providences (AB=Alberta, MB=Manitoba, SK=Saskatchewan) containing strata supposedly assigned to the Dakota. However, in modern studies the supposed strata are not currently referred to Dakota strata, but rather contemporaneous with the Dakota strata.

Dakota strata were:

> "Deposits formed along the margin of seaways record the complex interactions of uplift, subsidence, sediment influx, distributary systems, tides, currents, and eustacy, as well as diverse biological assemblages. It is for this reason that depositional environments and correlation along marine margins can be among the most difficult to interpret" (Eaton and Nations, 1991: 1).

The modern stratigraphic concept of allostratigraphy using unconformity-bounded strata is increasingly being used to correlate the Dakota Formation (Brenner, *et. al.*, 2000; Hamilton, 1994). The North American Stratigraphic Code defines (North American Commission on Stratigraphic Nomenclature, 1983: Article 58) an allostratigraphic unit as "...a mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities," while Boggs (1995: 490) describes a sequence as "packages of strata bounded by unconformities." Boggs (1995: 515) further states that sequences are "largely a theoretical concept tied very closely to the assumption of eustatic sea-level changes" comprising "major three-dimensional assemblages of lithofacies enclosed within sequence boundaries." Allostratigraphic units (allogroups, alloformations, and allomembers) are formal and appear in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983) while sequence stratigraphy classifications (depositional sequence, type 1 sequence boundaries, type 2 sequence boundaries, depositional systems, system tracts, parasequences sets, parasequences, and marine-flooding surfaces) do not appear in the North American Stratigraphic Code and therefore are not formal. However, allostratigraphic units and sequences are both unconformity-bounded (Miall, 1996).

This is important with respect to the Dakota because the formation is currently defined lithostratigraphically instead of allostratigraphically even though most recent stratigraphic interpretations have considered the Dakota as an unconformity-bounded alloformation (Hamilton, 1989). The allostratigraphic interpretation of the Dakota works well for regional-scale correlation but can present problems for locating or describing specific fossil collection sites. The sequence of events that deposited multiple sandstones, shales, and siltstones that resulted from different stands of the CWIS can be difficult to correlate in the field. Bounding-unconformities are not always visible and facies changes can be subtle.

Stratigraphic Description of the Dakota Formation

The Dakota Formation "consists of marine to non-marine interbedded sandstones and shales that were deposited on floodplains and areas adjacent to the Cretaceous Western Interior Seaway shoreline between 94 and 112 million years ago" (Macfarlane, *et. al.*, 1989a: xiv).

Originally Meek and Hayden's "Dakota Group" was a stratigraphic unit described mainly on its lithology, although they did indicate the presence of fossils and delineated those they had found to be present. Meek and Hayden's description (1862: 419) was "yellowish, reddish, and occasionally white sandstone with rather thick beds with interstratified alterations of various yellow and ash-colored beds and seams of impure lignite. Also, silicified wood, and great numbers of leaves of higher types of dicotyledonous trees," plus they list several genera of brachiopods.

Meek and Hayden did not designate a formal type section for their Dakota Group as would have been required today for a formal stratigraphic unit (North American Commission on Stratigraphic Nomenclature, 1983; Salvador, 1994). Their nebulous type area in the hills of Dakota County, Nebraska is unsatisfying and unworkable for today's stratigraphic studies. Use of the description of the Dakota strata based on Tester's description of a type locality where he described multiple "type sections" around Sioux City, Iowa is most common (1931). In 1943 Condra and Reed designated the first formal type section as would be required compared to current stratigraphic standards of Dakota strata such that a precise locality for reference purposes was established. Even as late as 1994, Ravn and Witzke noted major problems with all the previously defined type areas used in stratigraphic studies of Dakota strata. The biggest problem with previously described type localities that Ravn and Witzke (1994) noted was their inability to accurately relocate them in the field such that the type localities' sediments could be compared with other supposed Dakota strata to verify that the supposed strata is indeed Dakota. According to Macfarlane and other workers (Brenner, *et. al.*, 2000; Hamilton, 1994; Personal Communication

Macfarlane, 2005) today unconformity-bounded sequences can be correlated from northwest Iowa to the Front Range in Colorado using cores and borehole geophysical logs (Figures 7 and 8). The current interpretation of the correlation of stratigraphic units and sequences from the east flank of the Denver basin to the Kansas outcrop belt is based more on the Dakota Formation being treated as an allostratigraphic unit than as a lithostratigraphic unit (Personal Communication Macfarlane, 2005). The Dakota Formation/Graneros Shale contact is a transgressive disconformity, whereas the lower boundary is located at the SB3 sequence boundary of Hamilton (Brenner, *et. al.*, 2000; Hamilton, 1994) or the D1 boundary of Brenner *et al.* (Brenner, *et. al.*, 2000; Hamilton, 1994), as seen in Figure 8.

The "Dakota Problem" As It Pertains To Stratigraphy

A sequence stratigraphic interpretation for the Dakota Formation can be problematic for the paleontologists and paleobotanists currently collecting and analyzing Dakota specimens. Paleontologists and paleobotanists working in the field would like a simple "classic layer cake stratigraphy" explanation to correlate strata and describe where the fossil specimens are from. Describing the individual beds producing fossils in the field is straightforward in instance of "classic layer cake stratigraphy." Unfortunately, the strata that make up the Dakota Formation are not conducive to such a simple explanation.

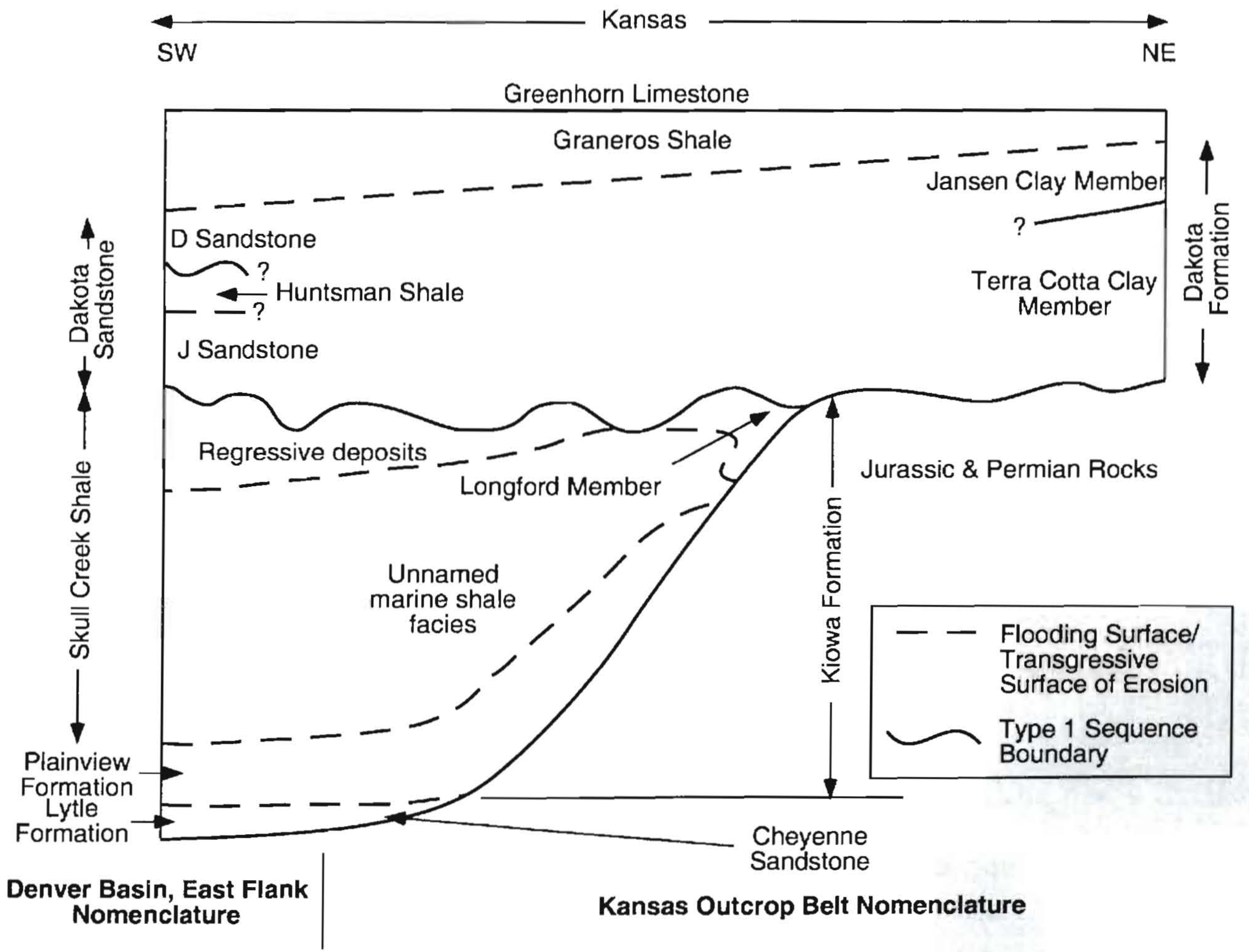

Figure 7: Cross-section of Western Kansas Cretaceous Strata. Western Kansas Cretaceous stratigraphic relationships are depicted in this cross-section illustrating the location of the unconformities. Figure from (Personal Communication Macfarlane, 2005).

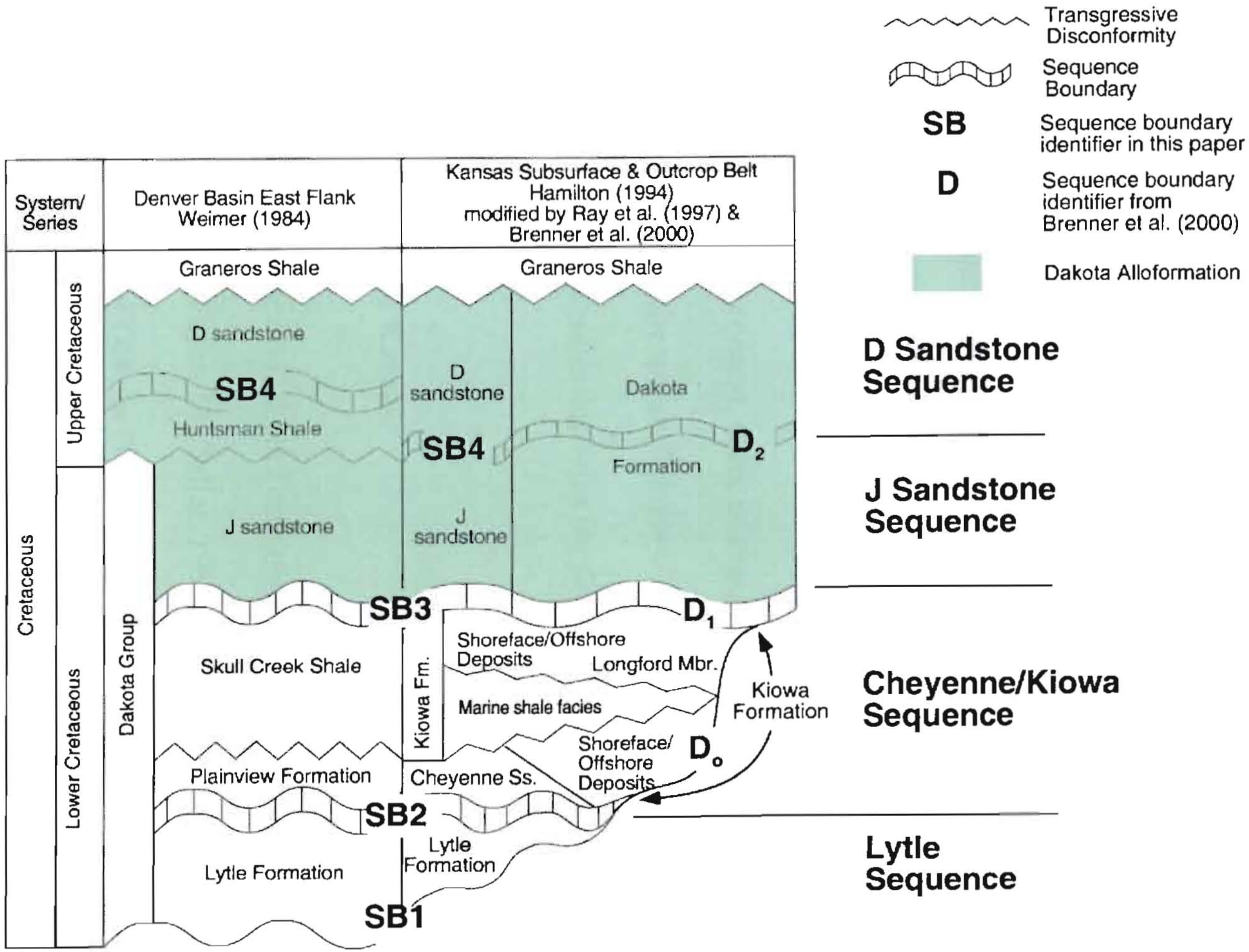

Figure 8: Correlation of Denver Basin strata to Kansas Outcrops. Cross-section illustrating the current interpretation of correlation of stratigraphic units and sequences from the east flank of the Denver basin to the Kansas outcrop belt. Figure derived from (Personal Communication Macfarlane, 2005).

The Dakota strata can be problematic when the units are defined/bounded by unconformities that cannot be easily seen in the field and where the units are spatially-variable/time-transgressive. Additionally, the allostratigraphic unit concept is not well-understood by all researchers and does not provide easily describable stratigraphic context for collected specimens or specimen collecting. Stratigraphic interpretations of the Dakota are further complicated by the fact that the Dakota contains multiple packages of fluvial cut and fill sediments with a complex hierarchy of bounding surfaces (Miall, 1996). Lateral tracing of lithologies along outcrops as per Walther's Law is therefore not possible over long distances. In this context, there is a need for greater understanding of correlation methods appropriate for use with allostratigraphic units to better correlate Dakota fossil collection sites for fieldwork and paleoenvironmental interpretations.

The Dakota in Central Kansas

In Kansas, the term Dakota Formation includes the Janssen and Terra Cotta Clay Members (Figure 9) (Zeller, 1968), although other correlations (Figures 7 and 8) of the Dakota Formation are based on subdividing the unit into the D Sandstone and the J Sandstone (terms originally applied in the Denver basin) (Personal Communication Macfarlane, 2005). The Dakota Formation in Kansas is typically 200-300 feet (61.0-91.4 meters) thick in the subsurface (Macfarlane, *et. al.*, 1989a).

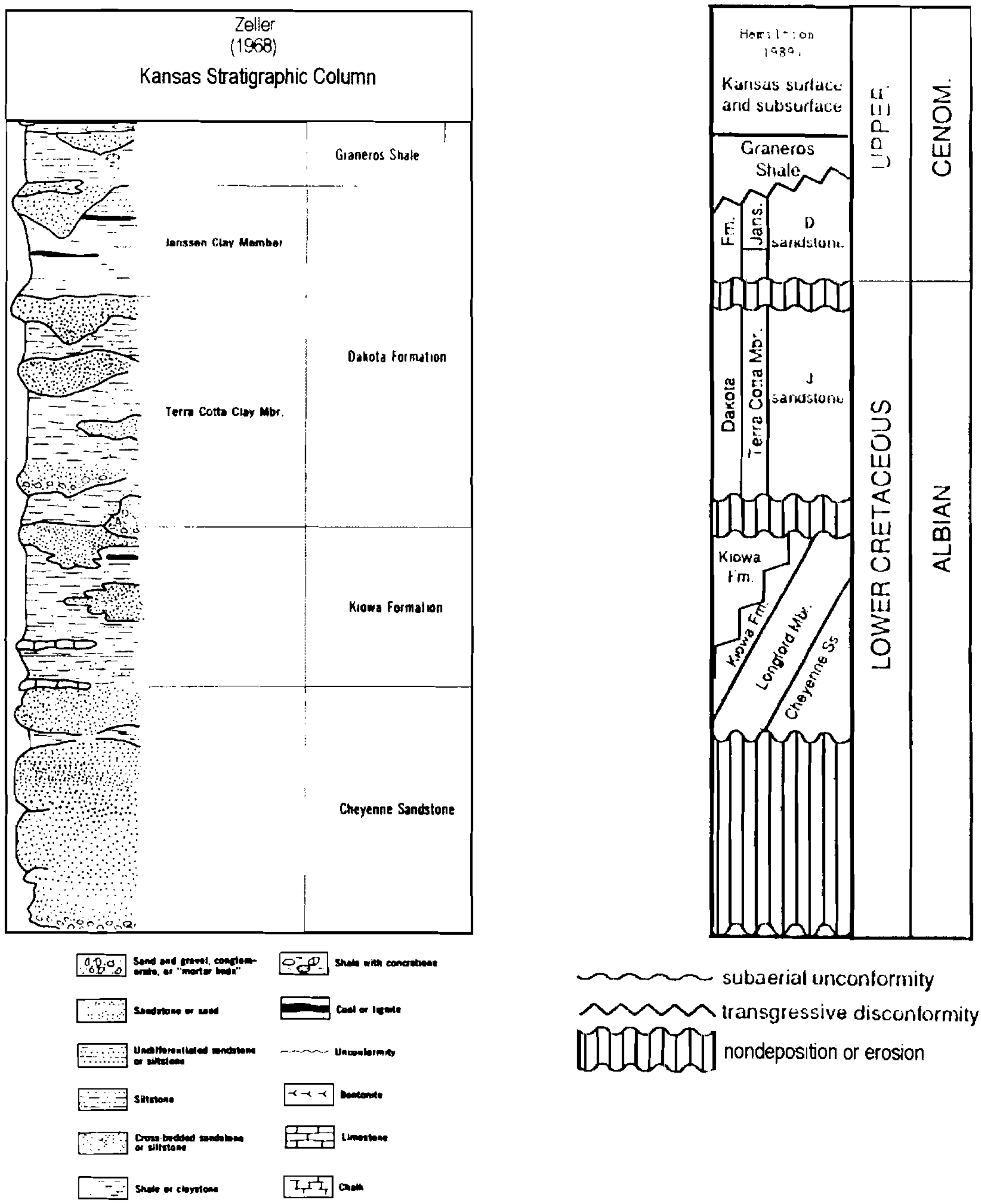

Figure 9: Kansas Lower Cretaceous Stratigraphic Columns. Lithostratigraphy on the left modified from Zeller (1968: Plate 1) and sequence stratigraphy on the right modified from Hamilton (1989: 6).

The Dakota Formation outcrop belt extends northeast to southwest across Central Kansas. Many of the most prominent natural outcrops of the Dakota strata are the more resistant and conspicuous sandstones (Figure 3), although shales and claystones are present as outcrops (Figure 10). Overall, the Dakota Formation is only approximately 30 percent sandstone with shales and claystones comprising the remainder—70 percent (Personal Communication Macfarlane, 2005).

Figure 10: Dakota Formation Outcrop in Central Kansas. Dakota Formation outcrop showing that the shales and claystones are part of the Dakota Formation strata exposed at the surface in Central Kansas as viewed in the field. However, even here the shales and claystones are capped with sandstone that is more weather resistant.

The thicker sandstone bodies are thought to be fluvial channel deposits formed in lower coastal plain and shoreface environments. The age of the

Dakota Formation strata in central Kansas is Albian to early Cenomanian (Personal Communication Macfarlane, 2005).

Error Sources in Determining Historical Specimen Collection Localities

In paleontology location of the fossils and the rocks containing those fossils, is important in determining such factors as depositional environment, paleoclimatic conditions, correlation, and age. The location incorporates both vertical (stratigraphic) and horizontal (geographic) positions and is increasingly being examined using GIS to compare spatial characteristics of formations and fossils. In GIS, the spatial component of data is essential to the comparisons of locations inherent in spatial analyses. Errors in the spatial component of data include locational accuracy and resolution as well as problems caused by missing or partial data. These errors can be generally categorized as coming from either the inadequacies of existing data or the conversion process from site descriptions to geographic coordinates necessary for GIS analysis.

Locational Errors

Several different types of errors affect the accuracy of spatial data derived from museum collections information and published research. These errors are a function of inconsistencies in collection, recording, and analyses of locational data through time. Furthermore, often more than one person collects spatial location data. Equipment, techniques, and methods are constantly improving the accuracy and precision of the spatial data.

Fossil collections, collection site descriptions, and field notes contain valuable, but difficult to use information for determining geographic location. Because these data sources must be used to determine specimen collection location, the inherent nature of the data, its storage medium, and its potential sources of error needs to be understood. It should be noted that for all data types involved, the media has degraded over time. Typically, the paper on which the data has been recorded has yellowed and become fragile with age. This increases potential errors in the locality information, because spatial data are deteriorating and often incomplete and difficult to read or cannot be acquired.

General Problems with Historical Data & Previous Studies

Historical data and/or data from previous studies contain errors and inaccuracies that can enter into subsequent research especially if the data have a spatial context. These errors are associated with the techniques, technologies, theories, and resources in use at the time the data were collected. Oftentimes the precision of such information is limited because landmarks have been modified or removed since the time of they were referenced. Additionally, previous studies may or may not have been readily available at the time that then current studies were being carried out; even now not all Dakota studies can be easily located for consultation.

Much early work has been lost, or purposefully overlooked because of professional rivalries between researchers and collectors (Mulder, 2005; Nudds and Palmer, 1990). In addition, the geographic extent of referenced cities, towns, *etc.* has often increased or decreased in size, changed names, or completely disappeared. This situation usually is most noticeable in the descriptions associated with fossil collection sites.

General Problems with Fossil Collections

Both historical and present day fossil collections do not always contain information about the collection sites. Even when collection site information is provided, it may not be sufficiently specific to relocate the collection site. Some of the more common reasons for this insufficiency are listed here. Fossils were and continue to be a commodity for sale. Therefore, specifics were not divulged to preserve the location for future collection and sales. Fossil collection sites sometimes include descriptions by local individuals using the local or non-standard place names that do not appear on published maps. Additionally, the same name may have been applied to more than one physiographic feature, often resulting in multiple features with the same name (*i.e.,* Spring Creek could refer to multiple streams in a single county—the problem multiples when the geographical extent is expanded in scale). Sometimes only generalized locations were recalled at the time the collection site information was recorded for a specimen by a collector and/or museum curator. The recollection of only generalized locations when collection site information was recorded seems to be an especially troublesome problem if the limited collection site information of specimen labels found on historical and modern fossils is any indication.

Further complications are introduced because not all fossil collections of scientific importance are housed in museums and the curatorial conditions under which each collection is maintained may vary considerably in quality or ease of access. These curatorial conditions may also influence the ability of researchers to visit and/or work with the collections and the extent to which fossil collection site spatial data can be useful. Each specimen label and specimen often needs to be scrutinized for proper locality information.

General Problems with Collection Site Descriptions

Collection site descriptions have their own spatial data problems. Collection site descriptions, while possibly from a single visit by a researcher to a location, have increasingly been written by multiple researchers, following multiple visits. Therefore, a temporal component has often been added to spatial data describing a location description that has not always been acknowledged. Furthermore, the locations of collection sites and landmarks have been taken for granted by those familiar with the area and/or formation. Therefore, the area has not often been described sufficiently for those who are unfamiliar with it to ascertain that they have indeed relocated the same collection site if found. Rowe and Jones (1999: 5) discussed locating and collecting techniques in paleobotany and stated, "recognition of exposures can be difficult in certain sites" because of soil and/or vegetation cover. While this is true primarily for the modern paleontological collection sites they were discussing, it is even more of a problem when attempting to relocate historical paleontological collection sites. Even if a typical description of a field location contained compass bearings, descriptions of conspicuous landmarks, and photographs, they are often not as useful as one might expect or hope for when attempting to utilize them for collection site relocation (Rowe and Jones, 1999).

General Problems with Fieldnotes

Notes taken in the field provide documentation of activities or observations made by the writer. However, the level of detail captured in the field notes and the level of description will vary from one scientist to another. Unfortunately, when the scientist retires or dies the retrieval of field notebooks may be difficult or impossible if they have not been properly archived in a secure location. If field notes are archived, they may be kept confidential for a variety of reasons. If the field notes are available for historical studies, the handwriting and abbreviations must be deciphered and transcribed into usable formats. This process usually adds inaccuracies to the original data.

Combined Errors in Locational Data

Early explorers had surveying devices and used ground survey techniques that were very similar to those we have today (DeMers, 2000). The early techniques relied on references to local landmarks. These landmarks were often not permanent and or accurately located. Therefore, a significant reinterpretation must be done to tease out the historical fossil collection sites information.

Chapter 2: Methods

General Methods

Although 130 years have transpired since the collection of many of the Dakota Flora specimens, individual collection site descriptions have traditionally been lumped into a Dakota Flora single well-defined geographic area concept. For the Dakota Flora to be useful to the geologists and paleontologists the individual collection sites need to be relocated and the specimens appropriately assigned to them. It is hypothesized that the use of GIS, when combined with individual collection site descriptions acquired from historical specimens, specimen labels, and publications will allow the historical collection sites to be locatable in the present day and aid in the accuracy of their position.

To approach this historical and paleontological study in a geographic context, while still paying attention to the geology, a variety of methods were applied. These methods included curatorial, archival, field, and GIS components. The curatorial components included visiting museums and their fossil collections to view specimens. This facilitates collection of specific collection site descriptions from specimen labels and allows searching for publications and other data sources within the museum that might contain specific collection site descriptions. The archival components involved searching out as many of the various publications and other data sources as possible before combining these data with museum information into a summary to ensure that much of the historical background of the Dakota strata and flora as possible was known. Used together, these historical and modern record components lead to documenting many of the locations of Dakota Flora collection sites. The collection site descriptions then were transformed into spatial data for use in GIS analysis that utilized other existing GIS datasets to help relocate fossil collection sites.

Museum and Library Data Sources

This project involved collecting data from many museums and libraries including:

1. The Johnston Geology Museum (JGM) and William Allen White Library (WAW Library) located at Emporia State University (ESU) in Emporia, KS.
2. The Natural History Museum and Biodiversity Research Center (KU NHM) and the Anschutz Science Library (Anschutz Library) located at the University of Kansas (KU) in Lawrence, KS.
3. The Sternberg Museum of Natural History (Sternberg Museum or SMNH) located at Fort Hayes State University (FHSU) in Hays, KS.

4. The Florida Museum of Natural History (FLMNH) and The George A. Smathers Library (Smathers Library) located at the University of Florida (UF) in Gainesville, FL.

A variety of media from these libraries and museums were consulted, copied, photographed, and studied including historical and modern specimen labels, museum documentation, monographs, journal articles, books, maps, and photographs.

Museum Sources

The museum sources mainly consisted of the specimen labels and museum documentation; however, occasionally maps, photographs, or other publications were also found. Specimen labels included a combination of paper labels in the specimen boxes, those written directly on the specimen, and stickers on the specimens (Figures 11 and 12). Museum documentation included the logbooks of the collections, catalogues of the collections, any computerized or databased information, and file folders of publications or collection sites that contained locality descriptions associated with the collections. The maps and photographs were located in the file folders containing publications or collection site and locality descriptions associated with the collections and/or the computerized information for the collections.

Figure 11: Historical Specimen Paper Label. Historical specimen label glued to the back of FLMNH specimen number UF 15743 #1 photograph showing how deteriorated some historical specimens get.

Figure 12: Historical Specimen with Written-on Specimen Labels. FLMNH specimen number UF 18466-25781 photograph showing painted-on modern and historical specimen numbers, along with a historical sticker label of additional numbers. The modern specimen number label reads "UF 18466-25781." The prior specimen number reads "IU 185." The label on the historical sticker reads "1264" (over the line) and "8.6B" (below the line).

Library Sources

The library resources supplied monographs, journal articles, books, maps, and photographs. These resources came from a variety of historical publications. Many were only a page or chapter from various places within a library's holdings. Anschutz Library and Smathers Library are science libraries; however, the WAW Library is not. Surprisingly, the WAW Library had resources that were difficult or impossible to obtain from the others mostly because of the direct accessibility of the materials by the library user.

In addition to the libraries, both personal reprint collections and reading rooms were accessed, which supplied additional notes and publications. Included were:

1. Dr. David L. Dilcher's personal collection of reprints (Dilcher is curator of Paleobotany and professor of Geological Sciences and Botany at UF) housed in the FLMNH.
2. John Hall's reprint collection (Hall was a professor of Biological Sciences at the University of Minnesota) housed in the FLMNH in the Paleobotany Collections.
3. The Earth Science Reading Room materials located in the Earth Science Department at ESU.

4. A portion of Dr. Gilbert A. Leisman's personal collection of reprints (Leisman was a well-respected paleobotanist and professor of Biological Sciences at ESU) housed in the JGM.

Much useful information was available in the Earth Science Reading Room from the extensive publications on Kansas geology that date back to the 1800s. These resources had, as an added benefit to the actual publications, underlined or highlighted text, and even occasionally notes in the margins pertaining to the Dakota.

Library Literature Mining

Library research is often challenging and time consuming. When research requires historical data and background, additional complications materialize. Abundant literature about the Dakota strata and flora reaches back into the late 1800s. An intensive and often unconventional search strategy is needed to follow the tracks and clues through the libraries to the gems buried within the literature. Often, "each academic discipline has its own body of literature and its own peculiar way of looking at the set of problems it chooses to investigate" (Durrenberger, 1971: v). Scientists, "in studying the facts of spatial distributions and space relations of the Earth's surface, are engaged in data-gathering and classification and in developing theories which will contribute to their understanding" (Durrenberger, 1971: 20). Knowledge of these unconventional search strategy methods is important; however, it usually requires new eyes and creative methods to shed new light on old research because often library research skills are established early on and not updated as researchers progress in their career (Brown, 1995; D'Aniello, 1993; Durrenberger, 1971; Frick, 1995; Kronick and Winters, 1985; Mann, 1998; Martinson, 1972).

Each researcher makes their own decisions about how pertinent each piece of literature is for their research. "When reviewing the literature, therefore, most scholars subject it to a rigorous winnowing but recognize that they must still look at all items that appear pertinent" (D'Aniello, 1993: 56). However, as Mann (1998) points out, often not all resources are located. He says this is because the only sources usually consulted are those easily determined through electronic indexes and bibliographies, footnotes, and colleagues. Therefore, according to many librarians and literary researchers, most of the historical literature, government documents, and lesser-known literature are usually untapped by scientific researchers.

I hoped that the treasure hunt for literature on the Dakota strata and flora, but especially the flora, would produce locality and collection site information, as well as previously overlooked background, which would aid in the relocation of the Dakota strata and flora collection sites. Controlled vocabulary and keyword searching; browsing and scanning indexes, bibliographies, and bookstacks; citation and related-record searching; as well as using known experts, other literature, and Boolean combinations were just some of the research techniques exercised in this study.

These library research techniques are little known and not often used in studies, despite their powerful nature (Brown, 1995; D'Aniello, 1993; Durrenberger, 1971; Frick, 1995; Kronick and Winters, 1985; Mann, 1998; Martinson, 1972). The Dakota strata and flora are complex research topics (especially when trying to encompass all their names). Using very old literature in which names of journals and publications might have changed (*e.g,. American Journal of Science and Arts* to *American Journal of Science* or *Proceedings of the Academy of Natural Sciences of Philadelphia* to *Proceedings of the Philadelphia Academy of Sciences*), or no longer exist as current publications further complicates research efforts (*e.g., Kansas City Review of Science and Industry*). The changes in publication names and publications without current equivalent publications added to the difficulty in locating the literature of the Dakota strata and flora. Because the references to older publications use abbreviations not used today and often are not as precise as desired. The help of experienced librarians is often required to track down the publications. Anything that appeared related to the Dakota strata or flora had to be located and skimmed for relevance; however, some known references have still not been located. Items of relevance were added to the resources being collected about the Dakota strata and flora.

Discoveries in Museum Collections

Time-consuming visits to museums and examination of the Dakota Flora housed there are important in studying where they were collected. Each specimen has its own label(s), which not only included information on the identification of the specimen but most of its curatorial history. This curatorial information included when and where it was collected and by whom. Although each museum collection usually has a logbook or catalogue, each specimen must be examined because these records are often not comprehensive. The incompleteness of the logbook or catalogue is often because of insufficient updating as additional information is found about each specimen. In addition, not enough room exists in many of the written logbooks or catalogues for all the locality and collection site information. If the museum records have been computerized, the data usually came from these written records and not from the data on individual specimen labels.

Examination of the museum records and specimen labels was also complicated because of lack of standardization from collection to collection and museum to museum. In addition, the museum might have changed the method and/or style for producing specimen labels. Therefore, multiple specimen labels sometimes exist for the same specimen. A specimen might have one label written directly on the specimen, another written by the original collector, another written by the first museum curator, and yet another meeting the current specimen label specifications, usually typed (Figures 13-16). Because the last label is typed from the original handwritten label or labels, less information is often recorded because of either deterioration or inability to decipher the original label.

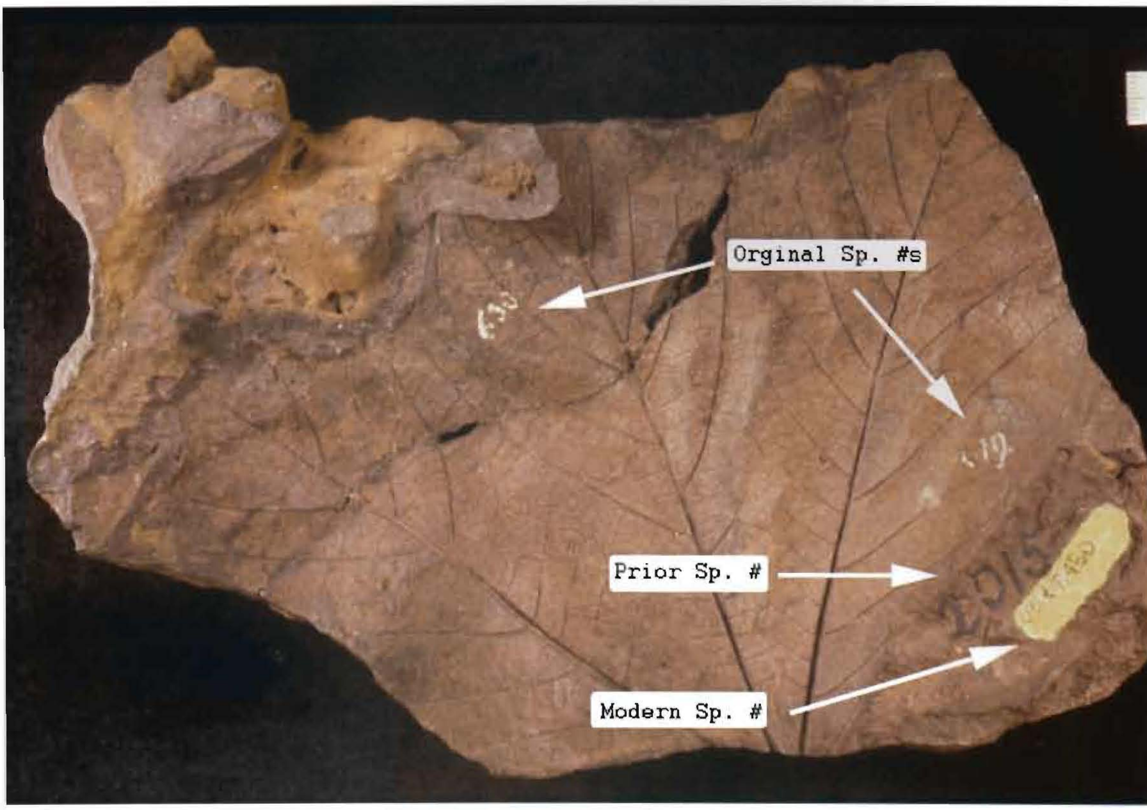

Figure 13: Written-on Specimen Labels. FLMNH specimen number UF 18450 with painted-on specimen numbers. The modern specimen number reads UF 18450, the prior label in India ink number reads 2015, and the historically painted-on numbers read 619 and 630. (Figures 13–16 are all associated with the same fossil specimen—UF 18450.)

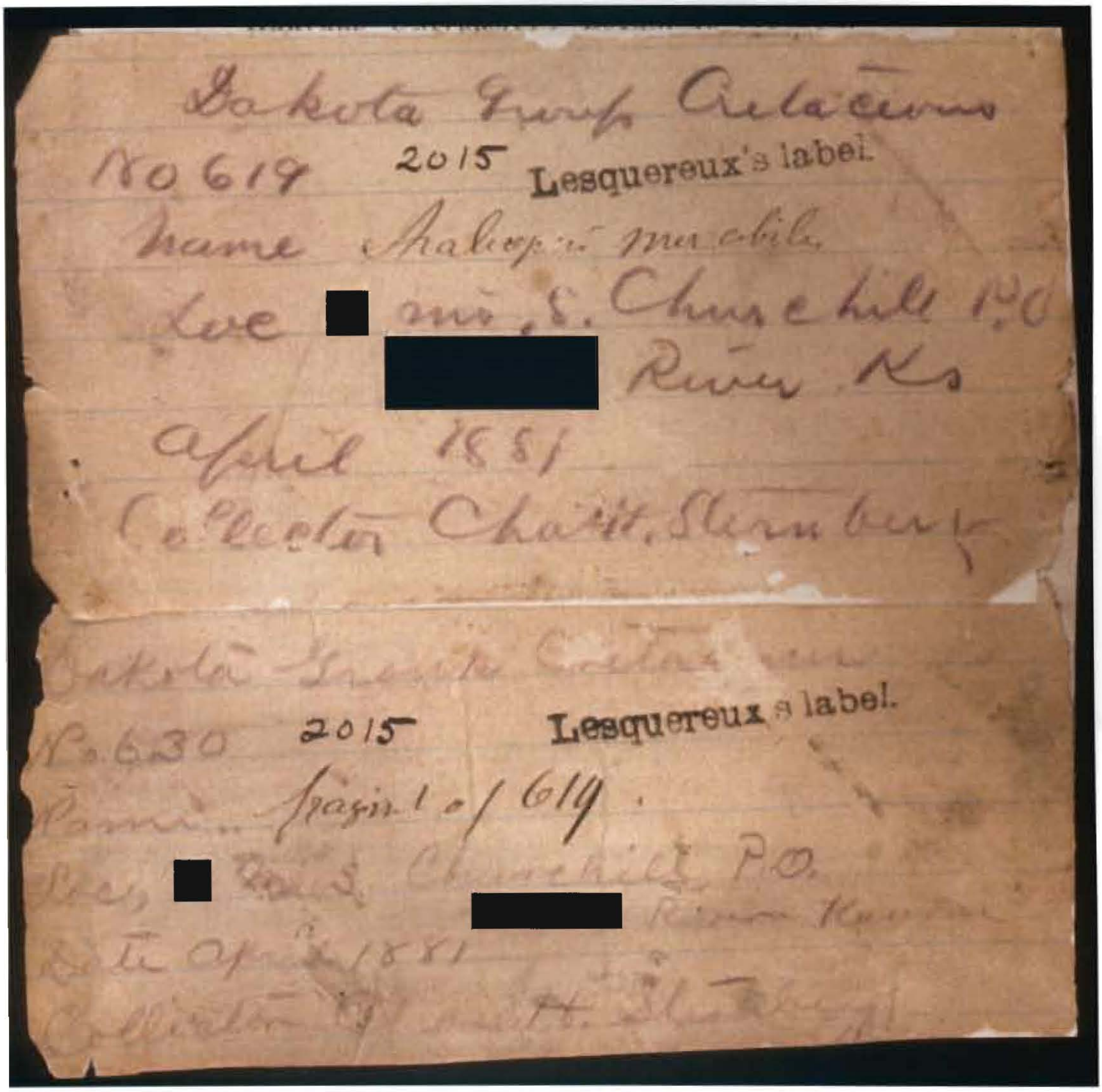

Figure 14: Specimen Labels from the Original Collector. Historical specimen labels of FLMNH specimen number UF 18450 (as it was broken at one time) in the original collector (Charles H. Sternberg) and original identifier (Leo Lesquereux) handwriting on them (specific details obscured to protect collection site). (Figures 13–16 are all associated with the same fossil specimen—UF 18450.)

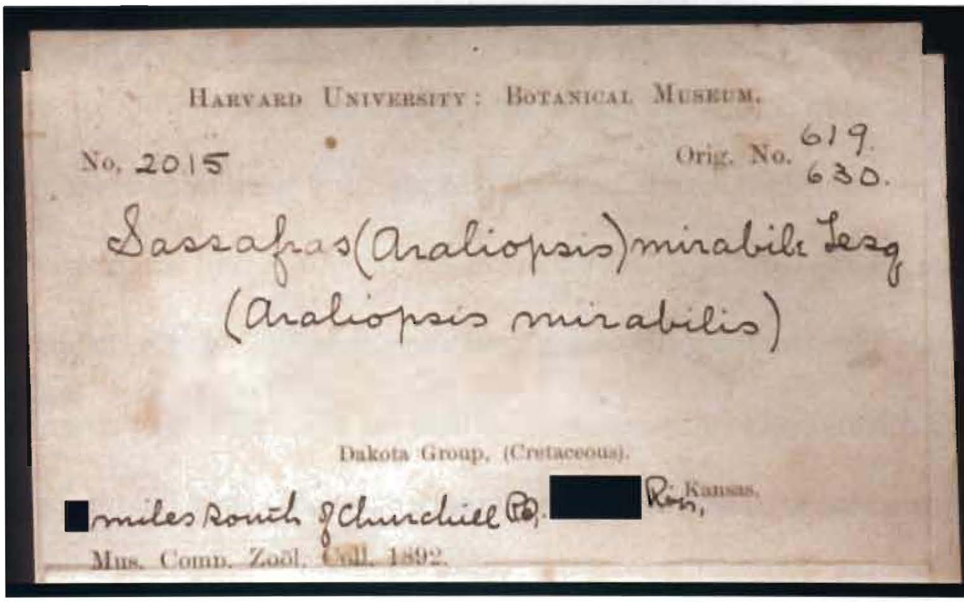
Harvard University: Botanical Museum.
No. 2015 Orig. No. 619. 630.
Sassafras (Araliopsis) mirabile Lesq
(Araliopsis mirabilis)
Dakota Group. (Cretaceous).
[redacted] miles South of Churchill P.O. [redacted] Riv, Kansas.
Mus. Comp. Zoöl. Coll. 1892.

Figure 15: Original Museum Specimen Label. Original museum specimen label for the FLMNH specimen number UF 18450 illustrating handwriting (specific details obscured to protect collection site). It was previously part of the Harvard University Botanical Museum. (Figures 13–16 are all associated with the same fossil specimen—UF 18450.)

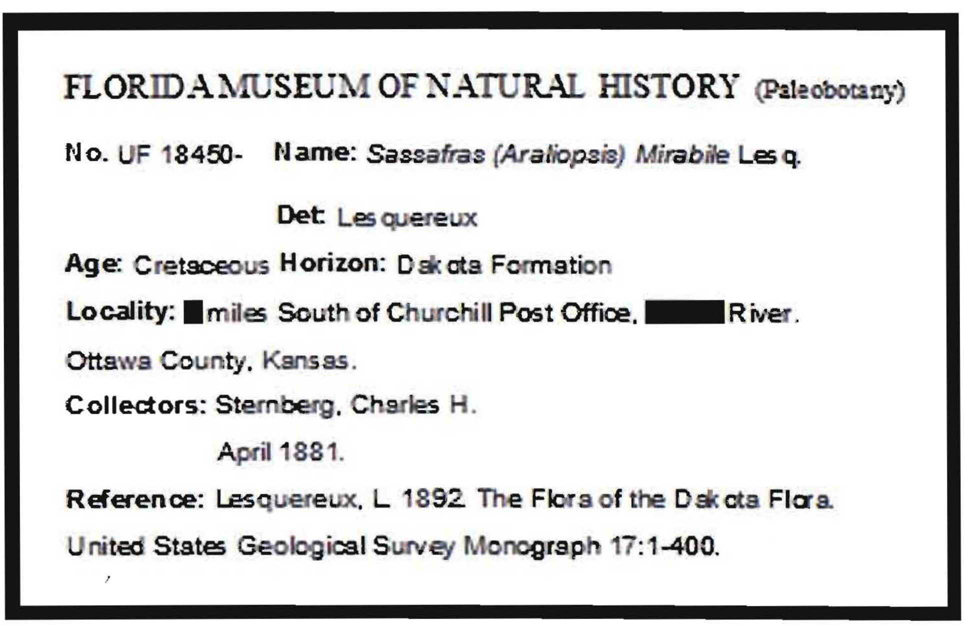
FLORIDA MUSEUM OF NATURAL HISTORY (Paleobotany)
No. UF 18450- Name: *Sassafras (Araliopsis) Mirabile* Lesq.
Det: Lesquereux
Age: Cretaceous Horizon: Dakota Formation
Locality: [redacted] miles South of Churchill Post Office, [redacted] River.
Ottawa County, Kansas.
Collectors: Sternberg, Charles H.
April 1881.
Reference: Lesquereux, L. 1892. The Flora of the Dakota Flora.
United States Geological Survey Monograph 17:1-400.

Figure 16: Current Museum Specimen Label. Present day specimen label photograph of FLMNH specimen number UF 18450 (specific details obscured to protect collection site). (Figures 13–16 are all associated with the same fossil specimen—UF 18450.)

The procedures followed in processing information at museums were thorough. In addition to following the policies specific to each museum collection, there were some basic approaches used at each museum visit. When each collection was first examined, the available logbooks and/or catalogues were consulted for any information available, including where in the collection the specimens were. Copies or copious notes were made of any entries that were about the Dakota Flora. Once a specimen was located, the data contained on the specimen label(s) accompanying the fossil was compared with what was in the logbook or catalogue and any differences recorded. Whenever possible, historic labels associated with a specimen were located and recorded, and sometimes photographed. It was expected to find the specimen label in the box containing the specimen and not on the specimen itself; however, for the Dakota Flora specimens' historical labels were usually attached or marked directly on the specimen.

Once the labels were observed and the museum records read, the information needed to be deciphered and interpreted. Because most of the historic labels were handwritten and in an earlier American (1850-1900) vernacular, this deciphering and interpretation required extensive scrutiny and combination with data obtained from the literature.

Archiving the Dakota's History

Accumulating the monographs, journal articles, maps, photographs, specimen label information, and museum documentation was just the beginning. After the resources about the Dakota strata and/or flora were found, they needed to be arranged in some manner that allowed their history to be determined. Researchers, myself included, painstakingly sift through many seemingly unimportant or mundane facts to gain the ones most useful. Therefore, one must "pore through layers of information until the accumulation lets you derive answers in the end" (Brown, 1995: 45). Answers often must be extricated from the literature, and what might seem unrelated or mundane might be what is important later on. Therefore, it is also necessary to record all, even remotely related, publications and resources examined even if it was not thought to be relevant at the time, including where it was observed in case one needs to go back to it.

Because the Dakota Flora is so historical in nature, Frick's (1995: 81) observation regarding historians of "Geographic information that surrounds events...the location, context, and terrain of happening...is vital" is applicable to study of the Dakota. D'Aniello (1993) points out that books from one hundred years ago as primary sources and books that just recently appeared as new interpretations are both necessary. Even after the literature has produced the gems of locational information concerning the collection sites, Durrenberger

(1971: 17) observes, "field observation is still required today...to check observations obtained."

Field Studies of the Localities and Collection Sites

Field studies in central Kansas were part of the investigations to determine where the fossil collection sites for the localities in the Dakota strata existed and how they might be relocated today. While the field studies gave a better sense of the various aspects of the Dakota Formation, they also helped determine what was important in the descriptions of localities and collection sites. There were two main components of the field studies. The first was the preliminary visit(s) to central Kansas prior to any GIS work. The second was a series of fact-finding trip(s) to help with the interpretation of GIS analyses.

Preliminary Fieldwork

Preliminary fieldwork mainly consisted of a survey to obtain an understanding of the Dakota and its outcrops, in the real world as opposed to GIS. Therefore, a visit to central Kansas, which is the heart of the Dakota Flora collecting area, was required. Geological maps, topographical maps, and a Kansas Gazetteer (DeLorme, 1997) were consulted and taken into the field. Preliminary field investigations focused on Saline and Ellsworth counties, which make up the prime collecting zones of the historically collected fossil angiosperm specimens.

While in the field, photographs and notes of geology, geography, and accessibility were taken. This overview was used with the literature to determine what further fieldwork would be needed and in attempting to understand what the literature portrays and means. In addition, this overview aided in determining what GIS datasets would be useful or necessary for this study.

Fact-finding Fieldwork

Fact-finding fieldwork consisted of a variety of components whose intent was to gather data to help either confirm or deny facts gathered from the literature search or GIS applications. Fieldnotes were taken to record whatever discoveries were made. Additionally, while in the field, attempts were made to obtain insights into how to visualize the Dakota Formation, especially as it might have appeared in central Kansas in the past, to aid in determining how collectors would visualize the strata and its relationship to localities and collection sites. Attempts were also made to observe clues that might aid in locating additional localities and collection sites and/or additional data about known localities and collection sites. Global Positioning System (GPS) readings were taken, rock and fossil specimens were collected (when appropriate), and photographs of terrain and geology were taken (Figures 2 and 17).

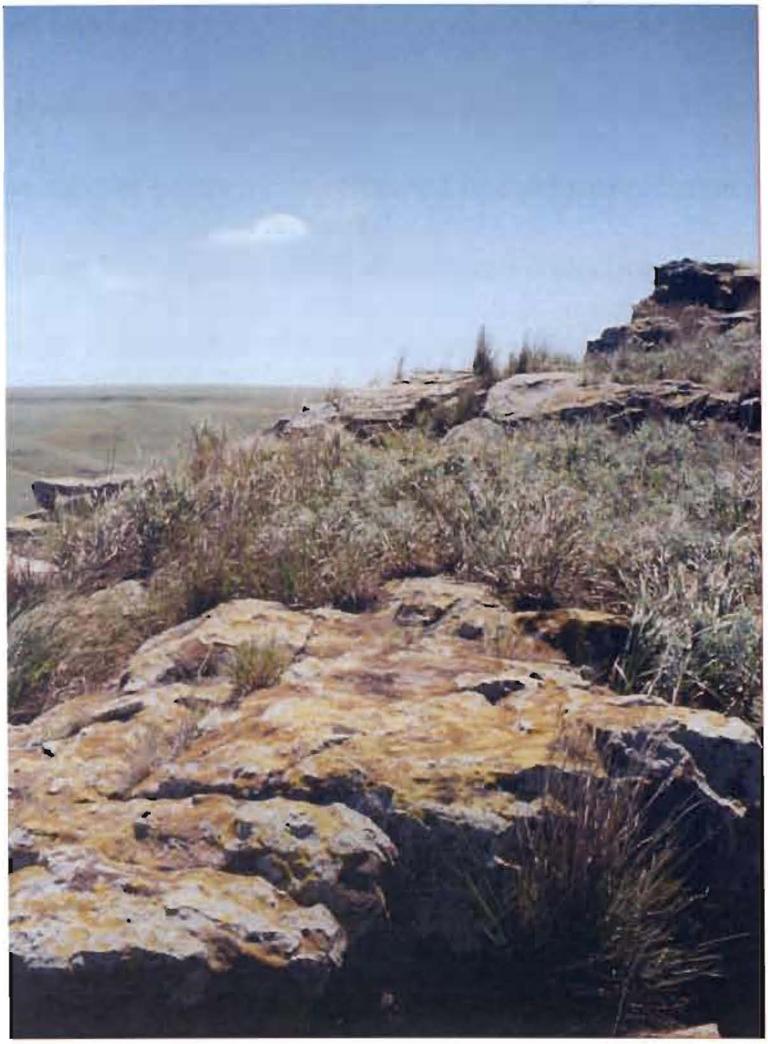

Figure 17: Typical Dakota Formation Terrain. A Dakota Formation outcrop on top of Buzzard's Roost in Ellsworth County, KS showing the hilly nature of the terrain that is typical of outcrops of this formation as seen in the field.

Known fossil collection site locations were visited to obtain a GPS reading from a Garmin GPS 12XL Personal Navigator using Universal Transverse Mercator (UTM zone 14) coordinates in North American datum 1983 (NAD 1983). Coordinates were used to plot the data using GIS so that the location of known fossil producing collection sites could be compared with descriptions found in the literature, in museum catalogues, and on specimen labels. The intent also was to compare them with other GIS datasets to better relocate the collection sites known less precisely. A GPS recording was obtained at additional field stops to allow them to be integrated into the current, and any future, GIS studies as well as allowing it to be correctly relocated in the future. Some specimens were collected from known and newly discovered collection sites as they were found to help with distribution of fossil-containing lithologies. Photographs were taken of collection sites visited to allow comparison with collection site descriptions already known and to aid in relocating the collection site in the future.

GIS Data Sources

This project utilized a variety of data sources. Both primary and secondary data source types were located, analyzed, and used to help relocate fossil collecting sites. Data types included both analog/paper and digital forms.

Initial digital data were downloaded from the Data Access and Support Center (DASC) at the Kansas Geological Survey (KGS). Various datasets were downloaded, including those containing county boundaries, roads, railways, cities, rivers, surficial geology, topography, public land survey, aerial photographs, and Dakota Aquifer information (Table 4). The Topologically Integrated Geographic Encoding and Referencing files (TIGER 2000 files) were used to obtain county boundaries, roads, railways, and cities.

Table 4: Summary of Input Data Used in This Study. Input GIS datasets and data used in this study. Note that collection site descriptions are not included here as they were not initially GIS datasets.

Data	Source	Initial Coordinate System	Resolution/Scale	Description of Data	Initial Format
Dakota Aquifer	DASC (2004)	Lambert Conformal Conic NAD 27 or NAD 83	Derived from 1:100,000, 1:175,000, 1:500,000, and 1:1,000,000 map Contours 100 meters	Extent, base, top, and potentiometric surface of the Kansas Dakota Aquifer	ArcInfo Interchange (Coverage)/ Shapefile
DOQQs—County 1991	DASC (2004)	UTM Zones 13-15 NAD 83	Pixel Resolution 1 meter ground	Digital orthogonally rectified black and white aerial photographs	MrSID—Multi-resolution Seamless Image Database (*.sid)
DRGs—County	DASC (2004)	UTM Zones 13-15 NAD 83	2.4 meters (8.2 feet) from 1:24,000 map	Registered and Rectified USGS topographic maps	Tagged Image File Format (*.tif)
Fort Harker	Archeological report (King, 1997)	Geographic NAD 83	Derived from 7.5 minute map	Archeological Map of Fort Harker	Paper Figure/Map
Surficial Geology	DASC (2004)	Lambert Conformal Conic NAD 27	0.006" from 1:500,000 map	Generalized surface geology: attributed by system, series, and group	ArcInfo Interchange (Coverage)

Table 4 (Continued)

Data	Source	Initial Coordinate System	Resolution/Scale	Description of Data	Initial Format
GPS Readings	Obtained in field using Garmin 12XL (Garmin Corporation, 1998)	UTM Zone 14 NAD 83	Position: 15m Elevation: 30m	Positions, elevations	Hand Recorded
Hypsography –100K	DASC (2004)	Lambert Conformal Conic NAD 27	From 1:100,000 map Contours 5 or 10 meters	DLG 1:100,000 Hypsography (Elevation Contours)	ArcInfo Interchange (Coverage)/ Shapefile
Kiowa Formation Top Surface Elevation	*Top Configuration of the Kiowa Formation* map (Macfarlane, *et. al.*, 1989b: Plate 5)	Lambert Conformal Conic NAD 27	From 1:1,000,000 map	Contours of the top of the Kiowa Formation, most of which is below ground	Paper Map
National Elevation Dataset	DASC (2004)	Geographic NAD 83	Derived from 7.5 minute map	Seamless mosaic of elevation data	ArcInfo Grid

Table 4 (Continued)

Data	Source	Initial Coordinate System	Resolution/Scale	Description of Data	Initial Format
Public Land Survey System	DASC (2004)	UTM Zones 13-15 NAD 27	99.95% (based on 8,000 sample pts) from 1:24,000 map—0.006 map inches or 12 ground feet	Townships, ranges, sections	ArcInfo Interchange (Coverage)/ Shapefile
TIGER 2000 files	DASC (2004)	Geographic NAD 83	Derived from 1:24,000 or 1:100,000 maps	County boundaries, incorporated areas, roads, railroads	Shapefile

In addition, Digital Raster Graphics (DRGs) and Digital Orthophoto Quarter Quadrangles/aerial photographs (DOQQs) were used to locate collection sites with reference to county boundaries, roads, railways, cities, rivers, and topography were used to obtain features that were not part of the TIGERfiles. The Public Land Survey System (PLSS) grids were the source of the public land survey township, range, and section used to help delineate the collection sites with legal descriptions. The surficial geology data needed to check the collection sites against was originally in countywide coverages when obtained in native format. The National Elevation Dataset (NED) and Hypsography were sources of surface topography above mean sea level. These datasets were in the form of coverages, shapefiles, grids, and images whose metadata indicated they were in a variety of different coordinate systems as indicated in (Table 4).

As GIS datasets come in many different formats and coordinate systems in any GIS analysis there is potential for inherent error in the datasets. Some of this error is due to the precision and accuracy of the GIS dataset and some of the error is a function of the precision and accuracy of the data used to create the GIS dataset. Therefore, each GIS dataset has its own precision and accuracy values; hence, these values are included as columns in the table of input data types (Table 4).

Hard copy (non-digital or analog) data used were from publications relating to the Dakota Flora, fieldnotes, historical maps, and both historic and modern museum specimen labels. Museums whose specimen labels were examined included the Johnston Museum, the FLMNH, the KU NHM, and the SMNH. The United States Geographic Names Information System (GNIS) (United States Geological Survey's National Geologic Mapping Program, 2000a) and historical maps were consulted to help locate towns or features whose names have changed. Examples included Churchill, KS now called Tescott, KS (though historical maps (Figures 18 and 19) suggest this might not be absolutely correct) and historic Fort Harker, near present-day Kanopolis, KS. Fieldnotes were used for developing strategies for using map component or GIS compilations of data most effectively. Although numerous publications on the Dakota Flora exist, collection site data were primarily obtained from Lesquereux's publications, especially his 1892 monograph on the Dakota Flora.

The collection site information was compiled from historical publications and specimen labels and was not without challenges. Often in Lesquereux's publications, the locality (which he appears to imply is the collection site of the specimen) is listed as "Ellsworth County, Kansas" or even simply "Kansas." Luckily, museum specimen labels for the same type specimens, when they can be found, contain additional information. Specimen labels from the late 1800s and early 1900s were written in India ink with a form of calligraphy not easily interpreted, especially when the ink partially smeared on the labels that were not acid-free (Figures 20 and 21). The labels are therefore extremely fragile and some are already partially missing.

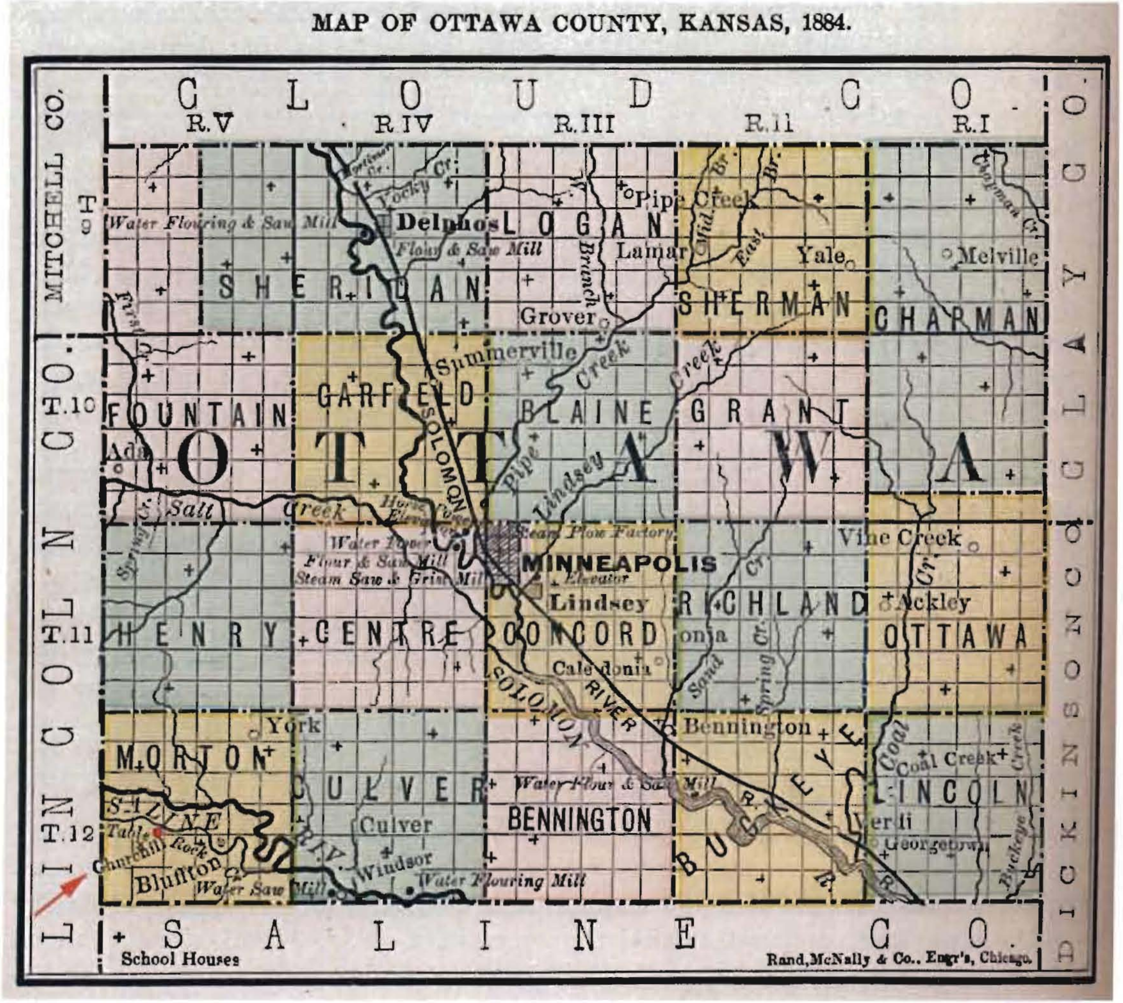

Figure 18: Ottawa County Circa 1884. A 19th century (1884) map of Ottawa County, KS that shows the position of Churchill located in the southwest corner of the map (red arrow pointing to red dot). Notice that Churchill is south of the Saline River on the map. Figure from (Kansas State Board of Agriculture, 1885: 308)

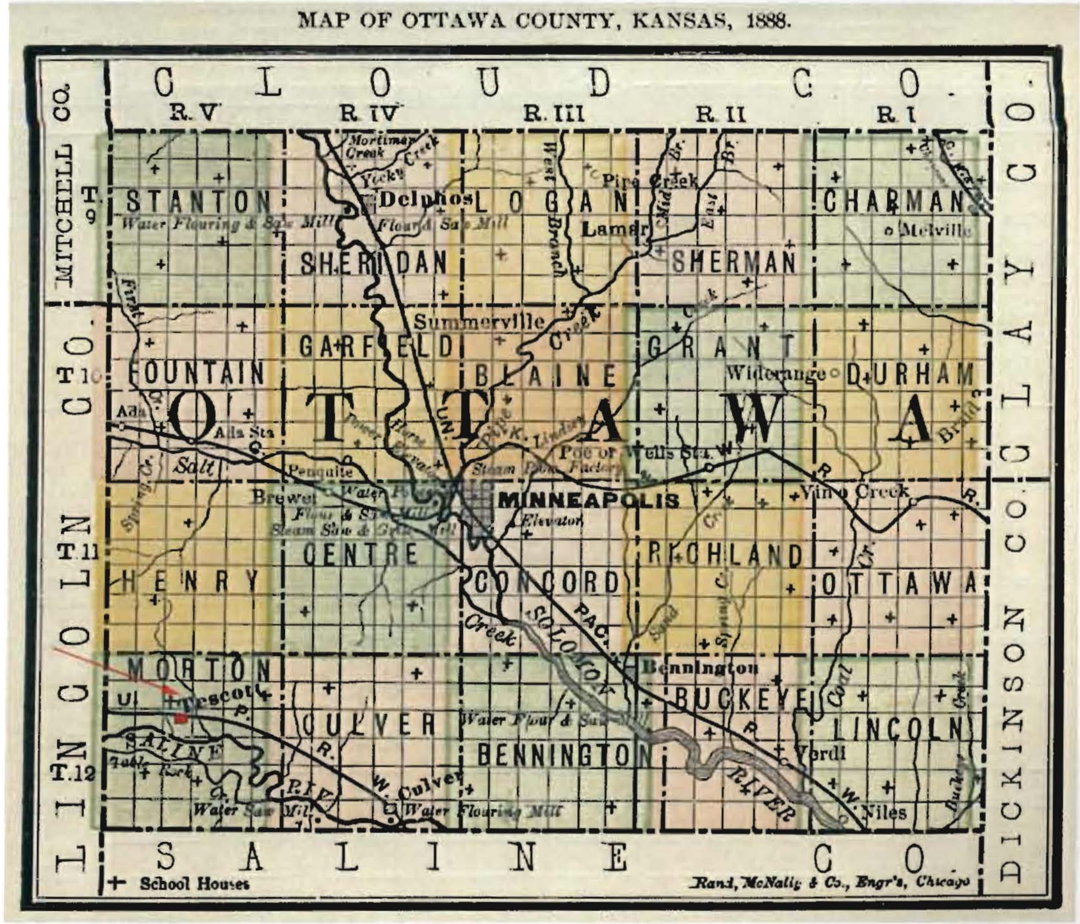

Figure 19: Ottawa County Circa 1888. A 19th map (1888) of Ottawa County, KS that shows the position of Tescott located in the southwest corner of the map (red arrow pointing to red dot). Supposedly, Churchill is now called Tescott (United States Geological Survey's National Geologic Mapping Program, 2000a). However, in this map, Tescott is north of the Saline River. On maps depicting the location of Churchill, it was shown as south of the Saline River. Figure from (Kansas State Board of Agriculture, 1889: 368)

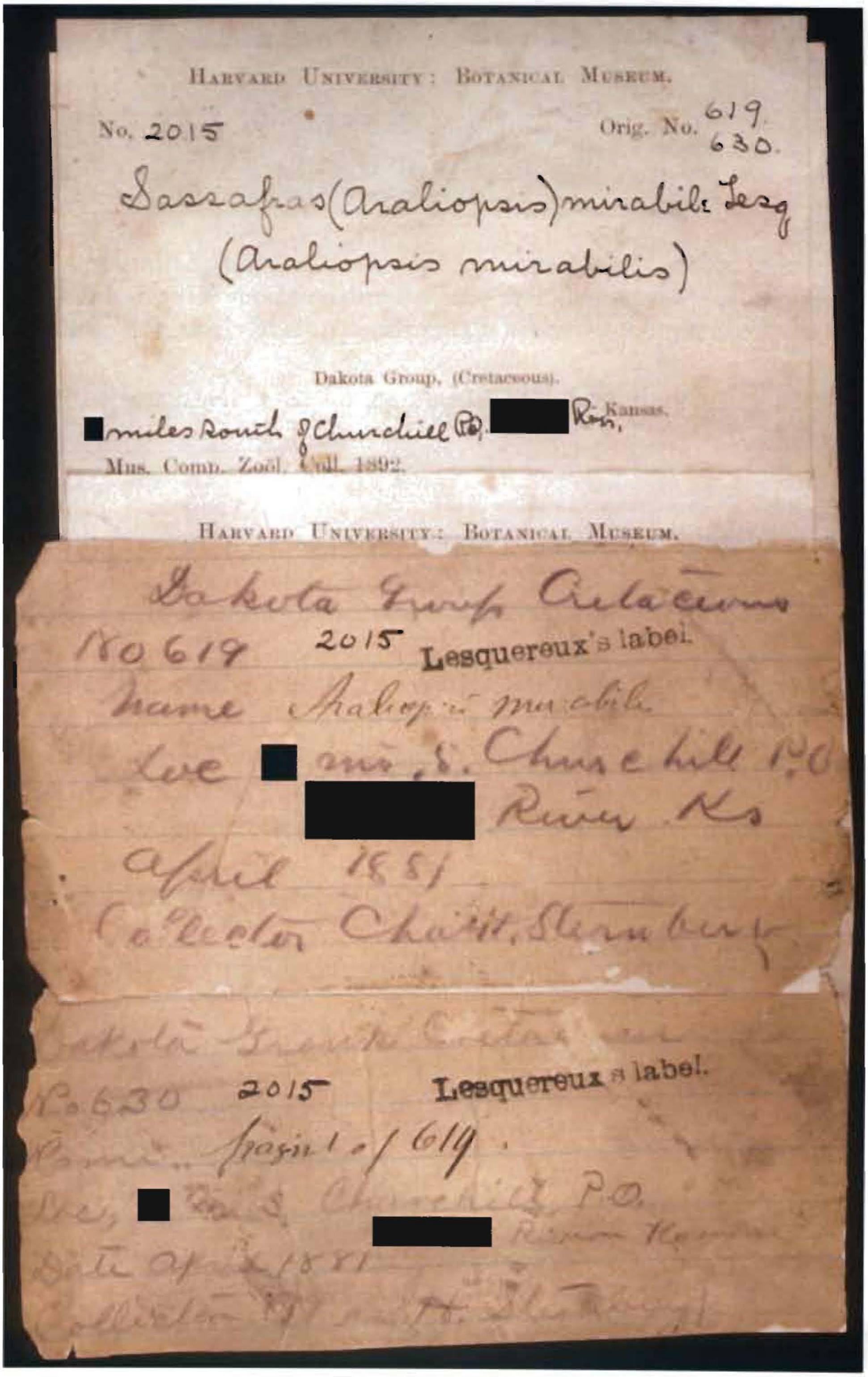

Figure 20: Historic Specimen Label. Calligraphy and spellings observable in a photograph of the historical specimen labels of FLMNH specimen number UF 18450 showing what creates difficulty in reading historical labels (specific details obscured to protect collection site).

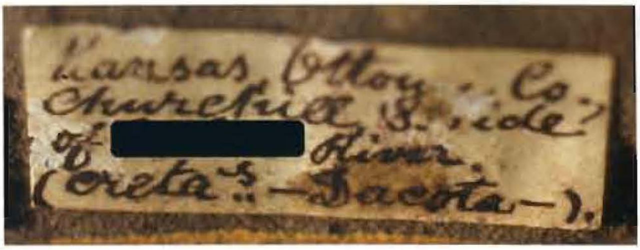

Figure 21: Churchill Specimen Label. Historical specimen observed label glued to the back of KU NHM specimen number 5031 that illustrates the calligraphy and spellings of historic labels (specific details obscured to protect collection site).

Although the specimen labels contain additional data, they are not always complete or just do not make sense because the location has errors such that the legal description is not in the specified county. For example, one label reads "Saline County, Township 15 S, Section 6" (incomplete—missing Range) and another reads "Ellsworth County, Township 13 S, Range 7 W, Section 11, E 1/4" (does not make sense—Township 13 not in Ellsworth County). Collection sites used in this investigation for analysis purposes were those with the most complete and easily interpreted descriptions, although a few of the slightly less detailed descriptions were used to see if they could benefit from GIS analysis techniques.

GIS Projection Information

For this project, GIS datasets were converted to a standard coordinate system to facilitate map overlay and spatial analysis (UTM, Zone 14 N, meters, NAD 83). Although not all of Kansas is in UTM Zone 14 N, it was chosen as the base coordinate system for a variety of reasons. Among those reasons were that most of the study area was in this UTM zone and the DRGs and DOQQs needed for the project were already in this coordinate system, therefore time-consuming reprojection of imagery was not required. The most important reason was that the primary collection zone of Ellsworth County was well within and near the center of the UTM zone. This is justified by Environmental Systems Research Institute's (ESRI) comment:

> "Coordinate systems such as State Plane and UTM use zones to minimize distortion. Often a study area crosses two zones, and features at the edges of the zones do not match. There are two ways to perform analysis on an area falling in two zones. The first and easiest way is to project one of the coverages into the zone of the adjoining coverage" (1994: Chapter 5 pg "5-5").

They further comment in their book about map projections (Environmental Systems Research Institute, 1994) that it is best if the majority of the study area falls into one UTM zone.

Because many of the other datasets were in different coordinate systems (Environmental Systems Research Institute, 1994: Appendix A) and datums, these datasets all were reprojected into the appropriate UTM zone (Zone 14 N, meters, NAD 1983). For those projections whose datum was NAD 1927, the NADCON (the North American Datum Conversion Utility) transformation process was used to convert them to NAD 1983 (Environmental Systems Research Institute, 1994: Appendix B).

GIS Processing

A wide variety of software was utilized in the organization and processing of data in this analysis. The Microsoft® Office 2000 suite consisting of Word, Excel, and Access was used to record and organize data. Additionally, Adobe® Photoshop 6.0, Microsoft® Notepad, and Kansas Automated Reference Conversion (LEO II and hereafter referred to as LEO) were used to enable transfer of data to GIS applications. ArcView 3.3 (hereafter referred to as ArcView), ArcMap/ArcView 8.3/ArcGIS 8.3 (hereafter referred to as ArcGIS), and ArcInfo/Workstation (hereafter referred to as ARC/INFO) were the GIS programs used. In order to make clear what GIS data processing methods I used in this study, I will make my explanations of the methods general. I included a more specific GIS data processing discussion in "Appendix B: GIS Processing Methods."

GIS data processing for the collection sites had several sub-projects. The collection sites were subdivided into Distance Collection Sites and PLSS Collection Sites. Distance Collection sites were described by the original collectors as being a given distance from a known location, usually a town, which occasionally also included the compass direction from the feature (*e.g.*, 2 miles South of Tescott). PLSS Collection Sites were described by the original collectors in terms of township, range, section, and part of a section, though descriptions might not have all of these terms. To understand the clustering of these collection sites it was also useful to understand where each collection site was in relation to Sternberg's residence (Fort Harker was used initially as proxy for the Sternberg Ranch; see pages 113 and 249). The surficial geology of the collection site, surface elevation of each collection site, and the topography of the base of the Dakota were all included in the spatial analyses of Dakota Flora fossil sites. Data processing was carried out for: the Distance Collection Sites, the PLSS Collection Sites, the location of Fort Harker, the location of Sternberg Ranch, the surficial geology, the Dakota Aquifer base elevations, the Dakota-Kiowa contact elevations, and the surface elevations (including hypsography).

Collection Site Data Processing

After the historic fossil collection site data were compiled from publications, specimen labels, and information written directly on the specimens, the collection site data were recorded such that it could be categorized and used in ArcView, ArcGIS, and ARC/INFO. As collection site information was obtained, it was entered into an Excel spreadsheet to be organized and sorted. Then the data were categorized by type (Unused, Distance, Limited Distance, or PLSS), each category was gathered together, and put into a systematic list to determine what types of GIS coverages would be needed to best determine the GIS coordinates for each collection site (Tables 5 and 6).

Table 5: Kansas PLSS Collection Sites Used in This Study. Collection Sites listed in this table were used in this study comprising those that are referred to as PLSS Collection Sites (unpublished specific details not included to protect collection sites). Locality numbers were assigned based on the county they were located in (EW= Ellsworth, OT=Ottawa, and SA= Saline), what type of legal description it is (QQ= Quarter-Quarter Section, Q= Quarter Section, H=Half Section, S=Entire Section, S#R= Entire Section with further limitation in description, MR= Legal Description Missing Range, T= Township and Range Only, T#R= Township and Range with further limitation in description, OS= Only Section Number), and then a sequential number was added based on the order of the numbers in the legal description.

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
EW-QQ1	Ellsworth		Legal Description		KU NHM Specimen Number ?#
EW-H1	Ellsworth		Legal Description		KU NHM Specimen Number ?#
EW-Q1	Ellsworth		Legal Description		KU NHM Specimen Number ?#
EW-H2	Ellsworth		Legal Description	Range # written as Roman Numeral	KU NHM Specimen # D 142
EW-S1	Ellsworth		Legal Description		KU NHM Specimen # 8522
EW-Q2	Ellsworth		Legal Description		KU NHM Specimen # 7293
EW-H3	Ellsworth		Legal Description	Range # was written as Roman Numeral	KU NHM Specimen Number ?#

Table 5 (Continued)

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
EW-S2R	Ellsworth		Legal Description plus further limitation		KU NHM Specimen Number ?#
EW-S3R	Ellsworth		Legal Description plus further limitation		KU NHM Specimen Number ?#
EW-S4	Ellsworth		Legal Description	Range # written as Roman Numeral	KU NHM Specimen Number ?#
EW-Q3	Ellsworth		Legal Description		KU NHM Specimen # 9010
EW-S5	Ellsworth		Legal Description	"6 cL" written on Label after Range #	KU NHM Specimen Number ?#
EW-T1	Ellsworth		Legal Description		KU NHM Specimen # 7286
EW-T2R	Ellsworth		Legal Description plus further limitation	Section # difficult to read, # written as "_ #"	KU NHM Specimen Number ?#
EW-Q4	Ellsworth		Legal Description		KU NHM Specimen # 7257
EW-H4	Ellsworth		Legal Description		KU NHM Specimen Number ?#
EW-OS1	Ellsworth		Legal Description plus further limitation	Section # written as Roman Numeral	KU NHM Specimen Number ?#

Table 5 (Continued)

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
FR-QQ1	Franklin	Ottawa	Legal Description		KU NHM Specimen Number ?#
OT-S1R	Ottawa	Tescott (Churchill)	Legal Description plus further limitation		KU NHM Specimen # 7298
OT-S2R	Ottawa	Tescott (Churchill)	Legal Description plus further limitation	Section # difficult to read	KU NHM Specimen # 5011
OT-S3	Ottawa		Legal Description		KU NHM Specimen # 5016
OT-H1	Ottawa		Legal Description		KU NHM Specimen # 7291
EW-S5	Ellsworth		Legal Description	"6 cL" written on Label after Range #	KU NHM Specimen Number ?#
SA-MR1	Saline		Legal Description plus further limitation	Section # written as Roman Numeral	KU NHM Specimen # 7290

KU NHM Specimen Number "?#" is used in the table for specimens observed whose specimen number was unable to be determined.

Table 6: Kansas Distance Collection Sites Used in This Study. Collection Sites listed in this table were used in this study comprising those that are referred to as Distance Collection Sites and those with directions are the Limited Distance Localities (unpublished specific details not included to protect collection sites). Those collection sites whose description field includes a direction are what are referred to as Limited Distance Collection Sites. Locality numbers were assigned based on an abbreviation of the nearest city (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) and then a sequential number was added based on the distance (lower first) and direction (Following Clockwise around the compass starting with north) with the description that was most specific being first.

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
G-1	Cloud	Glasco (Glascoe)	2 mi. from		Lesquereux, 1892
G-2	Cloud	Glasco (Glascoe)	2 mi. S		Lesquereux, 1892
G-3	Cloud	Glasco (Glascoe)	2.5 mi. from		Lesquereux, 1892
G-4	Cloud	Glasco (Glascoe)	2.5 mi. N		Lesquereux, 1874
G-5	Cloud	Glasco (Glascoe)	2.5 mi. S		Lesquereux, 1874 Lesquereux, 1892
G-6	Cloud	Glasco (Glascoe)	7 mi. from		Lesquereux, 1892
G-7	Cloud	Glasco (Glascoe)	7 mi. N		Lesquereux, 1892

Table 6 (Continued)

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
G-8	Cloud	Glasco (Glascoe)	7 mi. NE		Lesquereux, 1874 Lesquereux, 1892
E-1	Ellsworth	Ellsworth	Specified Distance SW of		SMNH Fossil Number ?#
K-1	Ellsworth	Kanopolis (Fort Harker)	3 mi. N		Lesquereux, 1874
K-2	Ellsworth	Kanopolis (Fort Harker)	In ravine, 3 mile E of		Lesquereux, 1883
K-3	Ellsworth	Kanopolis (Fort Harker)	3 mi. SSE		Lesquereux, 1874 Lesquereux, 1892
K-4	Ellsworth	Kanopolis (Fort Harker)	3 mi. S		Lesquereux, 1874 Lesquereux, 1892
K-5	Ellsworth	Kanopolis (Fort Harker)	4 mi. E of Minneapolis & 7 mi. NE of Glasco, S of		Lesquereux, 1874
K-6	Ellsworth	Kanopolis (Fort Harker)	7 mi. N		Lesquereux, 1874
K-7	Ellsworth	Kanopolis (Fort Harker)	7 mi. S		Lesquereux, 1892
K-8	Ellsworth	Kanopolis (Fort Harker)	On Thompson Creek, 7 mi. S of	Historical Sp. Could be Locality UF 18447?	Lesquereux, 1874
K-9	Ellsworth	Kanopolis (Fort Harker)	8 mi. S of		Lesquereux, 1883

Table 6 (Continued)

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
K-10	Ellsworth	Kanopolis (Fort Harker)	9 mile S of		Lesquereux, 1883
K-11	Ellsworth	Kanopolis (Fort Harker)	Near. 8 mi. S of station		Lesquereux, 1883
K-12 A, B, & C	Ellsworth	Kanopolis (Fort Harker)	8-10 mi. S of "3 mi. NE of Fort Harker, near Brooksville", Near		Lesquereux, 1883
K-13	Ellsworth	Kanopolis (Fort Harker)	Smoky Hill River, 8 mi. S of		Lesquereux, 1883
TC-1	Ellsworth	Terra Cotta	S side of railroad, Specified Distance W of	Written as "U. P. R. R." on label	KU NHM Specimen # "7257?"
D-1	Ottawa	Delphos	10 mi. NE		Lesquereux, 1892 Hongshan Wang unpublished data
D-2	Ottawa	Delphos	Red Shale, 10 mi. NE of		Lesquereux, 1892
M-1	Ottawa	Minneapolis	4 mi. NE		Lesquereux, 1874
M-2	Ottawa	Minneapolis	8 mi. NE		Lesquereux, 1874
T-1	Ottawa	Tescott (Churchill)	Along Creek/River, Specified Distance S of	Locality Name: Churchill Post Office Museum Locality: UF 18450	FLMNH Specimen # UF 18450

Table 6 (Continued)

Locality #	County	Nearest City (as Written)	Description	Notes	Reference(s)
T-2	Ottawa	Tescott (Churchill)	On S side of Creek/River		KU NHM Specimen #5031
B-1	Pawnee	Burdett	Specified Distance S of		SMNH Fossil # PB-141 to PB-176
BH-1	Russell	Bunker Hill	Specified Distance N of		SMNH Fossil # PB-34 to PB-61
L-1	Russell	Lucas	Specified Distance W of		SMNH Fossil # PB-13, PB-17, PB-18, & PB- 85
BV-1	Saline	Brookville (Brooksville)	4 mi. SW		Lesquereux, 1892
BV-2	Saline	Brookville (Brooksville)	Distance NW of		UF Paleobotany Teaching Collection Specimen # IU 181
BV-3 A, B, & C	Saline	Brookville (Brooksville)	8–10 mi. N of "Near Fort Harker" and 3 mi. NE of Fort Harker, Near		Lesquereux, 1883
S-1		Salina (Salina Station)	8 mi. above		Lesquereux, 1883

SMNH Fossil Number "?#" is used in the table for specimens observed whose specimen number was unable to be determined.

From the information obtained on collection sites (a total of 228), some were not sufficient for use in GIS (97 collection sites in Kansas and 28 collection sites in other States). Descriptions such as Ellsworth County, Kansas or just Kansas, as well as those described as vicinity of Fort Harker or Near Ellsworth were too vague to be used and were discarded for this analysis. In addition some more descriptive collection site location information was not correct geographically (*i.e.* the township was not in the county specified in the description) or the GPS values did not provide the datum necessary for mapping. The rest of the historic collection site descriptions (103 collection sites) were divided into two main categories as described above (Tables 5 and 6). Because most of the descriptions of Dakota Flora collection sites are in Kansas, the data used in the GIS analyses were limited to those within Kansas (this limited the study down to 71 collection sites).

The fossil collection sites described as being a certain direction and distance from a city seem to be concentrated around eleven cities in Central Kansas: Brookville, Burdett, Delphos, Ellsworth, Glasco, Fort Harker (Kanopolis), Minneapolis, Salina, Churchill (Tescott), Terra Cotta, and Wilson. These specimen collection site descriptions were especially prevalent around Fort Harker, which was very near where C. H. Sternberg, the primary collector of the historic specimens lived. Due to complications in determining where the boundary of Fort Harker was located, the city of Kanopolis, KS was used for any description that specified a distance from Fort Harker in this study (further explanation can be found in the section "Processing Location of Sternberg Ranch" on page 111). The collection sites that specify a distance and a direction from a city (hereafter referred to by the term "Limited Distance Collection Sites") were first examined as just a distance from the city and then as both the distance and direction from the city. While some might argue that this artificially inflates the collection sites described as a distance from a city (hereafter referred to by the term "Distance Collection Sites"), all of the Distance Collection Sites also had Limited Collection Sites with the same distance specified in separate collection site description sources.

Although the fossil collection sites with legal descriptions are generally in the same vicinity, they seem more concentrated in northeastern Ellsworth County. The legal descriptions included entire sections as well as half sections and quarter sections. Only one workable description was of a quarter-quarter section (an area of approximately 40 acres). All but three of the workable legal descriptions were in Ellsworth County. Again, this concentration is probably related to where the primary collector lived.

Processing Distance Collection Sites

Processing for the collection sites described as a specified direction and distance from a city was performed using ArcView, ArcGIS, and ARC/INFO. TIGER 2000 files, DOQQs, and DRGs were downloaded from DASC and used in ArcView to determine city locations. In ArcView, each of the cities was converted to its own GIS data layer. However, four cities (Blackwolf, Carnerio, Crawford, and Terra Cotta) were not part of the TIGER 2000 files. These cities are either very small or they no longer exist; therefore, they were not collected as part of the census data in 2000 (which is what the TIGERfiles are based on). In order to have the location of these cities, DOQQs and DRGs for Ellsworth and Rice counties were used to create separate polygon shapefiles representing the locations for each of these four cities.

Terra Cotta, KS was mainly a railway-siding town that no longer exists; however, the name still appears on the map of Ellsworth County and the Venango 7.5 minute quadrangle (Figure 22). The name on the map, the location of the railroad, and the traces of roads in the area were used to create a small square where Terra Cotta seems to have existed. In all probability, the town boundary of the time was larger. However, until further information is available and another study is done, the small square was used as the city boundary of Terra Cotta.

At this point, the city shapefiles were converted into coverages utilizing ARC/INFO. This enabled each city boundary to be examined for subcomponents they might have had when viewed in ArcView (Figure 23). Any city that had subcomponents was then converted back to a shapefile and edited to include just the main entry. This both simplifies the buffering process and factors in the assumption that outliers are probably later additions to the city than the city boundaries that existed in the late 1800s and early 1900s.

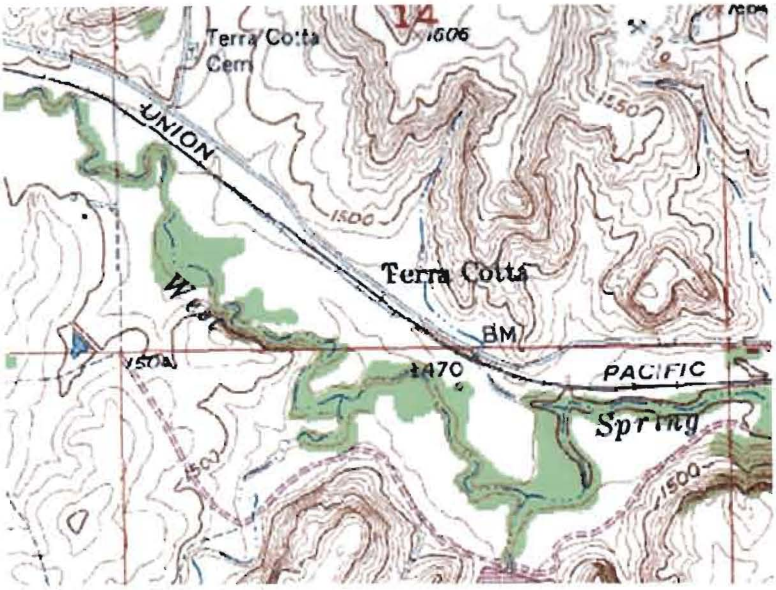

Figure 22: Terra Cotta as labeled on the Venango 7.5′ DRG. Portion of the Venango DRG downloaded from DASC (2004) is zoomed into the label Terra Cotta in the northeast corner.

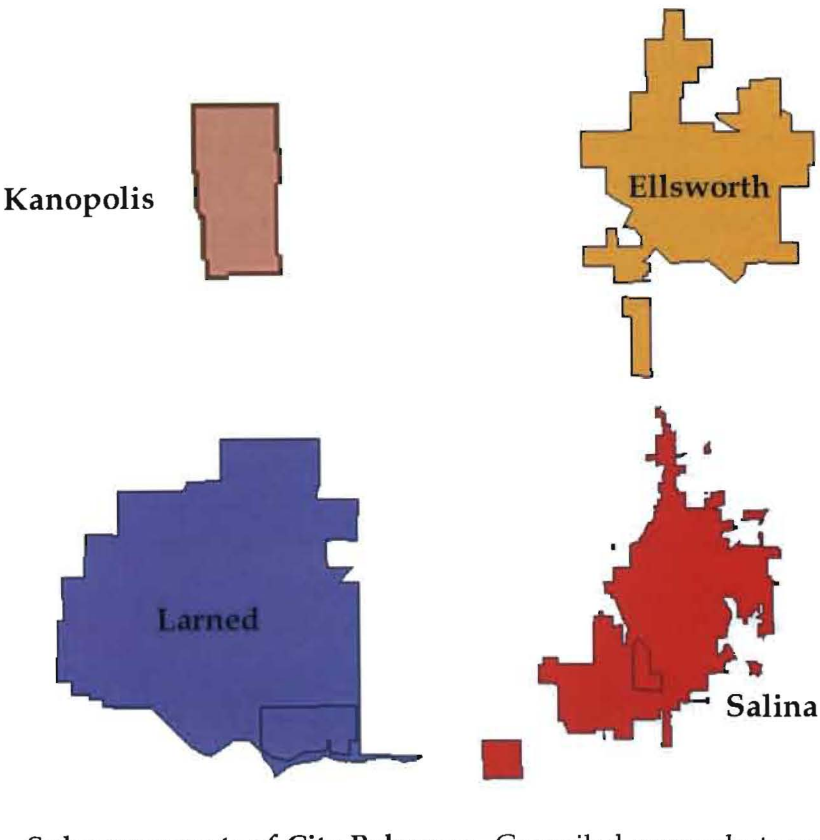

Figure 23: Subcomponents of City Polygons. Compiled screenshots used to illustrate the TIGERfile cities that had: no subcomponents (coral color), internal subcomponents (orange color), external subcomponents (purple color), or both internal and external subcomponents (red color) when downloaded from DASC.

Four cities (Clay Center, Concord, Larned, and Salina) had internal subcomponents and therefore required more processing than those that had external subcomponents. Salina had both external and internal subcomponents; therefore, it was processed first for external and then for internal subcomponents.

Once editing of these files was complete, they were processed in ARC/INFO to convert them into coverages (see above). At this point, the coverages were double-checked to ensure that they were in the proper coordinates/projection (UTM, Zone 14 N, meters, NAD83).

After the processing to ensure each city had only one component, the city coverages were added to an ArcGIS view for further analysis. Each coverage was then used to create appropriate collection site features as described by the distances from the city in order to create the appropriate buffer(s) of the city (Figure 24). This produced what I refer to as "Distance Collection Sites." The Distance Collection Site buffers were then limited to the direction specified by a variety of means in ArcGIS (Figure 24). I use the term "Limited Distance Collection Sites" to refer to a Distance Collection Sites whose description specified a certain distance and direction from a city. The direction was specified by angles that represented the twenty degrees assigned to each compass direction (Table 7). This allows the Limited Distance Collection Sites to be used more effectively in later GIS analysis operations.

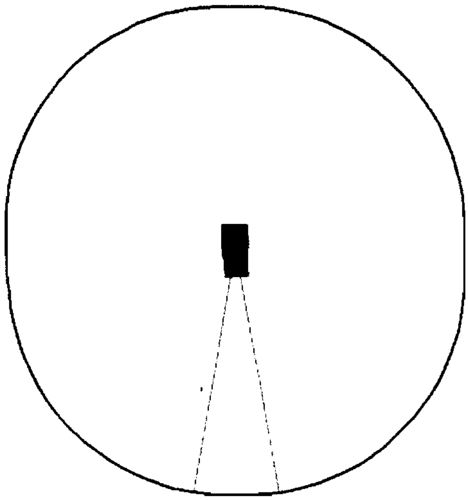

Figure 24: City Components Used for GIS Processing. Compiled screenshots used to explain the buffering process. Cities are represented as polygons (coral polygon) that are buffered from the outside of the polygon to the appropriate distance (green line) and then either: left as Distance Collection Sites or limited with directions. Those that are limited to Limited Distance Collection Sites are determined by drawing lines (blue lines) at the appropriate angles from the city center point (brown dot) until they intersect the outer edge of the buffer (green line) where the arc is located.

Table 7: Directional Angles for Limited Distance Collection Sites. The compass directions were assigned a 20-degree range of angle values to allow limitation of direction and account for possible error in directionality.

Direction	Angle Degree Range
North	350.0-10.0
North Northeast	12.5-32.5
Northeast	35.0-55.0
East Northeast	57.5-77.5
East	80.0-100.0
East Southeast	102.5-122.5
Southeast	125.0-145.0
South Southeast	147.5-167.5
South	170.0-190.0
South Southwest	192.5-212.5
Southwest	215.0-235.0
West Southwest	237.5-257.5
West	260.0-280.0
West Northwest	282.5-302.5
Northwest	305.0-325.0
North Northwest	327.5-347.5

Each coverage was also added into ArcView 3.3 where a shareware "XTools" extension (Delaune, 2003) was used to convert the cities into a point in the center of each polygon. This was done because the point used as the center of each city was needed to draw the lines to limit the Distance Collection Sites into the Limited Distance Collection Sites as well as to produce maps. Then the city coverages were consolidated into two coverages in ARC/INFO, creating one for the polygons and one for the points, to facilitate different cartographic uses (Figure 24).

Processing PLSS Collection Sites

Processing for the collection sites described by legal descriptions occurred in ArcView, ArcGIS, ARC/INFO, Notepad, Excel, and LEO. First, the PLSS file was downloaded from DASC and opened in ArcView. For the collection sites that specified full sections of a township and range, the specified section was selected and converted into its own shapefile. Collection sites that specified a half, quarter, or quarter-quarter section were transcribed into a format compatible with LEO. After processing with LEO, in which the data was converted to a latitude and longitude coordinate for the center of each legal description sub-section, Excel was used to make it compatible with GIS software in the ESRI family of programs. The center of each legal description sub-section was then used to create the appropriate half, quarter, or quarter-quarter section described collection sites as an individual shapefile in ArcGIS. Then the polygon shapefiles described by each legal description were converted into coverages utilizing ARC/INFO. The PLSS coverages were then consolidated into a single coverage in ARC/INFO.

Processing Location of Fort Harker

Processing for the location of Fort Harker was preformed in Photoshop and ArcGIS. Initially, the location of the Sternberg family ranch was only known as 2.5 miles south of Fort Harker therefore, Fort Harker was used as a proxy location in this study (Sternberg, 1990: 6). However, as the significance of the location of the ranch was investigation to determine its actual location was conducted (see "Processing Location of Sternberg Ranch" section on page 113). Determining the location of Fort Harker was complicated because Fort Harker is only listed as a historical fort (even though portions are still present), in the general vicinity of the city of Kanopolis, KS. The actual boundary of Fort Harker was to determine therefore, the city of Kanopolis, KS was used for any description that specified a distance from Fort Harker. However almost at the completion of this study, King's 1997 archaeological report of Fort Harker was discovered during a library search. King's report (1997) allowed the location of the Fort Harker's boundary to be more precisely established. It was decided that in the analysis of the results it would be useful to see each collection site's relationship to Fort Harker and the overall concentration of the collection sites around the fort. The location of Fort Harker was processed to be compatible with the ESRI family of GIS Programs and used in subsequent analyses.

In her report, King (1997: 3) included a figure similar to Figure 25 in which the boundary of historical Fort Harker was drawn on a topographical map. Because the topographical map was the same as the DRG of Ellsworth County, a flatbed scanner and Photoshop were used to scan in the figure from King (1997) and convert it into a digital image compatible with GIS. Then the digital image was added to ArcGIS along with the DRG of Ellsworth County. The Fort Harker boundary image was digitized in ArcGIS as a shapefile after the image was registered and rectified using the DRG. The Fort Harker boundary shapefile was converted into a coverage in ARC/INFO.

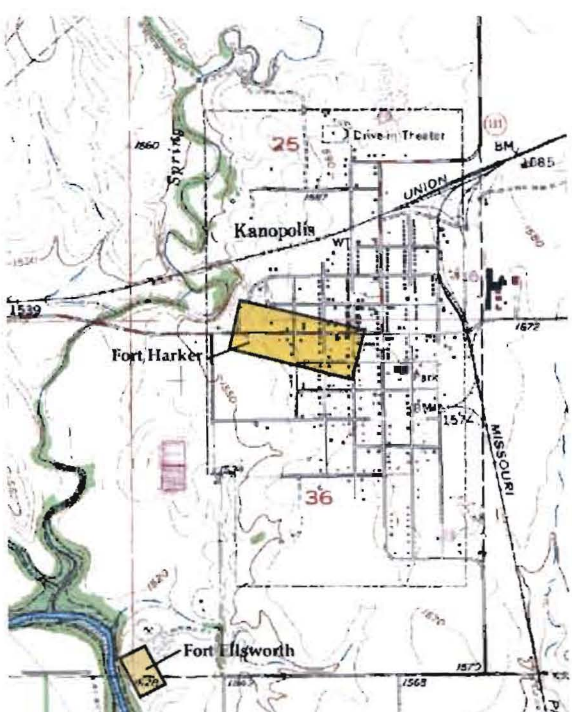

Figure 25: Map from Archaeological Report on Fort Harker. The location derived from illustration in the archaeological report (King, 1997: 3) of Fort Harker (bright yellow box) archeological site in Ellsworth County, KS.

Processing Location of Sternberg Ranch

Processing for the location of the Sternberg family ranch was performed in ArcView and ARC/INFO. Two conflicting descriptions for the Sternberg Ranch have been published: 1) 2.5 miles south of Fort Harker (Sternberg, 1990: 6) and "a ranch of approximately 600 acres along the Smokey Hill River, south of the fast growing town of Ellsworth" (Rodgers, 1999:11). Until the significance of the location of the ranch was realized, Sternberg's description was used. Clarification for the location of the ranch was obtained through consultation with the Ellsworth County Historical Society. The actual location of the Sternberg Ranch was obtainable at the county courthouse in Ellsworth County from a plat map of land ownership of the time period when C. H. Sternberg was said to be collecting Dakota Flora specimens (Personal Communication Ellsworth County Historical Society, 2005). It was determined that it would be useful to see relationships of the location of the Sternberg Ranch to the collection sites and the location of Fort Harker for analyses. Therefore, the legal description of the location of the Sternberg Ranch was digitized using the ESRI family of GIS Programs.

The Ellsworth County Historical Society (2005) supplied a legal description in PLSS format. Therefore, the PLSS dataset from DASC (2004) was opened in ArcView and a shapefile was created for the Sternberg Ranch boundary. The Fort Harker boundary shapefile was then converted into a coverage in ARC/INFO for further analyses.

Processing Surficial Geology

Processing for the surficial geology was performed using ArcView and ARC/INFO. First, the surficial geology coverages for all counties in Kansas were downloaded from DASC and imported using ARC/INFO. All county coverages were then combined together in ARC/INFO and the county lines were eliminated. At this point, ArcView was used to open the surficial geology coverage to make sure the surficial geology was joined seamlessly along county boundaries. Any place where it did not appear to be joined seamlessly the original county surficial geology coverage for the area in question was consulted to fix the Kansas-wide coverage. The Kansas surficial geology coverage with formation names was opened with ArcView, and the Dakota Formation was converted to a shapefile of its own. At this point, the Dakota Formation shapefile was converted into a coverage utilizing ARC/INFO.

Dakota Aquifer Base Elevation Processing

Subsurface data also exists that may provide useful information about the Dakota Formation. Hydrogeologists studying the Dakota Formation's strata as part of an aquifer have created contour lines representing the topography of the base of the Dakota Aquifer in Kansas (Data Access and Support Center, 2004;

Macfarlane, *et. al.*, 1989b). Processing for the Dakota Aquifer data was performed using ArcView, ArcGIS, and ARC/INFO. The Dakota Aquifer data were downloaded from DASC and opened in ArcView. Only the Dakota Aquifer base data were processed, although other data were looked at to aid in its processing. The Dakota Aquifer base was visually inspected in ArcView to see that the data was downloaded and opened correctly (Figure 26). The observation was made that the base contours included the surficial extent lines, which included the northern and western edges of Kansas, as well as a subsurface fault line. Therefore, the Dakota Aquifer base elevation coverage was converted to a shapefile and edited to delete all line features that were not contours (Figure 27). A field with altitude in meters was added to the shapefile by performing a calculation conversion on the altitude in feet so that analysis could be done using metric units (meters).

The edited Dakota Aquifer base contours were then transformed into a coverage in ARC/INFO. Then ARC/INFO was used to create a Triangulated Irregular Network (TIN) of the base before the TIN was converted into a grid (cell size 1600 square-meters). The grid was created so that calculations utilizing the Dakota Aquifer base elevations and surface elevations derived from other sources could be performed.

It is understood that the Dakota Aquifer base elevation coverage includes Cretaceous strata older than the Dakota Formation.

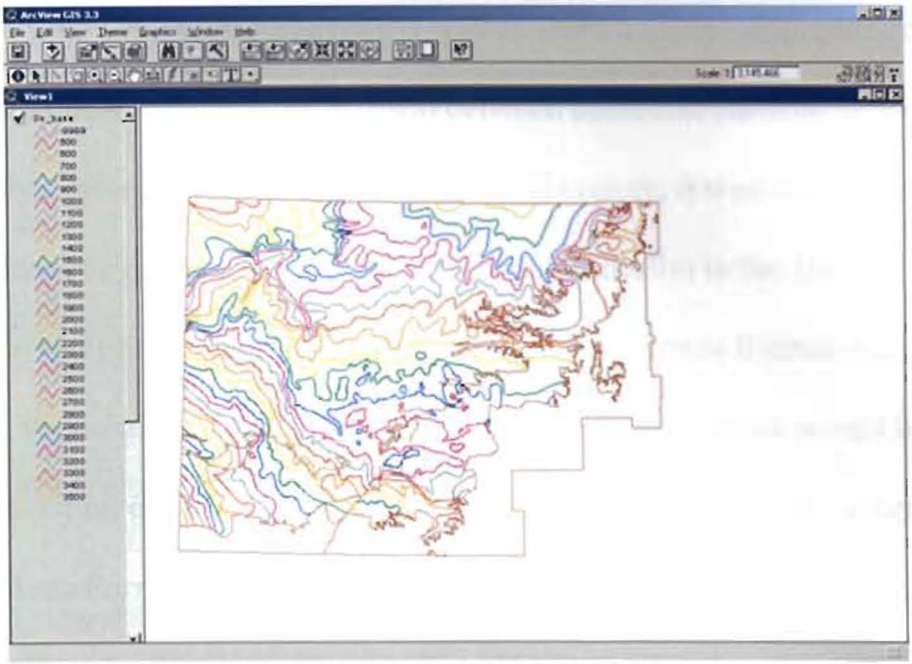

Figure 26: Dakota Aquifer Base Elevation As Downloaded. The Dakota Aquifer base elevation coverage as it appears in a screenshot when downloaded from DASC.

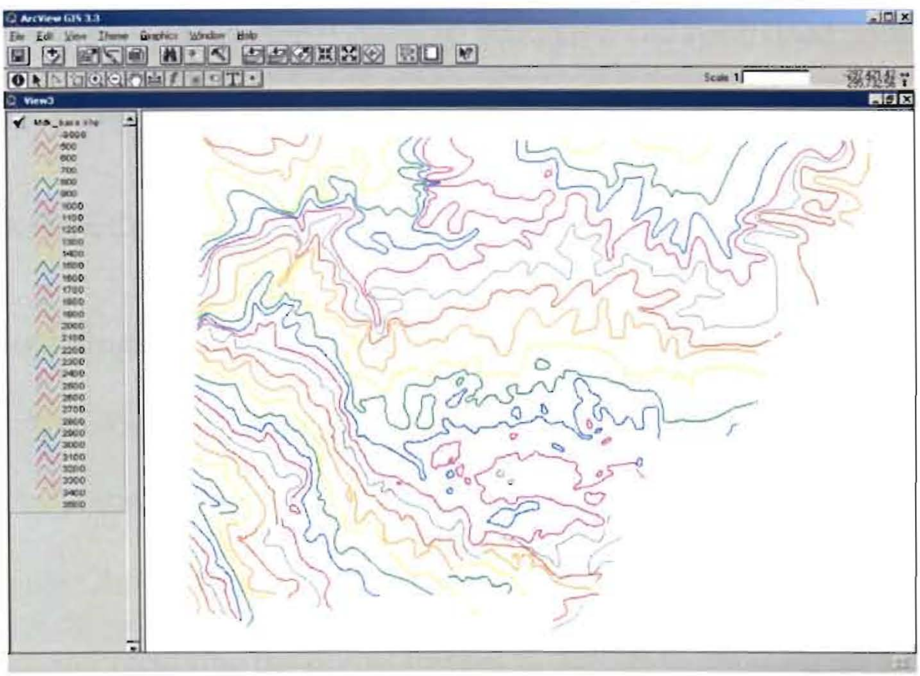

Figure 27: Dakota Aquifer Base Elevation Only Contours. Screenshot of the Dakota Aquifer base elevation coverage after the extraneous extent and fault lines are removed, leaving only the contour lines of the Dakota Aquifer base elevation.

However, the Dakota Aquifer base elevation was an easily obtainable coverage that would allow a general comparison between basal and surficial elevation of the mainly Cretaceous age strata in the area. Therefore, it was used in this study in an attempt to gain some control over where (vertically) in the Dakota Formation each collection site was located and to determine if obtaining a better source of the basal configuration of the Dakota Formation strata would be worth the effort. Upon examination of available data sources for a basal configuration of the Dakota Formation strata The Top of the Kiowa Formation was selected as a potentially more accurate measurement. However, the elevation of the base of the Dakota Aquifer was kept as part of this study both because it processing was already complete and because it could be compared and contrasted with the elevations obtained from the top of the Kiowa Formation.

Dakota-Kiowa Contact Elevation Processing

Processing for the Dakota-Kiowa contact data was performed using ArcView, ArcGIS, and ARC/INFO. The Dakota-Kiowa contact data was obtained by scanning the *Top Configuration of the Kiowa Formation* map from the *Dakota Aquifer Annual Report of 1989* (Macfarlane, *et. al.*, 1989b: Plate 5) and registering and rectifying the digital images in ArcGIS to the same map projection as the downloaded Dakota Aquifer coverages (Figure 28). The contours of the top of the Kiowa Formation were then digitized into a new Dakota-Kiowa base shapefile.

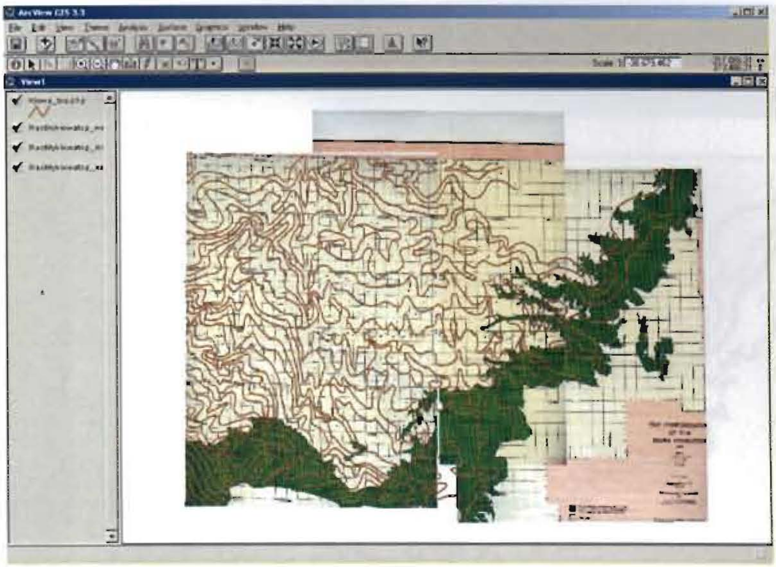

Figure 28: Digital Version of Dakota-Kiowa Contact Contours. The Kiowa Formation top elevation (in the subsurface) as it appears when processing occurred as seen in an ArcView screenshot.

The attributes for the contours in meters were then added to the shapefile before the Dakota-Kiowa shapefile was transformed into a coverage in ARC/INFO. The Dakota-Kiowa coverage was visually inspected in ArcView for accuracy.

The Dakota-Kiowa contact contours were then transformed from lines to points in ArcView using the "poly2pts" extension (Huber, 2002) because insufficient data was present along the edge to produce a TIN or grid of the entire area. Once the contours were present as points, additional points were added at the edges of the extent of the formations based on a comparison with the placement of the contours of both the Dakota-Kiowa contact and Dakota Aquifer base (Figure 29). Elevation values in meters were then added to the attribute tables for the resulting additional points.

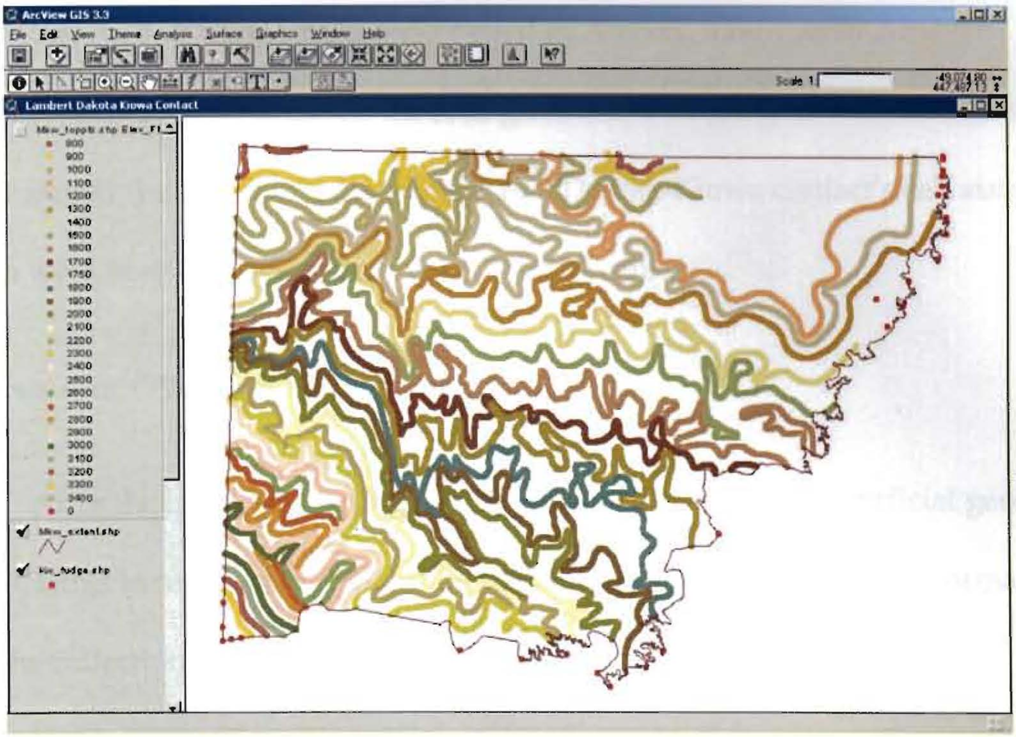

Figure 29: Dakota-Kiowa Contact "Contours" With Additional Edge Points. The Dakota-Kiowa contact elevation coverage after the contours are converted to points including the additional points that were added to the edge (shown in red) as seen in an ArcView screenshot.

The edited Dakota-Kiowa contact "contour" points were then transformed into a coverage in ARC/INFO. Then ARC/INFO was used to create a TIN and then transform the TIN into a grid (cell size 1600 square-meters). The grid was created so that calculations utilizing the Dakota-Kiowa contact elevations and surface elevations derived from other sources could be performed.

Surface Elevation Processing

Processing for the surface elevation as represented by the NED was accomplished using ArcGIS and ARC/INFO. First, the four NED parallel grids were downloaded from DASC and opened in ArcGIS. The Spatial Analyst extension was used to combine the four grids into a single grid with a cell size that matched the Dakota Aquifer base's and Dakota-Kiowa contact's cell size which were both 1600 square-meters (40 m x 40 m).

Processes for GIS Analysis

After the initial processing for the collection sites and the surficial geology used for this investigation, processing to determine where the Dakota Formation and the collection sites overlapped was done. First, all of the coverages were opened in ArcGIS. Then the collection sites were symbolized as outlines only and the entire State's surficial geology coverage was displayed for each formation. This allowed visual comparison between different datasets to be performed. For example, the location of Fort Harker was compared with the locations of collection sites. This allowed a visual confirmation of the bias of the collection sites to an approximation of the primary collector's residence (Figure 30).

The Dakota Formation, the combined Distance Collection Sites, the combined Limited Distance Collection Sites, and the combined PLSS Collection Sites coverages were added to ArcView. The Geoprocessing Wizard extension was used to limit the Dakota Formation to only those areas where the combined Distance Collection Site data, the combined Limited Distance Collection Site data, and the combined PLSS Collection Site data existed.

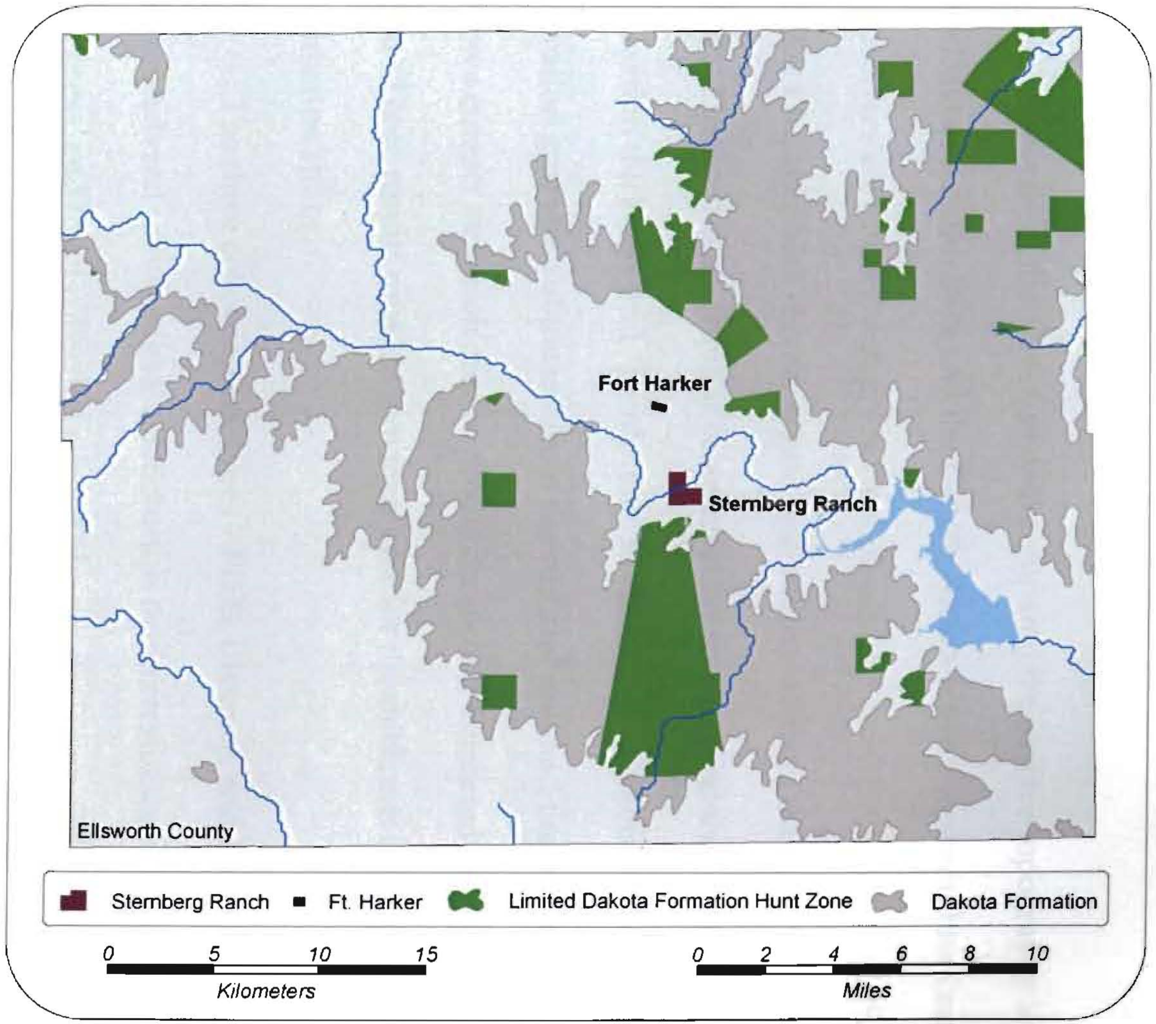

Figure 30: Fort Harker, Sternberg Ranch, and Dakota Flora Collection Sites. Ellsworth County, KS map created to illustrate the location of Fort Harker and Sternberg Ranch in relation to the collection sites in that county.

Then the two versions of the distance clipped Dakota Formation were each combined with the PLSS clipped Dakota Formation by the Geoprocessing Wizard extension. The Geoprocessing Wizard extension was also used to remove the lines produced by the outlines of the city boundaries visible in some of the collection sites.

Analysis of the elevation data compared the surface topography with both the Dakota Aquifer base and the Dakota-Kiowa contact topographies (mainly subsurface elevations) using ArcView, Excel, and ArcGIS. Using ArcGIS, the Dakota Aquifer base elevation grid was subtracted from the surficial grid and limited to the Dakota Aquifer base elevation area to produce an estimated formation thickness grid. In addition, in ArcGIS, the Dakota-Kiowa contact elevation grid was subtracted from the surficial grid and limited to the Dakota-Kiowa contact elevation area to produce a second estimated formation thickness grid. These results provide two measures for the thickness of the Dakota Formation strata.

The three collection site types—PLSS, Distance, and Limited Distance—were analyzed to investigate relationships between surface elevation, formation thickness, and fossil collection sites. This was done primarily by using a built-in function of ArcView that summarized the area of the collection site to obtain statistics about the surface elevation, Dakota Aquifer base elevation, Dakota-Kiowa contact elevation, and the two estimates of formation thickness at each collection site. To make this process easier, each collection site type was combined into a shapefile by the "XTools" extension (Delaune, 2003) before the process was performed. This process produced a table that contained, among other things, the mean elevation, minimum elevation, maximum elevation, and the standard deviation of elevations at each collection site. The tables were then exported from ArcView to Excel for analysis of the values. In Excel, the data was used to create a box and whisker graph representation of the mean elevation, minimum elevation, maximum elevation, and standard deviation for surface elevation, Dakota Aquifer base elevation, Dakota-Kiowa contact elevation, and the two estimates of formation thickness for each collection site type in order to look for patterns or clusters of similarity between collection sites.

After a pattern or cluster was determined for the surface elevation, the pattern was analyzed with the hypsography of the area. In ArcView, the contours of the hypsography (400–550 m) that appeared to make up the elevational pattern of collection site locations were selected from the hypsography coverages and converted into a new shapefile. The shapefile was then compared with the Dakota Formation surface outcrop and any similarities determined. In addition, to allow further investigation of the topographic relationships, the individual hypsography coverages for each collection site were combined into a single coverage and the individual hypsography shapefiles were combined into a single coverage. Both these combined hypsography coverages were clipped by the Dakota Formation boundaries to allow for a comparison with the elevations of the collection sites.

Chapter 3: Results and Discussion

The data gathering and analyses in this study resulted in a variety of types of information about the Dakota. These results can be roughly classified into results from the literature and archival search and GIS results.

Annotated Results of the Dakota Literature/Archival Search

Dakota Collection Sites Or Where the Specimens Are Geographically Found?

"The more resistant sandstone caps the hills and covers the slopes with residual sand and slumped fragments" as Plummer and Romary (1942: 327) described the landscape from which the Dakota Flora was collected. Charles H. Sternberg and other collectors who gathered the historical type specimens of the Dakota Flora apparently used these sorts of outcrops as their primary collection sites based on comments in Sternberg's biography and autobiographies (Rodgers, 1999; Sternberg, 1990).

Charles H. Sternberg collected a substantial amount of Dakota Flora specimens within the State of Kansas, some of which became type specimens. In his 1874 publication, Lesquereux specifically mentions a number of fine specimens of fossil leaves from the Dakota Group near Fort Harker, Kansas, where some localities and collection sites exist that are rich in remains of fossil plants.

> "In Kansas I have followed this formation along the Kansas Pacific Railroad, from the mouth of the Solomon River, for seventy-five miles to the west," says Lesquereux of the Dakota and that with the work of Professor Mudge it has also been traced up the Arkansas River from Fort Larned, Kansas to the boarder of the [S]tate (Lesquereux, 1874a: 12).

Therefore, "from the mouth of the Salina River to Fort Harker...banks of this red sandstone" are present (Lesquereux, 1874a: 18).

> "Concretionary specimens were found at more than twelve different localities, in groups covering limited areas, the largest tract being about 100 yards, the others not more than 20 yards in width, altogether distributed upon a land surface of 5 to 8 square miles"

is how Lesquereux (1892: 21) described the three thousand specimens collected in Ellsworth County itself.

It appears that these early observations by Lesquereux about collection sites and localities of the Dakota Flora are important based on observations from my field experiences. The fossil leaves that could be found in Dakota strata did indeed appear to be a relatively localized phenomenon. The fossils that are in sediments most like the type specimens also appeared to be from the sandstone outcrops on the hilltops and nearby fragments slumped from them.

Preservation in the Dakota

The strata containing these fossils are "more or less coarse, sandy materials, regularly stratified, more or less impregnated with oxide of iron, and according to the prevalence of this mineral, either hard, compact, dark red, or yellowish" (Lesquereux, 1874a: 19). However, Lesquereux and others observed that leaves are preserved in yellowish, friable, or easily disaggregated sandstones.

Lesquereux (1874a) gives this description of fossil leaf localities:

> "The leaves, indeed, are found sometimes rolled or crumbled as may have been dry leaves when falling upon a muddy surface where they may have been imbedded in that condition, and often, too, penetrating the mud edgewise, either vertically or in various degrees of inclination to the plane of the mud deposits; at some places they may have been rolled by the waves" (pg 28).

Lesquereux (1874a) also notes the homogeneity of leaf deposits, he states:

> "The leaves, moreover, are not variously mixed, as they should be if they had been carried from any distance by currents or any other kind of motive-power; but are generally found in groups of representatives of same or analogous species" (pg 29).

This is evidenced by a specimen in the Sternberg Museum (Figure 31). In addition, it is well known that bias often exists in collecting fossils, towards looking for similar specimens in areas where fossils have been collected before.

Figure 31: "*Sassafras*" Slab from the Dakota Formation. Large slab of Dakota sandstone from Washington County, KS where incomplete/broken leaves were chipped away said to be containing nothing but leaves of *Sassafras cretaceum* var. *grossedentatum*. The Sternberg Museum also owns a similar large slab of Dakota sandstone from Washington County, KS (SMNH Fossil Number PB192) that is an unprepared slab also said to be containing nothing but leaves of *Sassafras cretaceum* var. *grossedentatum*. While the leaves in the two specimens are similar whether they are *Sassafras cretaceum* var. *grossedentatum* by today's naming standards is in doubt.

Nickel (1972) states:

> "The imprints are found on...well cemented sandstone with iron oxide cement...[and] probably were more highly cemented because of greater iron oxide precipitation around the leaves" (pg 47)

while attempting to describe the preservation of the Dakota Flora. Lesquereux described the mode of preservation of the Dakota Flora (1892) as:

> "In Ellsworth County, Kansas, of a very large number of leaves embedded in concretions in the same manner as remains of Carboniferous plants have been preserved in the celebrated nodules of Mazon Creek, Illinois"(pg 21).

This hypothesis about preservational method is corroborated with Rodgers's (1999) accounting of a Sternberg field assistant. Rodgers (1999) states:

> "Barta remembered hunting for peculiar oval or rounded concretions that appeared to fit together like the halves of an eggshell. Breaking them open revealed the perfect imprints of leaves" (pg 225).

Work Done to Date on the Dakota Flora—As Understood

"The plants of the Dakota Group, as known mostly by detached leaves, are striking from the beauty, the elegance, the variety of their forms, and from their size" as Lesquereux states (1883: 4). These leaves vary widely in size, as Lesquereux describes "fully developed" leaves ranging from one inch to one foot and even up to one and a half feet in diameter (Lesquereux, 1883: 4). In investigating the museum specimens for collection site and locality data, size variation was also apparent as leaf-sizes ranged from 2 mm to 20 cm (Figures 32 and 33).

Historical accounts of fossil leaf specimens, especially those of Lesquereux, also indicate that they are very abundant within a locality of small extent. However, where the fossils appear in the sediment horizon usually disappears entirely for miles or is not found again (Lesquereux, 1874a). "The locality near Salina, from which a large number of fine specimens have been obtained, covers scarcely three acres of ground" (Lesquereux, 1874a: 28).

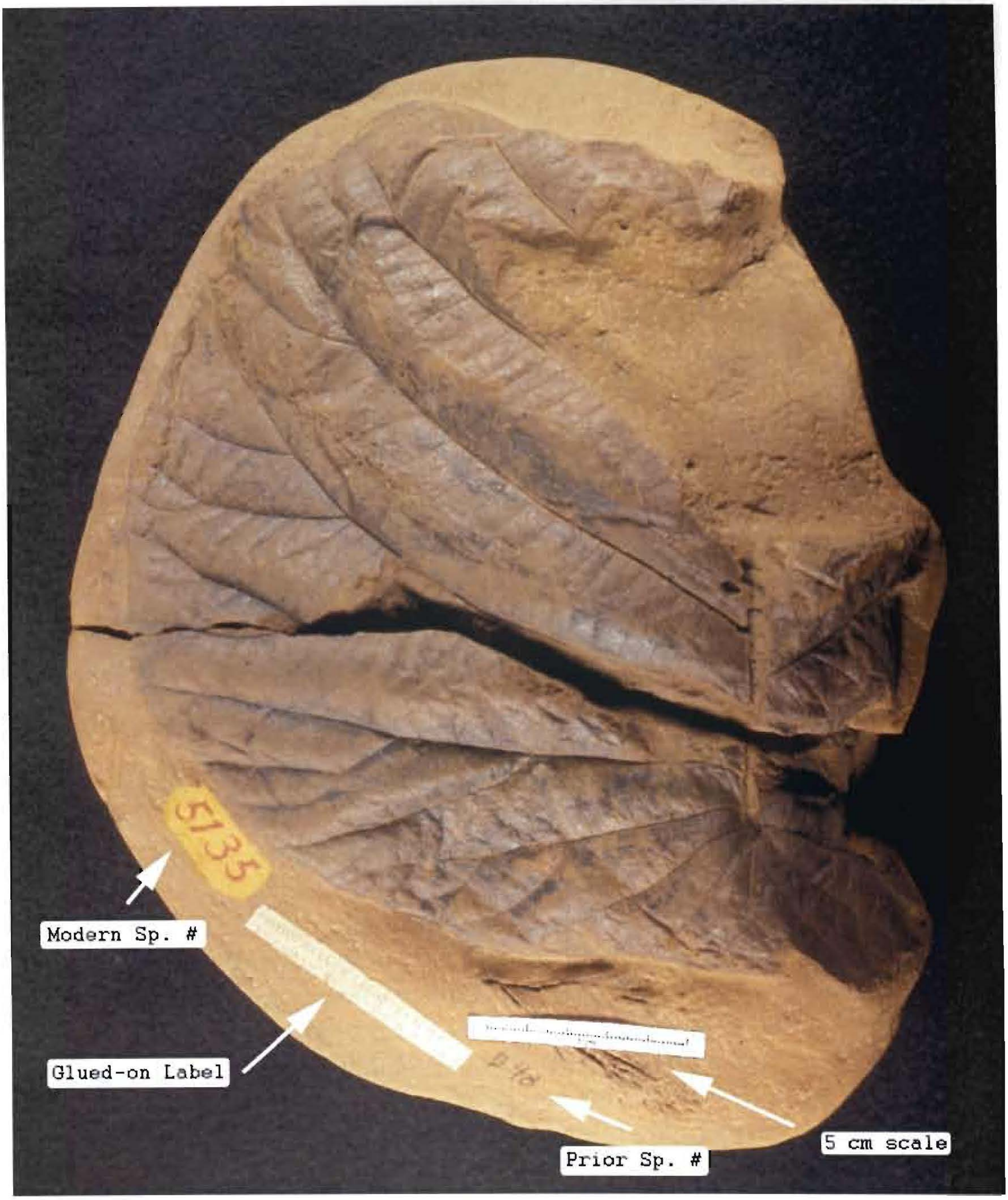

Figure 32: Largest Dakota Formation Leaf Specimen Observed by the Author. The largest leaf (approximately 20 cm) observed by the author from the specimens labeled as Dakota, is specimen number KU NHM 5135 at the University of Kansas Natural History Museum, and is Plate XL in Lesquereux's 1892 Monograph.

Figure 33: Smallest Dakota Flora Leaf Specimen Observed by the Author. The smallest leaf (only 2 mm) observed by the author from the specimens labeled as Dakota, is specimen number ESU 1048 on display at the JGM.

In fact, Lesquereux (1874a) said that according to Mudge:

> "The fossil plants are found at certain intervals of territory. In searching for them, we have frequently examined every visible outcrop for fifteen or twenty miles without finding a specimen; then, perhaps, a single square mile would furnish several good localities. ... The fossil plants are usually obtained from thin layers or strata, extending in a horizontal position along a ravine or around a hill. They may occur at several places in the same vicinity, but usually without any connection. ... The deposits appear to have been local; dependent upon circumstances" (pg 29).

My own observation in the field of more recently collected collection sites and localities tends to show exactly the type of pockets of plant fossils described by the historical collectors.

Based on my observations of locatable type specimens and the assumption, for the time being, that all types come from the same locality, approximately 20-35 morphotypes appear present. At least 15-20 of these morphotypes are presumably in the University of Kansas Natural History Museum Paleobotany Collection. Probably 5-15 additional morphotypes are added if slides of Smithsonian Institute type specimens are also considered. While morphotyping has been available for some time as a tool for paleobotanists to use, any through study of diversity should begin with a direct comparison of the flora in question. During the 19th century and first half of the 20th century, paleobotanists tried to identify fossil leaves by comparing their overall shapes to living plants (Dilcher, 1974; Wing, 1984). Perhaps this explains why indications of early morphotyping appear on the specimens and specimen labels at the Sternberg Museum.

Lesquereux was far-reaching in his vision when he stated in 1883:

> "we may consider the formation of the Dakota Group as produced by a very slow, gradual, prolonged depression of the Western slope of the continent, bringing up from the South or West the invasion of ocean water charged with muddy materials, periodically heaped farther and farther inland by powerful tides. We may suppose, too, the invading flow as bringing with it seeds or fragments of roots of plants derived from a country now covered by the sea, and distributing here and there those germs of vegetable organisms. But all this does not account for much in the solution of the problem; it may explain the distribution, but the first appearance, and it seems the simultaneous multiplication, of the

> dicotyledonous plants remains a fact inconceivable to reason" (pg 24).

Perhaps this statement played a role in Lidgard and Crane's (1988) decision to exclude this flora in their Cretaceous study. However, further studies of the diversity of the Dakota Flora, in its entirety, to verify the magnitude of the diversity of species are necessary in order for the Dakota Flora to be useful in the study of the early history of angiosperms. These studies are especially important since I perceived a higher diversity than the 20 species that Lidgard and Crane (1988) found for Cretaceous floras in the specimens I observed. Whether or not this increased diversity is due to: combining sediments as the sea transgressed or due to multiple localities and collection sites being grouped into an overall single well-defined geographic area is still largely an uninvestigated question.

Locational Errors Associated With Dakota Flora Fossils

The Dakota strata and flora may contain spatial data problems or location accuracy errors. In fact, since the Dakota Formation includes a variety of geological and paleontological aspects, numerous collection site and locality errors are present. These accuracy problems are mainly the result of the many previous studies resulting in spatial location data that contains locational accuracy problems. Collection of Dakota Flora by more than one person and changes in equipment, techniques, and methods has occurred therefore, the recording of the spatial data has affected the potential for spatial studies of Dakota material.

Each data type presents its own benefits and challenges based on its strengths and weaknesses, the inherent problems with each type of data need to be understood, especially as it relates to the Dakota (both the strata and the flora). Because the Dakota (both the strata and the flora) was first studied in the early 1800s, the media on which the data was recorded/documented have been altered, usually for the worse, by time. This is evident in the Dakota (both the strata and the flora) data that was recorded on paper that has become yellowed and fragile with age. In the following discussion of problems and errors of previous work special care was taken, not to single out a particular individual/organization as the problems and errors are due mainly to the age of the data and the media on which the data was recorded.

Dakota Historical Data & Previous Studies

In the case of the Dakota Flora, the techniques, technologies, and resources in use when the specimens were collected have indeed greatly changed and therefore the theories used to interpret the Dakota Flora have also changed. While the Dakota (both the strata and the flora) was first described and published in a time of widespread scientific literacy where researchers and interested parties could readily access most published works, by modern standards they are not readily available mainly due to the greater number of researchers (and libraries) desiring the publications and problems with preservation of those publications. In addition, the Dakota strata and flora were investigated when results were not necessarily widely published/distributed or readily available, making for difficulty in locating the papers today (*e.g.*, *The Compass*). The late 1800s and early 1900s are known for poor referencing of prior studies in current studies according to librarians and literary scholars (Personal Communication Akers, 2005; Nudds and Palmer, 1990). In addition, this time-period is also known for pseudo re-releases of a paper by multiple agencies/publishers under slightly different titles (*e.g.*, Lesquereux's 1874 publications *Contributions to the Fossil Flora of the Western Territories – Part I: The Cretaceous Flora* and *Report on the Cretaceous and Tertiary Floras of the Western Territories: Extracted from the Annual Report of the United States Geological and Geographical Survey of the Territories for 1874*). Much early work has been lost or purposefully overlooked on a variety of geological and paleontological topics as its popularity went out of vogue in favor of newer theories and techniques. Once the previous study and/or historical data are located, one still must contend with the techniques, theories, and technologies utilized then as opposed to current methodologies. This is often difficult, if not impossible, as historical data often do not supply sufficient information where discovered that would allow the data to be used in present day comparisons and studies. Instead, the historical data often refers to a previous study or assumes the reader/observer has knowledge of the techniques, theories, and technologies of the time. In addition, items about the location and nearby towns have changed by either growing or shrinking in aerial extent (*e.g.*, Ellsworth, KS), changing names (*e.g.*, Churchill, KS to Tescott, KS) or completely disappearing (*e.g.*, Terra Cotta, KS) (United States Geological Survey's National Geologic Mapping Program, 2000a). This is most apparent in the descriptions associated with fossil collection sites and localities as it was observed on their labels in museums.

Dakota Fossil Collections

The Dakota Flora specimens in fossil collections, most of which were collected in 1860s and 1870s, often do not contain much detail about the collection site or locality from which the specimens were collected. While the labels associated with the specimens often contain collection site information they are often illegible because of deterioration of the paper on which they are written or the uneven surface on which they are written on, the calligraphy in which they are written, and the earlier American (1850–1950) vernacular which was used. Once the collection site and/or locality information has been read and interpreted, it is often not as specific as one would like. One of the reasons for the incomplete Dakota Flora fossil collection site data is the fossils were a sold, hence specifics of location were not given to the buyer as the collector was hiding the location for future sales. For example, many *Sassafras* specimens are simply labeled Sassafras Hollow, a name used by locals to name the collection site location though it probably was officially called something different and is therefore unknown today. Additionally, some specimen labels and monographs only specify Ellsworth County, Kansas or simply Kansas because only generalized locations were recalled when recorded for the museum/collector.

Complications are also introduced because specifications in the monographs of the late 1800s and early 1900s indicate that not all fossil collections of scientific importance are housed in museums and their current location is unknown and therefore inaccessible. Curatorial conditions and collection policies of organization housing the Dakota Flora collections may limit the ease of access and the usefulness of the visit if there is any disorganization or limitations of materials a researcher can observe. Limitations of Dakota Flora collections were observed in this study. However, it is also understood and appreciated that the organizations housing the collections of Dakota Flora visited in this study each have their own budgetary concerns, guiding principles, and protocols. These factors however had, and continue to have, some impact on their collections.

Gathering spatial data from fossil collections can be time consuming as each specimen label and specimen often needs to be scrutinized and deciphered for collection site and locality data. This affects the quality and quantity of data that can be obtained from collection and museum visits, as visits tend not to be for prolonged time periods. Also given all the time involved to obtain the collection site data, one would hope that examination of fossil collections provides sufficient useful data to the study to make them worthwhile.

Unfortunately, while all data is useful to some degree, it was often found that many collection site descriptions were not sufficient to use in the study.

Dakota Flora Collection Site Descriptions

Collection site descriptions of the Dakota Flora have their own spatial data problems. Collection site descriptions tend to be vague and imprecise because they were made in the 1800s from multiple visits as the collector wandered the terrain of central Kansas. Therefore, an imprecise component from the vague descriptions and a temporal component from the multiple visits are often added to the Dakota collection site description spatial data. While I feel these imprecise and temporal components are always present, these components usually have not been acknowledged or taken into consideration in Dakota studies. Furthermore, location is taken for granted by those familiar with the hilly terrain of Central Kansas and/or the Dakota. While this may have been all they had to go by, these imprecise descriptions are often not sufficient for modern fieldworkers who wish to relocate the collection sites. When the typical field location descriptions of compass bearings, distances from cities or rivers, locally conspicuous landmarks, and old and modern photographs are available, they still need interpretation to get close to what might be the original collection site.

Fieldnotes on Dakota Collection Sites

Dakota fieldnotes about fossil collection are difficult to obtain, especially since all the early collectors and workers have retired and/or are now deceased. The locations of their field notebooks are not known or even if they were kept. Those fieldnotes whose locations are suspected (*i.e.*, those of the Sternberg family) usually reside in places where they are kept confidential for a variety of reasons. The few research or fieldnotes on the Dakota Flora collection sites that have been observed from the historical researchers have handwriting and abbreviations that had to be deciphered and transcribed into useable formats, which was a lengthy process (some are still not decipherable) that adds uncertainties.

Locational Data Considerations

Methods for describing research sites have changed with time. Modern studies usually involve GPS and GIS, which allow for datasets that are more accurate. Therefore, historical data needs processed to allow it to be incorporated into modern studies due to the spatial data needs of GIS. Therefore, to improve the usefulness and understanding of Dakota collection sites and localities, especially those of historically collected locations, the GIS-related processes of this study were required and will continue to be required if more historical data becomes available. These processes are especially important to those studies involving geographic and/or historical applications, like the Dakota strata and flora studies, to preserve the preceding efforts. Since the Dakota strata and flora relationships are complex and spatially variable, once they are better understood it should help generate insights into the stratigraphy, sedimentology, and paleontological aspects of the Dakota.

Annotated Results of the GIS Analyses

The results of analyses produced some intriguing and most probably significant correlations between the modern surface elevations (that are above mean seal level—AMSL) and the collection sites thereby suggesting some similarity in vicinities from which fossil flora were collected. A few basic maps of Kansas and the area in Central Kansas where most of the collection sites probably were located were produced to orient the reader to the general fossil collecting locations, surficial geology, surface elevations (AMSL), Dakota Aquifer base elevations (DB), Dakota-Kiowa contact elevations (TKW), and estimates of Dakota Formation thicknesses (ADB) in Kansas (Figures 34-41). From these basic Kansas maps more localized and specialized maps were produced to show the relationships between GIS narrowed fossil collecting locations, surficial geology, AMSL elevations, DB elevations, TKW elevations, and ADB thickness estimates in Kansas (Table 8).

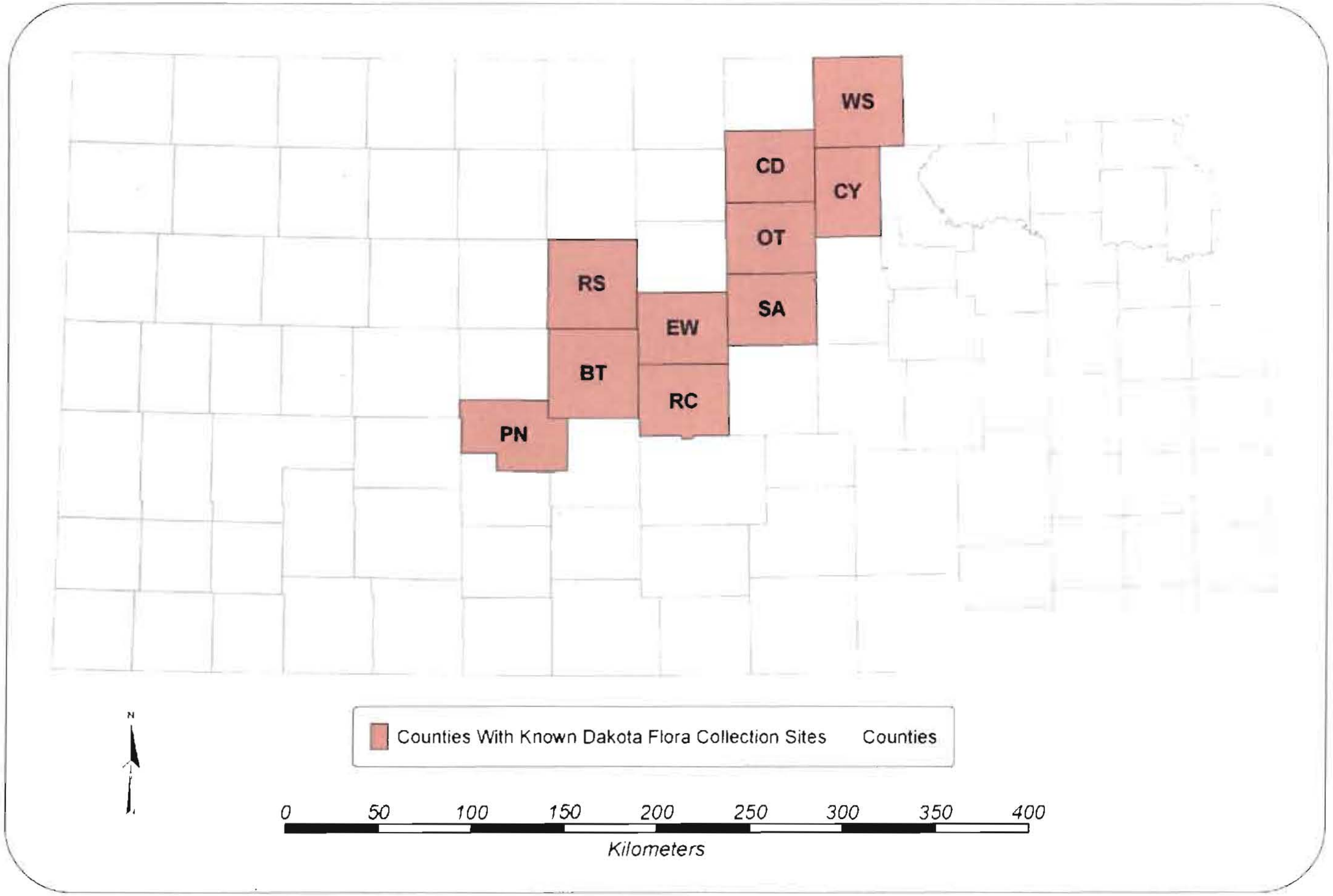

Figure 34: Kansas Counties Containing Dakota Collection Sites. Coral-shaded counties are counties (CY=Clay, CD=Cloud, BT=Barton, EW=Ellsworth, OT=Ottawa, PN=Pawnee, RC=Rice, RS=Russell, SA=Saline, and WS=Washington) in Kansas from which collection site data has been reported.

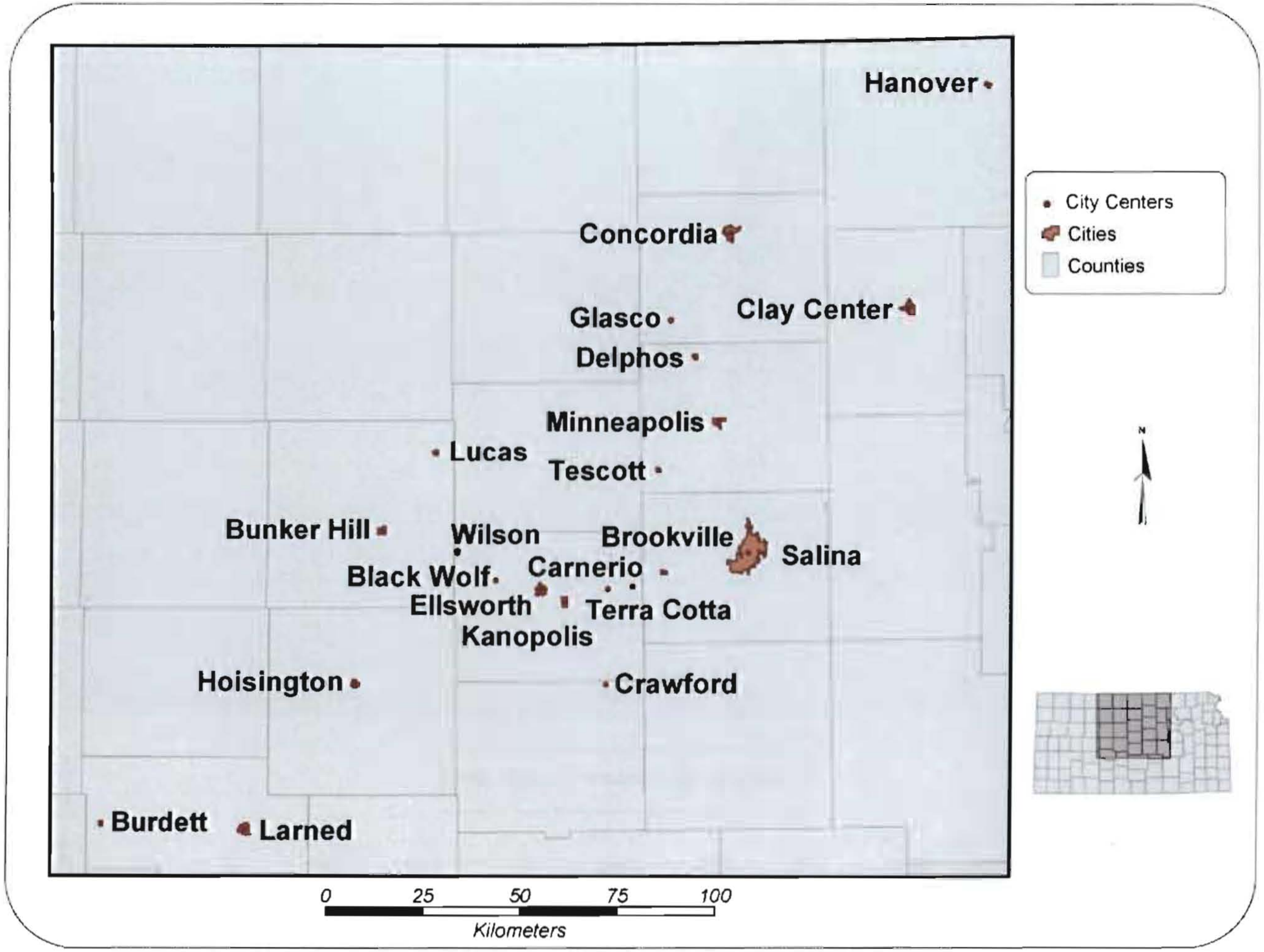

Figure 35: Kansas Cities Near Collection Site Locations. Locations of the cities (by modern name and location) mentioned in collection site descriptions. Although Terra Cotta, KS no longer exists it is shown as well.

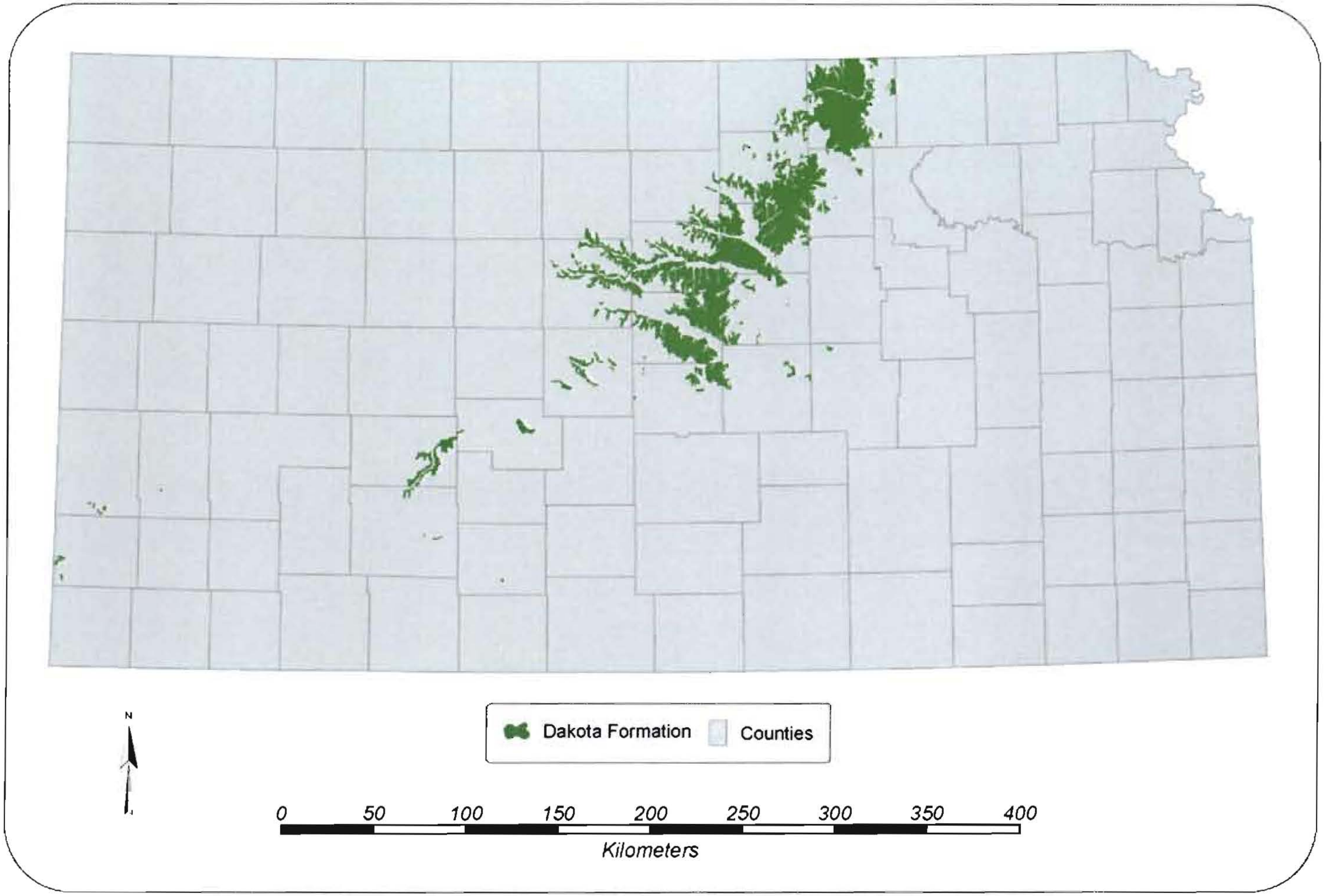

Figure 36: Kansas Dakota Formation Outcrops. Dakota Formation outcrops derived from statewide surficial geology coverages downloaded from DASC.

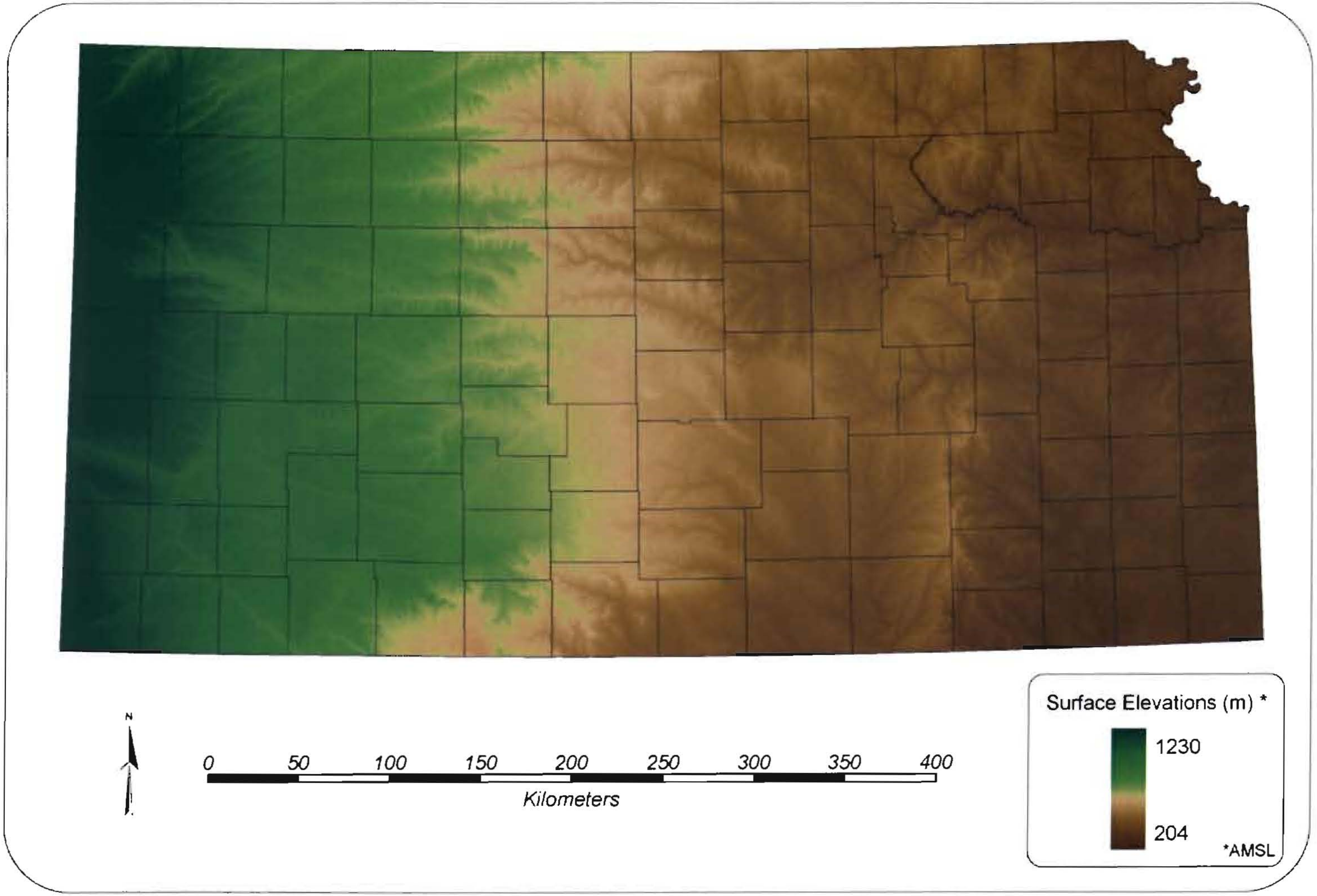

Figure 37: **Kansas Surface Elevations.** Surface elevations above mean sea level (AMSL) in Kansas created using NED data.

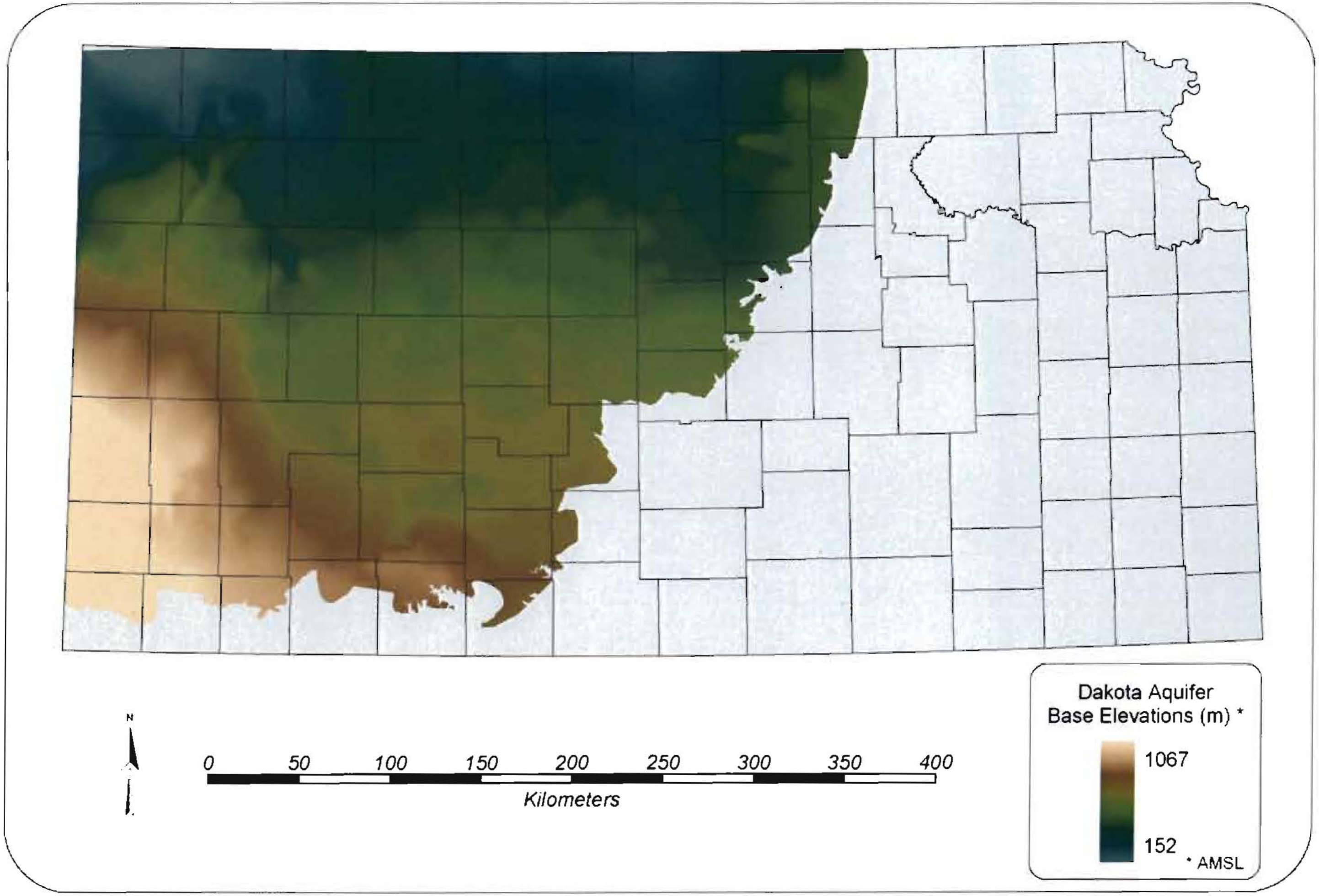

Figure 38: Kansas Dakota Aquifer Base Elevations. Dakota Aquifer base elevations above mean sea level (AMSL) in Kansas derived from Dakota Aquifer data downloaded from DASC.

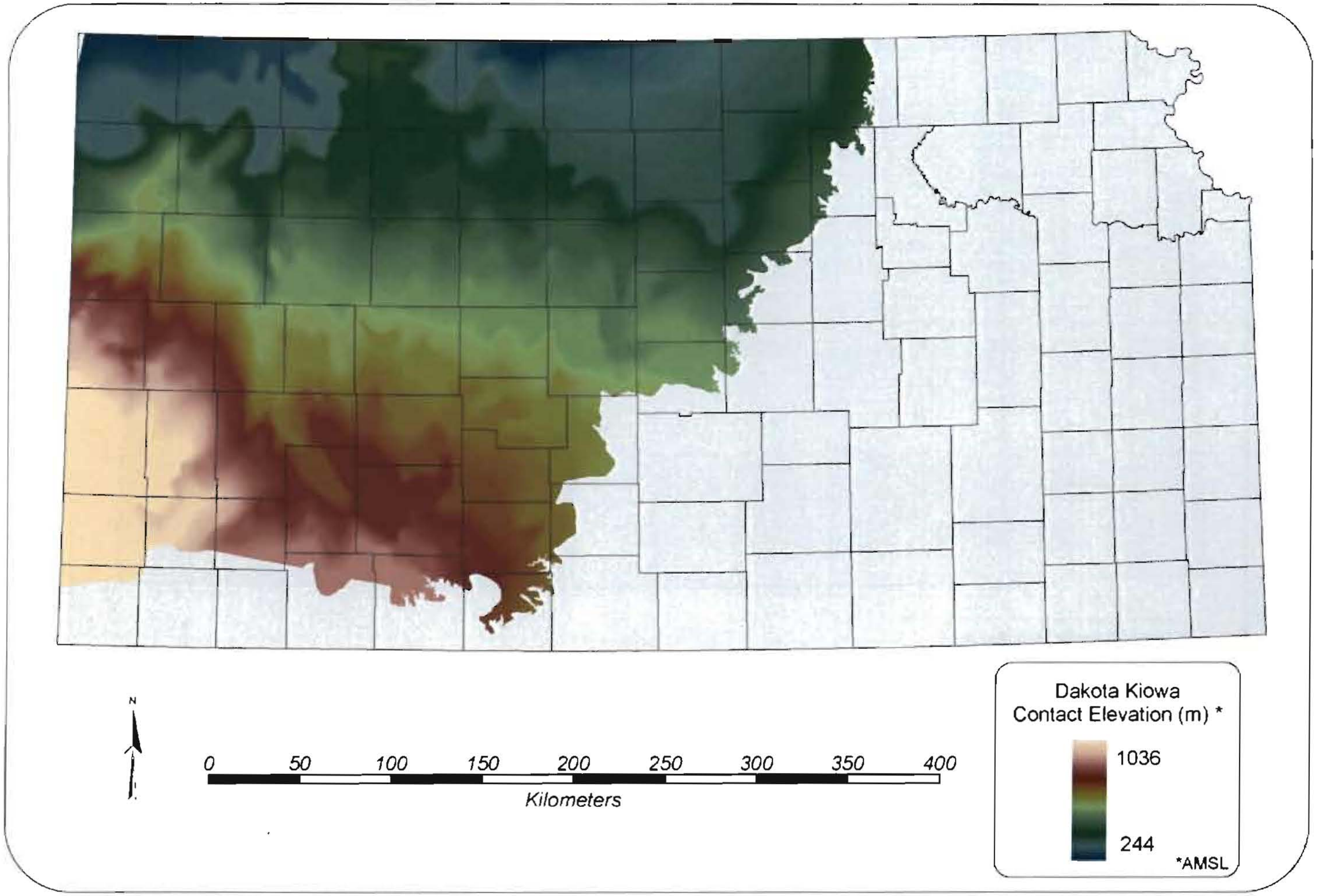

Figure 39: Kansas Dakota-Kiowa Contact Elevations. Dakota-Kiowa contact elevations above mean sea level (AMSL) in Kansas derived from digitized contours from the *Top Configuration of the Kiowa Formation* map produced in 1989.

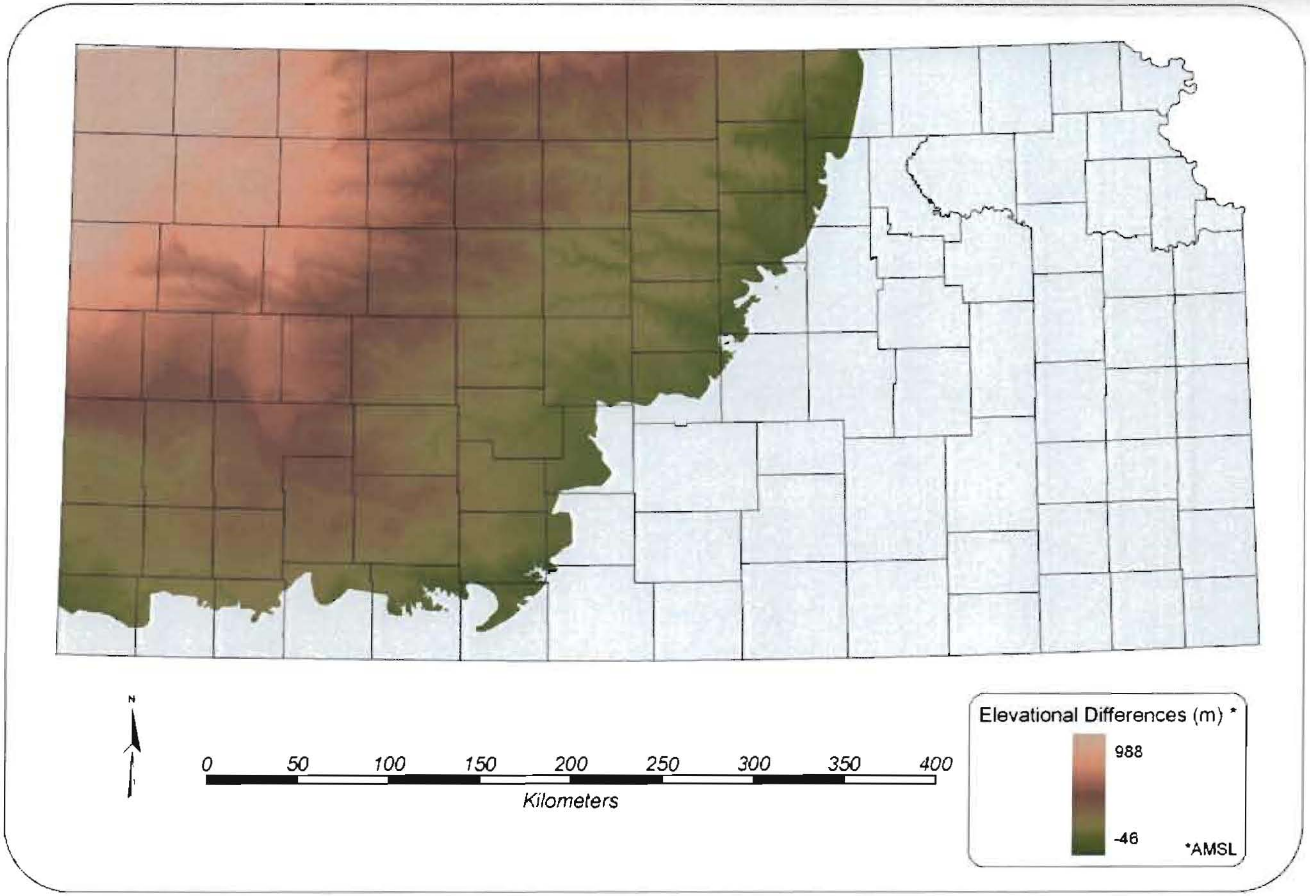

Figure 40: Dakota Formation Thickness Estimates from Dakota Aquifer Base Elevations. Map created from ABD # 1 thickness estimates for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Additional problems exist because in places the Dakota strata is not present and the base used was actually the top of the Permian strata. Negative values are better seen in Figure 42.

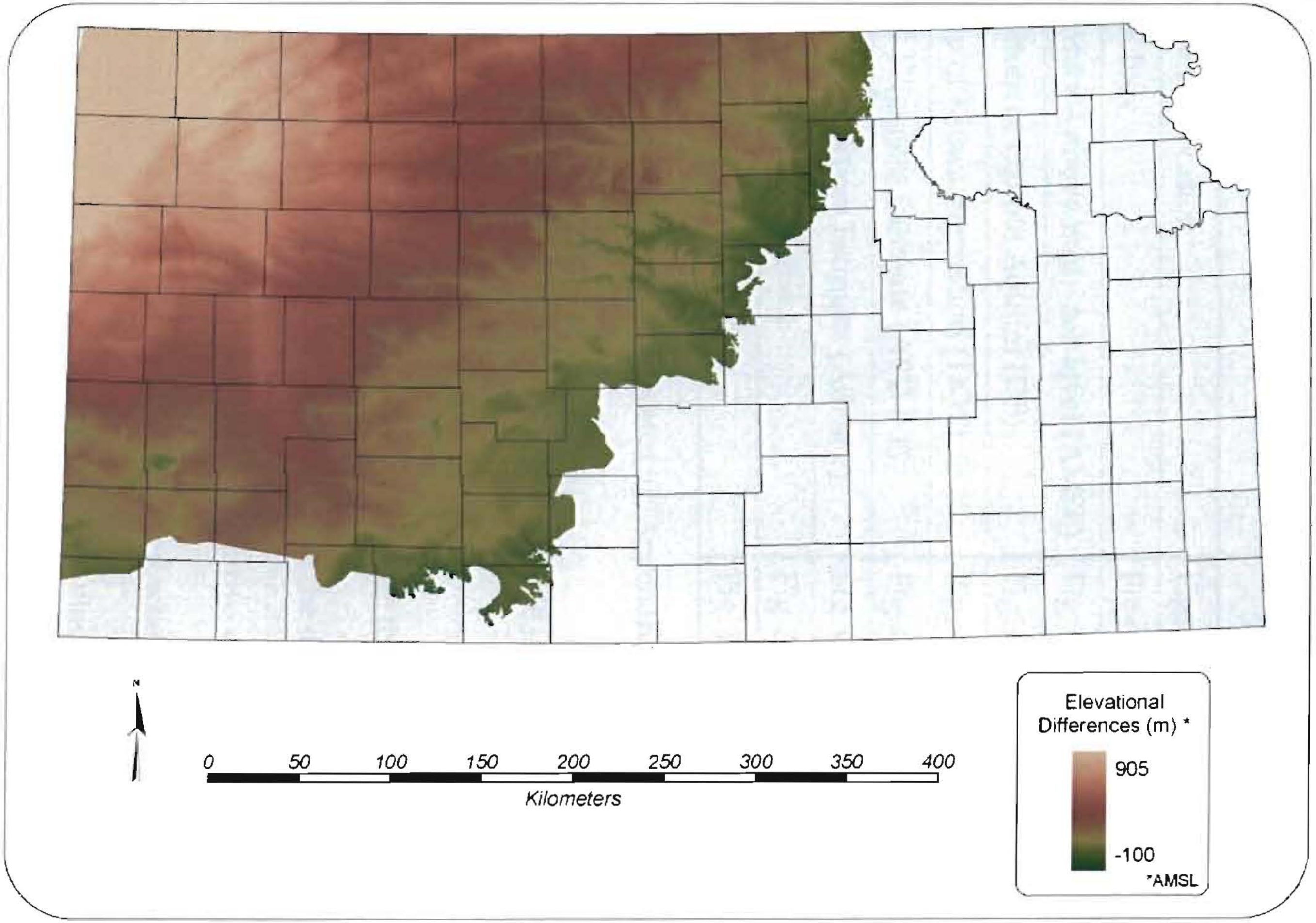

Figure 41: Dakota Formation Thickness Estimates from Dakota-Kiowa Contact Elevations. Map created from ABD # 2 thickness estimates for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Negative values are better seen in Figure 43.

Table 8: Summary of Collection Site Maps. Because multiple maps were created for all three types of collection sites as they were analyzed, a listing was created here for connivance.

Map Types	Collection Site Type		
	PLSS	**Distance**	**Limited Distance**
General Location	Figs. 44 & 45	No Fig.	No Fig.
Geology	Figs. 46 & 47	Fig. 48	Fig. 49
Surface—above mean sea level (AMSL)	Fig. C 1	Fig. C 2	Fig. C 3
Bottom of Dakota Aquifer (DB)	Fig. C 4	Fig. C 5	Fig. C 6
Top of Kiowa Formation (TKW)	Fig. C 7	Fig. C 8	Fig. C 9
DB Thickness Estimate (ABD # 1)	Fig. C 10	Fig. C 11	Fig. C 12
TKW Thickness Estimate (ABD# 2)	Fig. C 13	Fig. C 14	Fig. C 15
Edge Effects of ADB # 1	Fig. 51	Fig. 52	Fig. 53
Edge Effects of ABD # 2	Fig. 54	Fig. 55	Fig. 56

* Indicates an additional figure located in "Appendix C: Additional Figures" starting on page 269.

Both ABD thickness estimates have data in their maps based on the DB elevations or the TKW elevations and have some areas in which there are negative values (Figures 42 and 43). I surmise that there are several reasons for these negative values. I think one reason is the difference between the surface elevation and basal elevations created negative values has to do with the fact that the basal elevational data were not checked when they were produced at the scale of the NEDs used to obtain the surface elevations for this study.

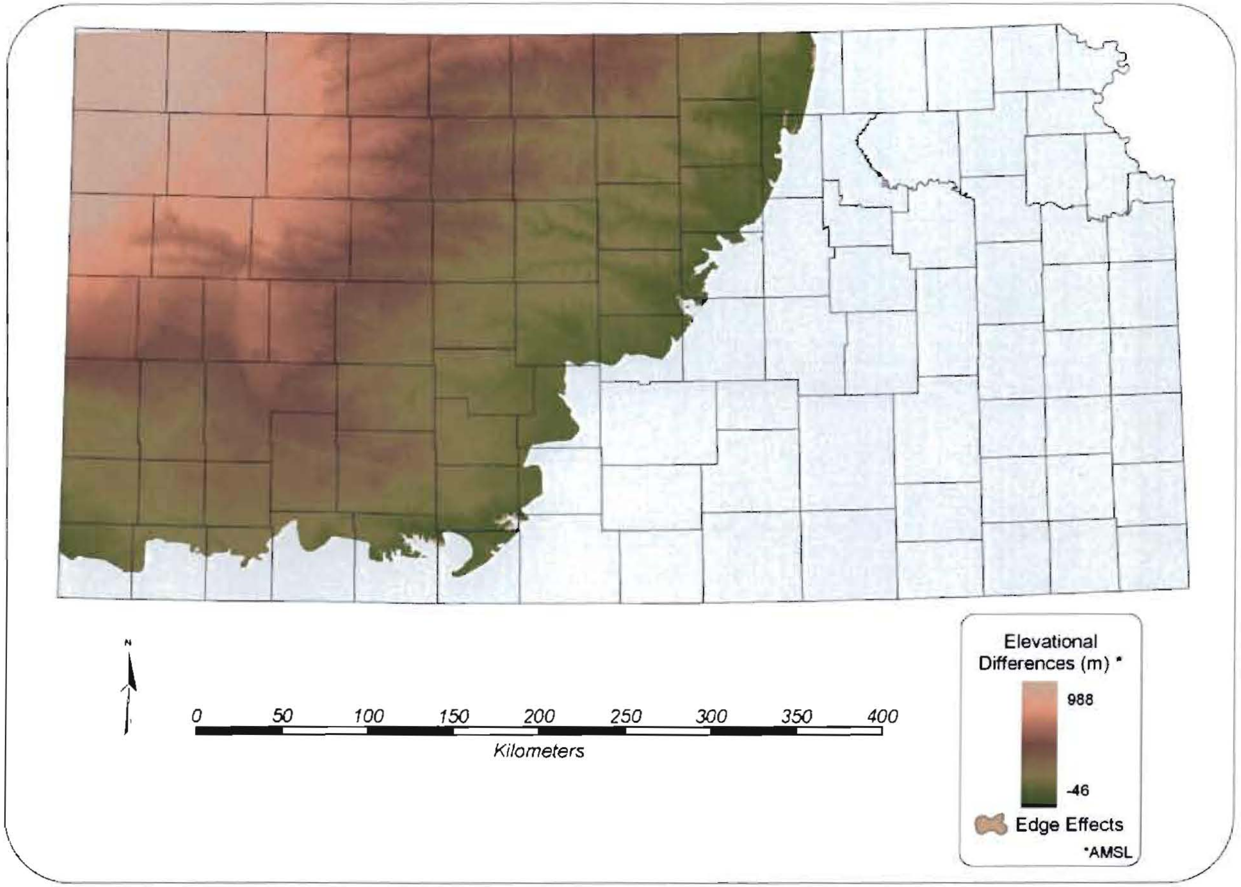

Figure 42: Edge Effects of Dakota Formation Thickness Estimates from Dakota Aquifer Base Elevations. The edge effects are almost unnoticeable on this map created from created from ABD # 1 thickness estimates for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Additional problems exist because in places the Dakota strata is not present and the base used was actually the top of the Permian strata.

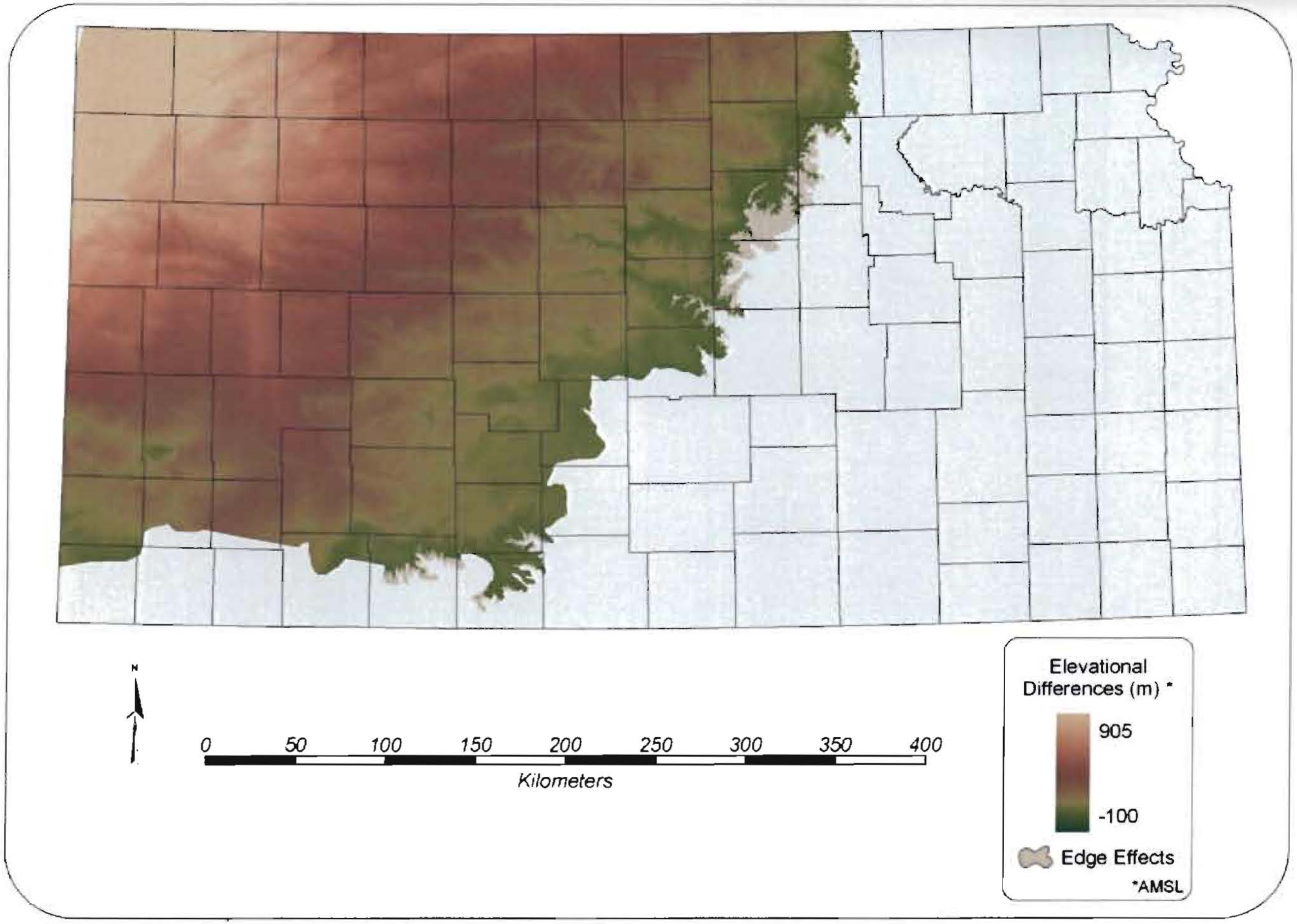

Figure 43: Edge Effects of Dakota Formation Thickness Estimates from Dakota-Kiowa Contact Elevations. Noticeable edge effects on this map created from created from ABD # 1 thickness estimates for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn.

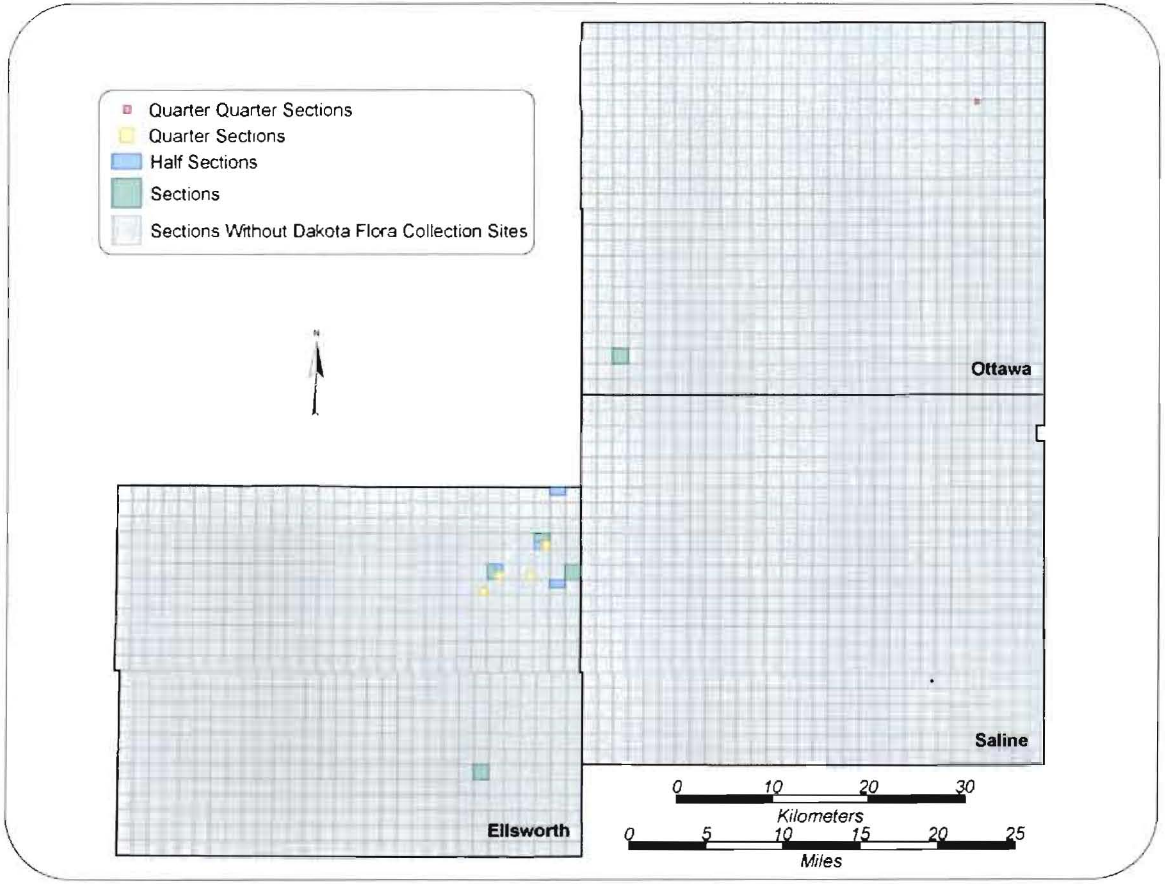

Figure 44: Kansas PLSS Collection Site Locations with Complete Descriptions. PLSS Collection Sites that have a legal description that is complete enough to narrow it done to one area are depicted on this created map. Because quarter-quarter sections are small areas, they are difficult to see on this three county map. Therefore, since there is only one quarter-quarter section location used in this study, its location (northeastern Ottawa County) is specified to ensure that it is not overlooked on the map.

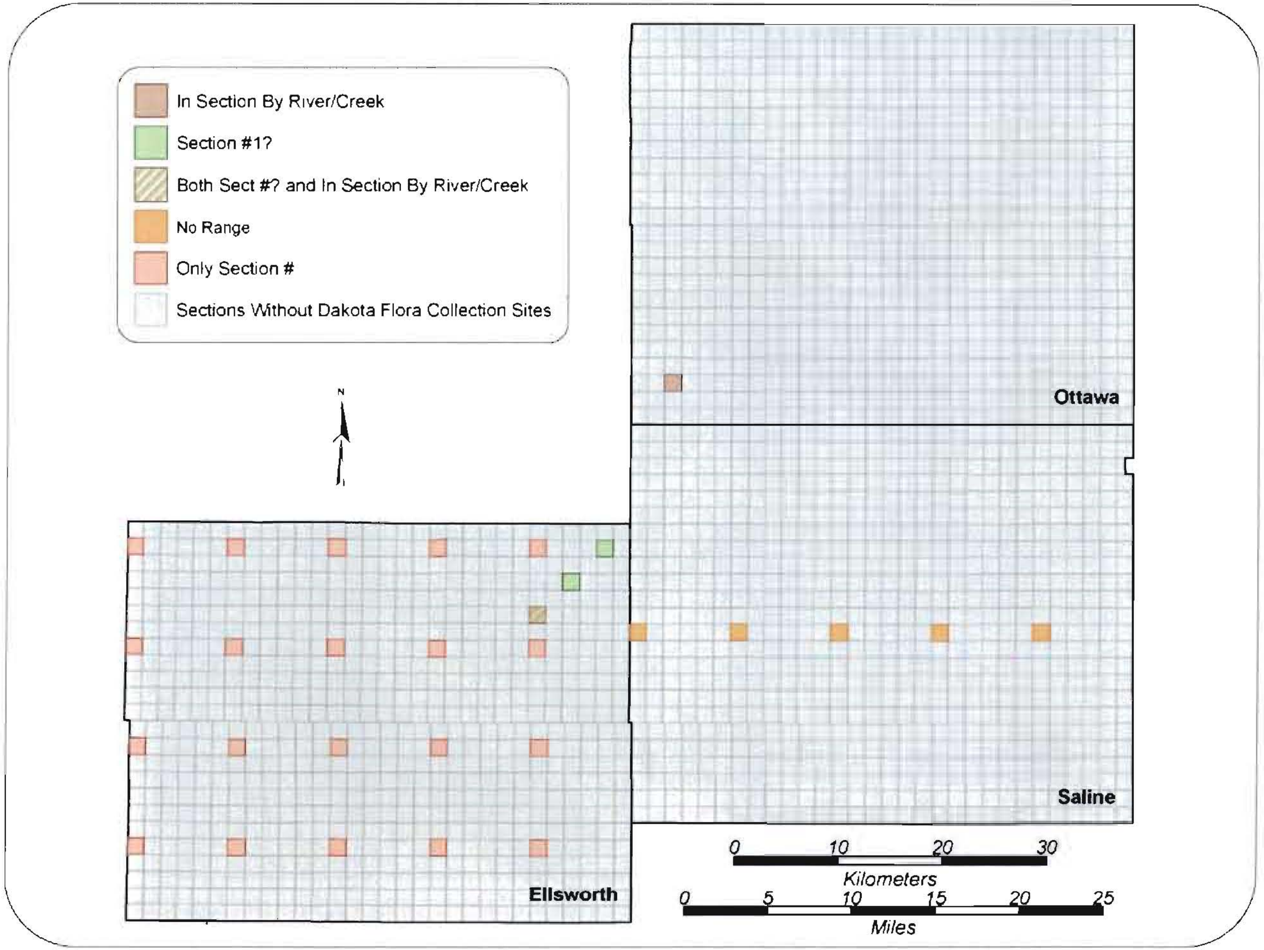

Figure 45: Kansas PLSS Collection Site Locations with Problematic Descriptions. PLSS Collection Sites that have a legal description that is ambiguous and needed further information to narrow it done to one area are depicted on this created map.

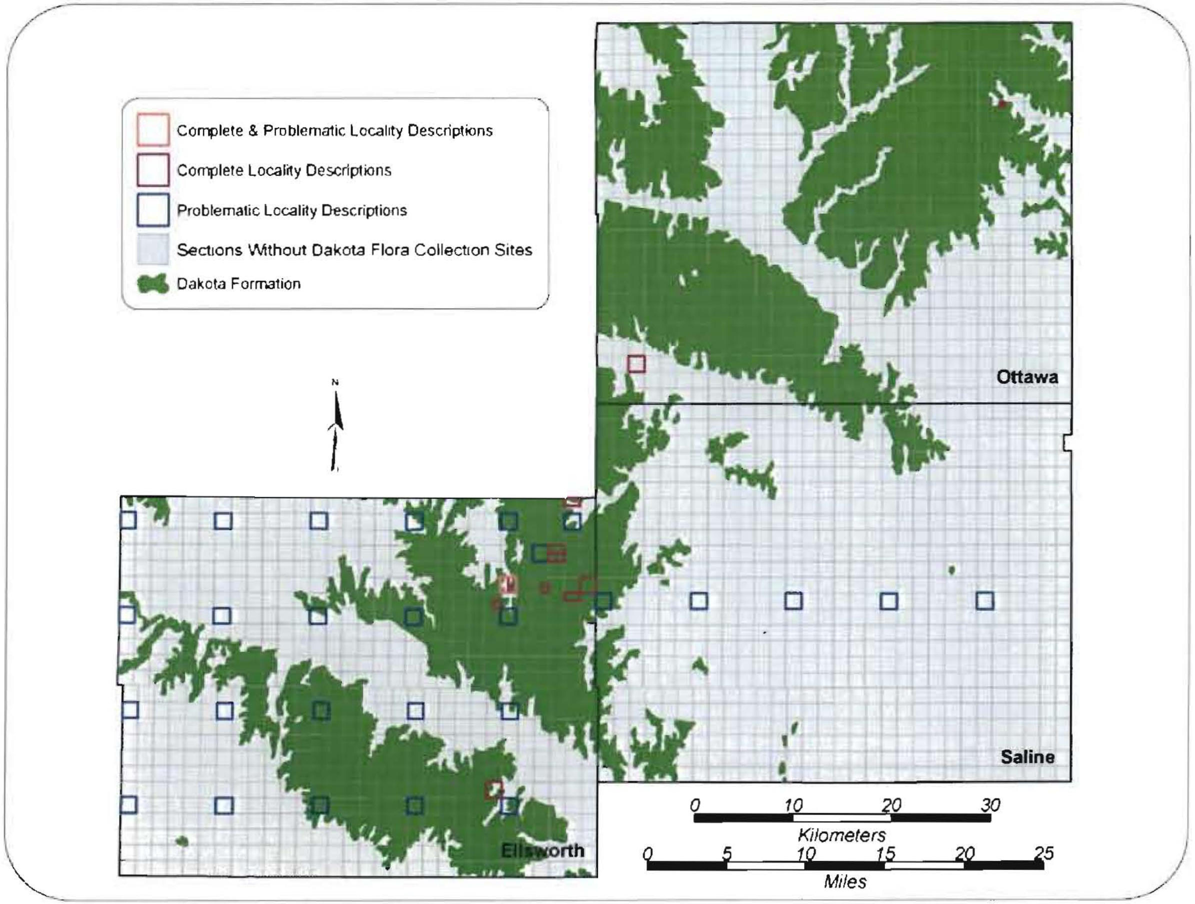

Figure 46: Kansas PLSS Collection Sites with Dakota Formation Outcrops. The PLSS Collection Sites used in this study are shown relative to the Dakota Formation's outcrop position area are depicted on this created map. Recall that because quarter-quarter sections are small areas they are difficult to see that on this map its location (northeastern Ottawa County) is specified to ensure that it is not overlooked on the map, it is a complete collection site description.

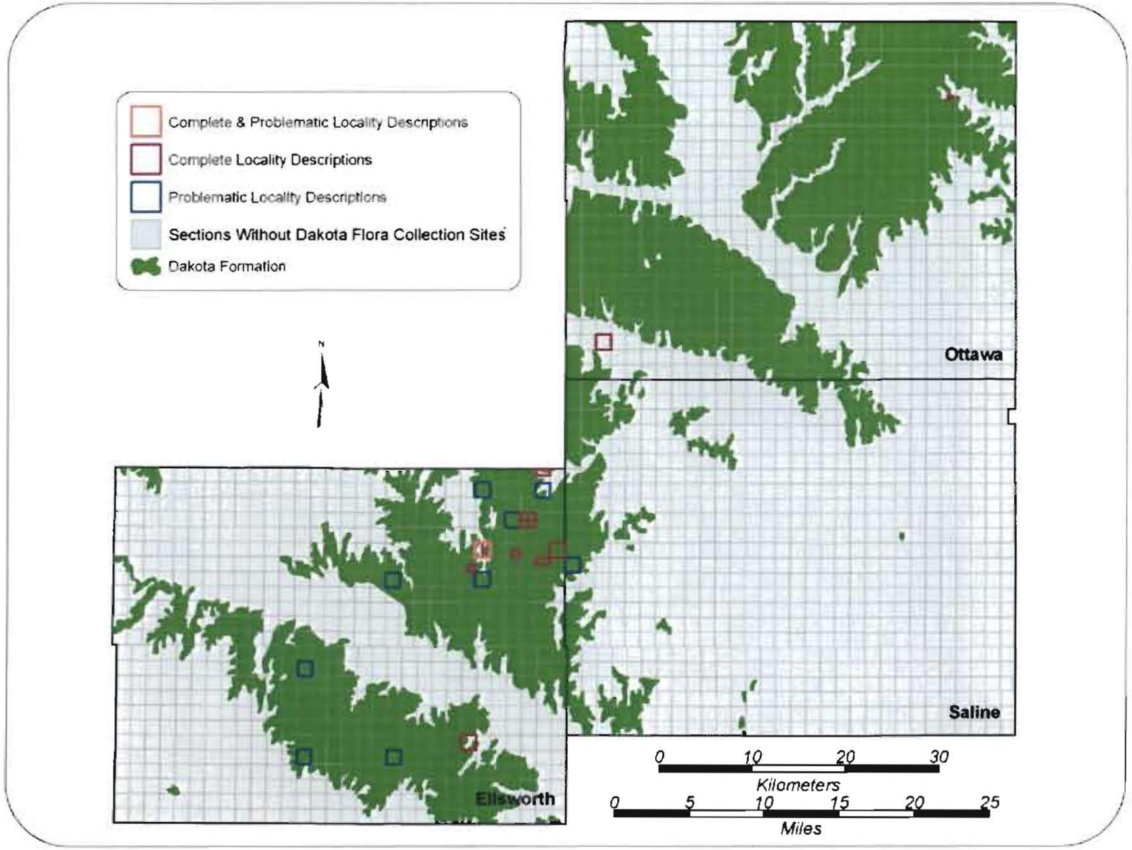

Figure 47: Kansas PLSS Collection Sites Including Collection Sites with Complete Descriptions and Suggested Solutions to Problematic Descriptions. The PLSS Collection Sites used in this study are shown relative to the Dakota Formation's outcrop position however; ambiguous collection sites are shown as only those sections thought most likely to contain the original collection sites area are depicted on this created map. Recall that because quarter-quarter sections are small areas they are difficult to see that on this map its location (northeastern Ottawa County) is specified to ensure that it is not overlooked on the map, it is a complete collection site description.

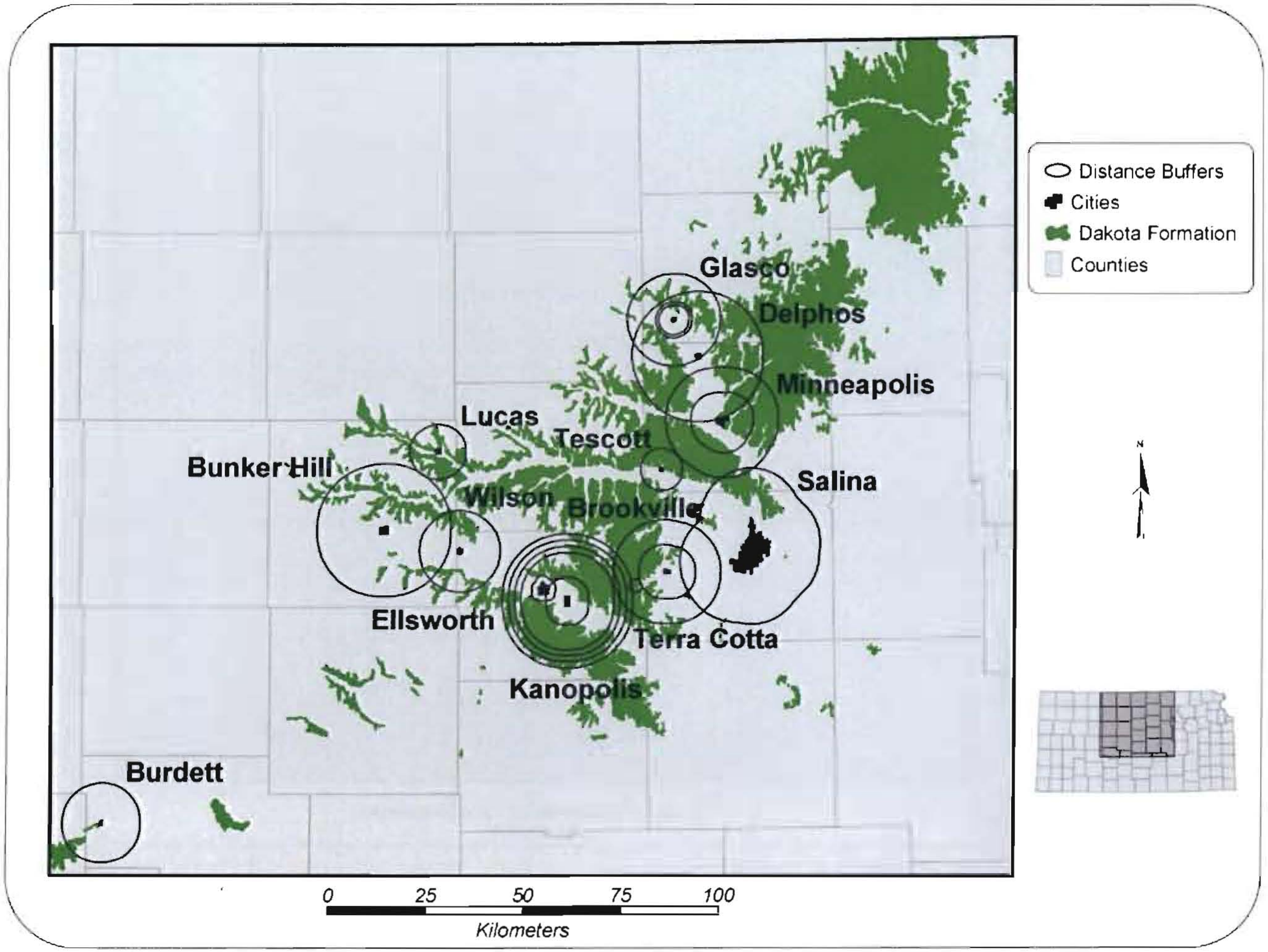

Figure 48: Kansas Distance Collection Sites with Dakota Formation Outcrops. The Distance Collection Sites used in this study are shown relative to the Dakota Formation's outcrop position area are depicted on this created map.

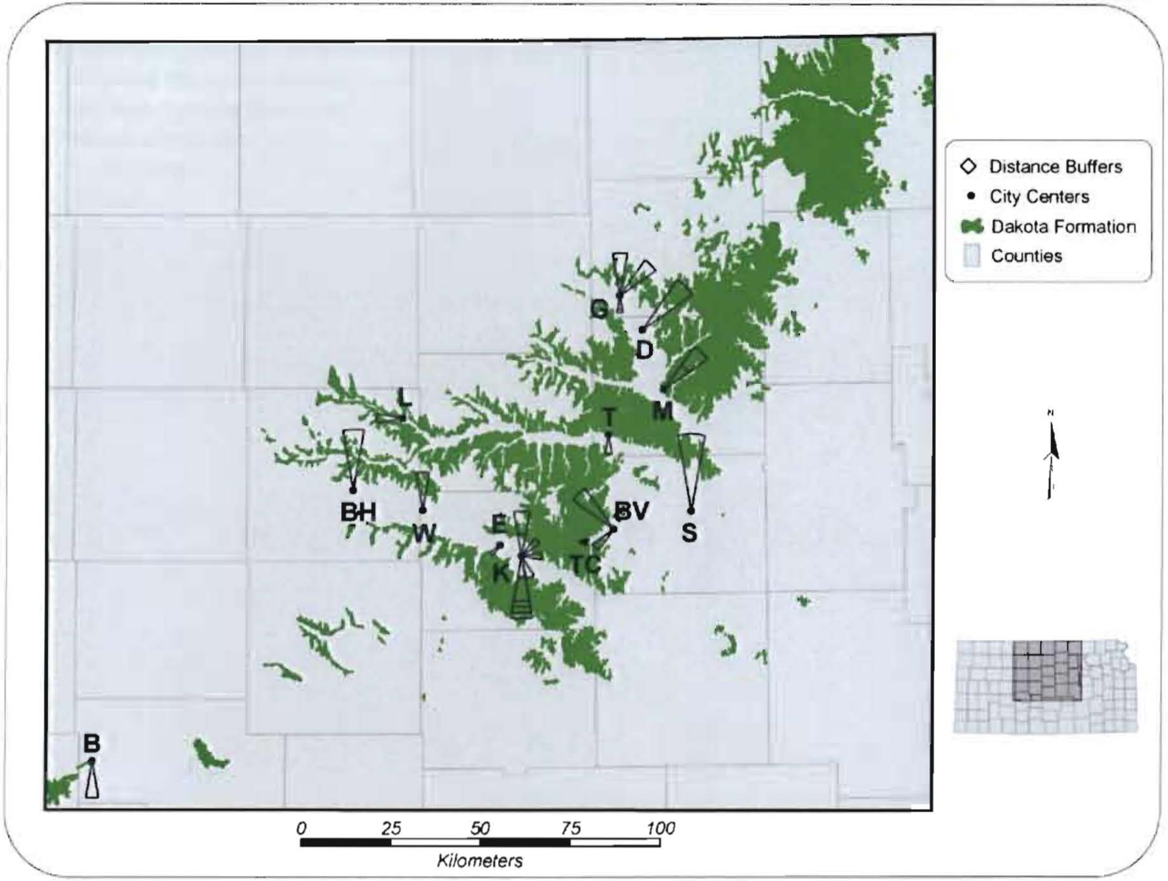

Figure 49: Kansas Limited Distance Collection Sites with Dakota Formation Outcrops. The Limited Distance Collection Sites used in this study are shown relative to the Dakota Formation's outcrop position area are depicted on this created map. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

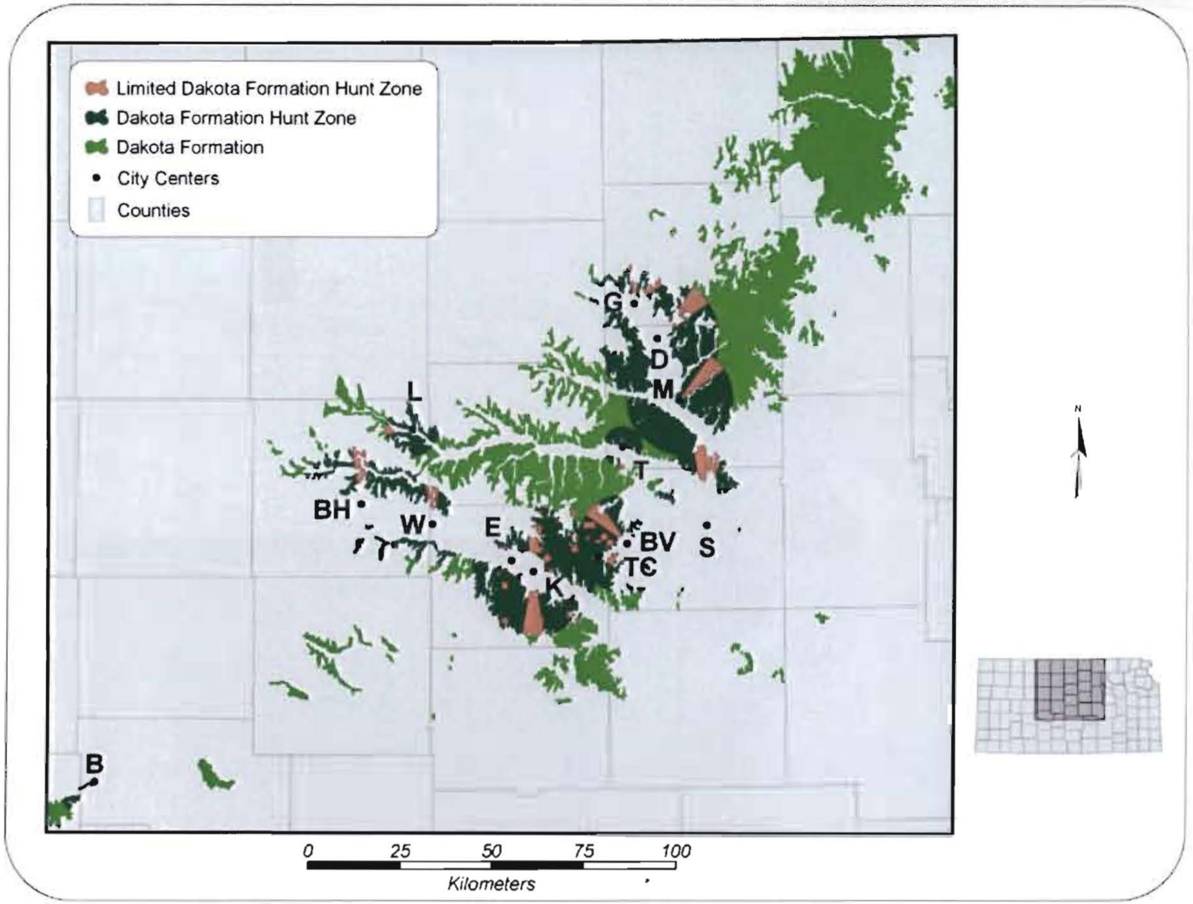

Figure 50: Dakota Collection Site Search Zones In Central Kansas. The Dakota Formation outcrop and how the Dakota Formation outcrop can be focus into a search zone for collection sites when limited with the Distance Collection Sites and Limited Distance Collection Sites area are depicted on this created map. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

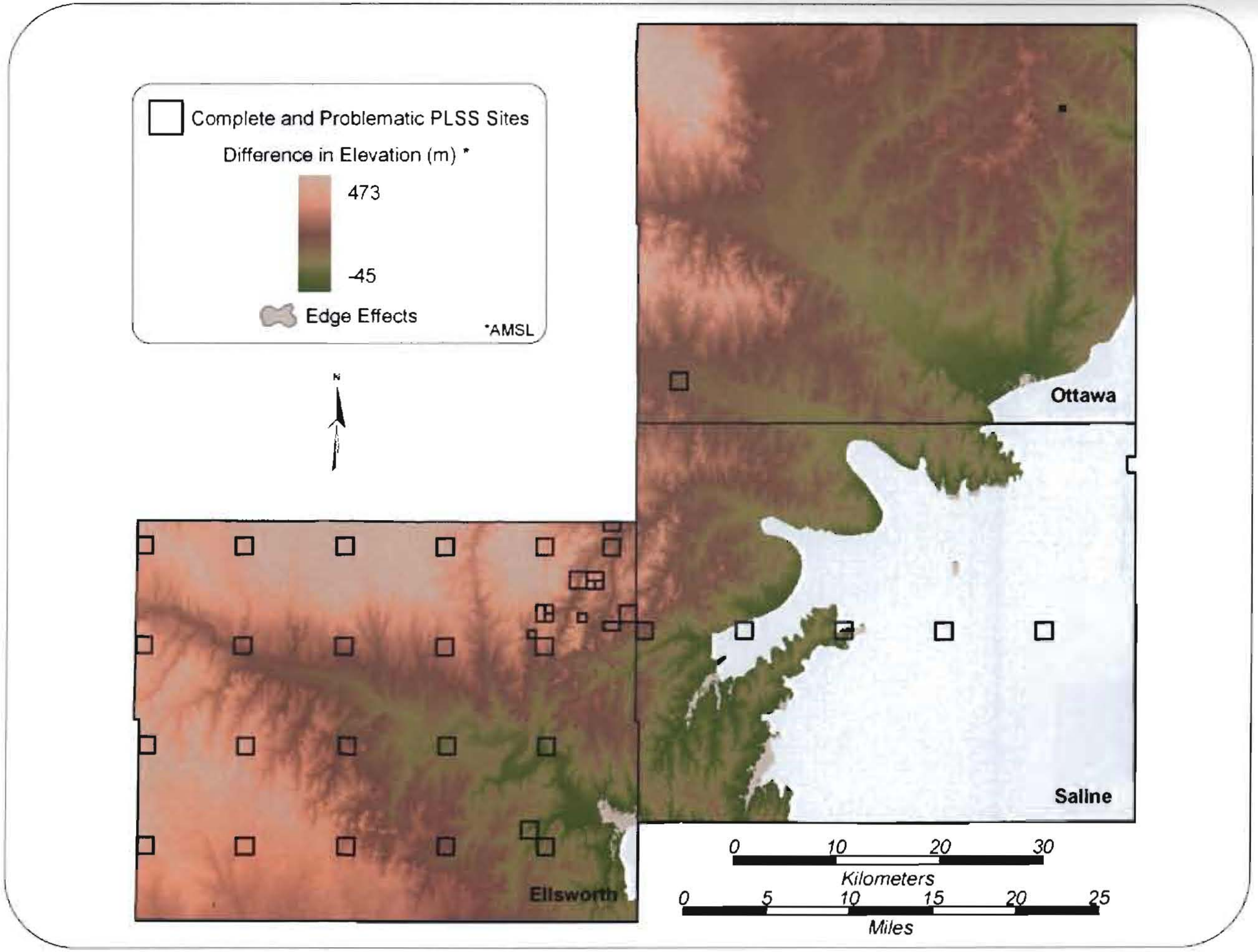

Figure 51: Edge Effects on PLSS Collection Site Locations' Elevation Dakota Aquifer Derived Dakota Formation Thickness Elevations of PLSS. Map of the edge effects near and involved in the PLSS Collection Sites Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas.

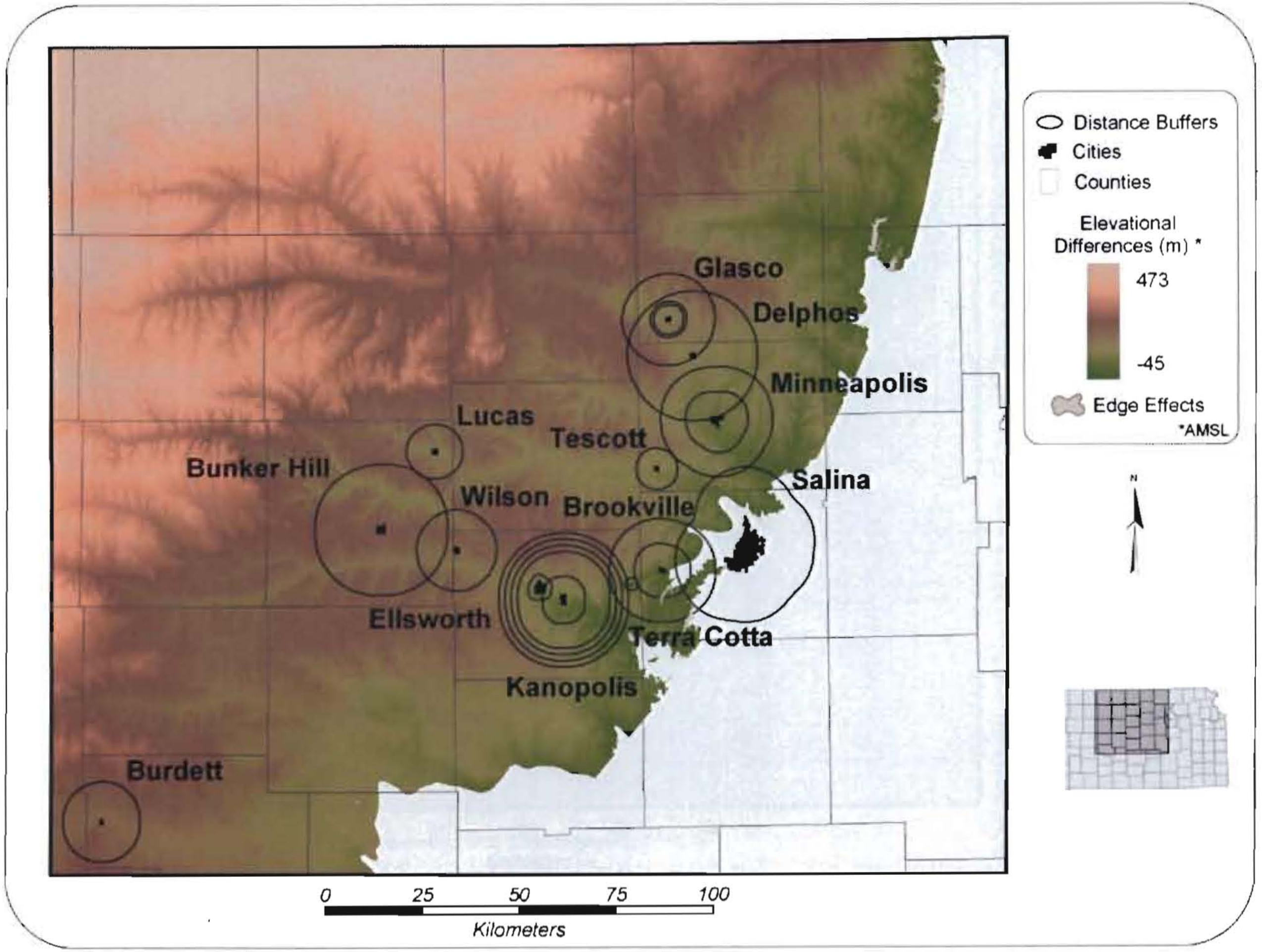

Figure 52: Edge Effects on Distance Collection Site Locations' Dakota Aquifer Derived Dakota Formation Thickness Elevations. Map of the edge effects near and involved in the Distance Collection Sites Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas.

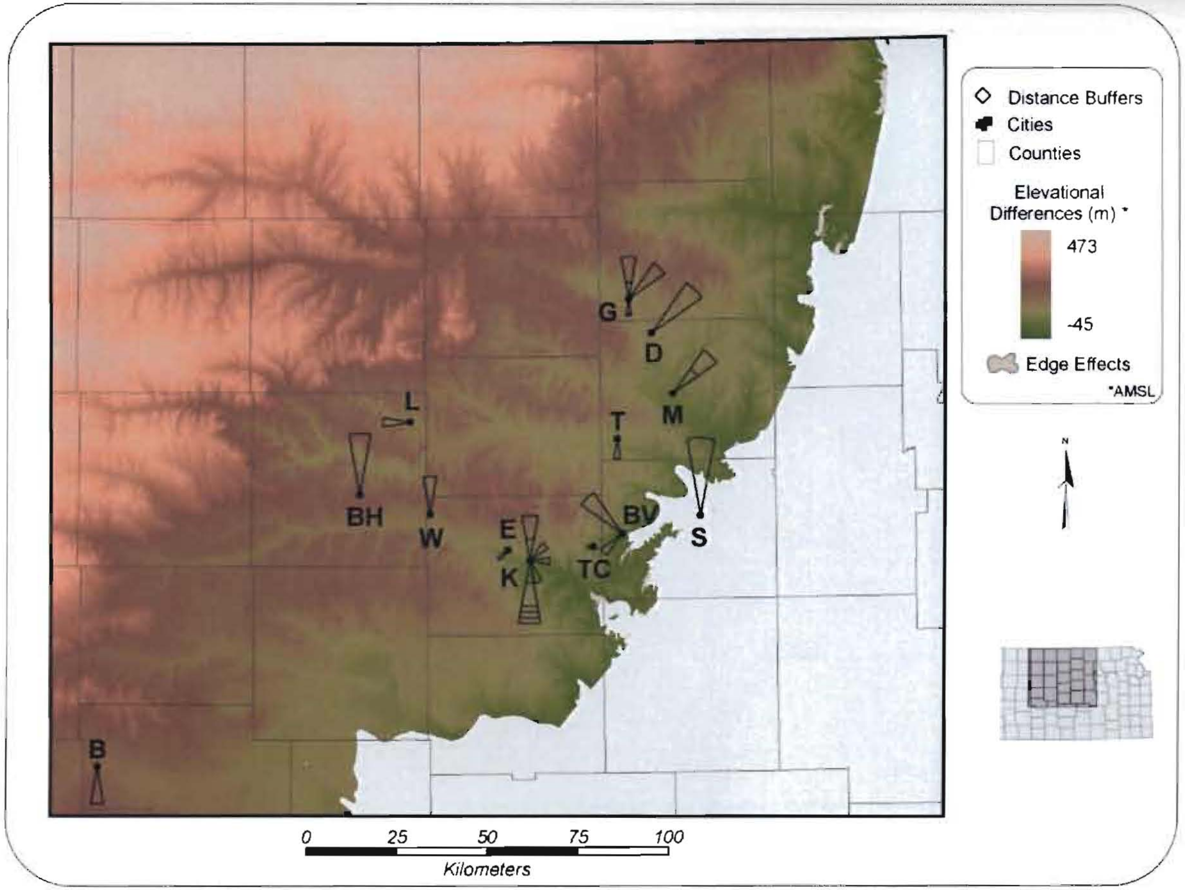

Figure 53: Edge Effects on Limited Distance Collection Site Locations' Dakota Aquifer Derived Dakota Formation Thickness Elevations. Map of the edge effects near and involved in the Limited Distance Collection Sites Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

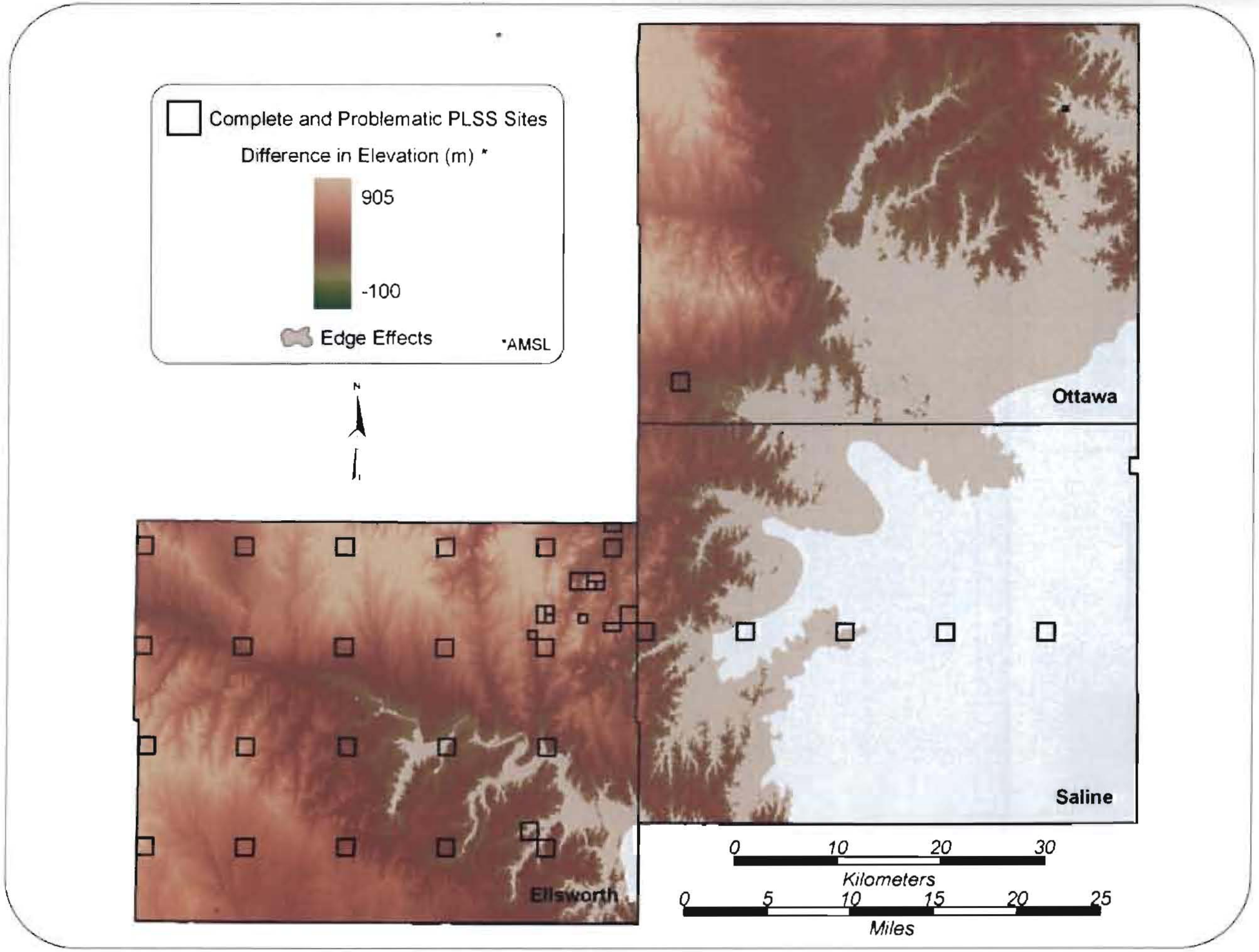

Figure 54: Edge Effects on PLSS Collection Site Locations' Kiowa Formation Derived Dakota Formation Thickness Elevations. Map of the edge effects near and involved in the PLSS Collection Sites Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas.

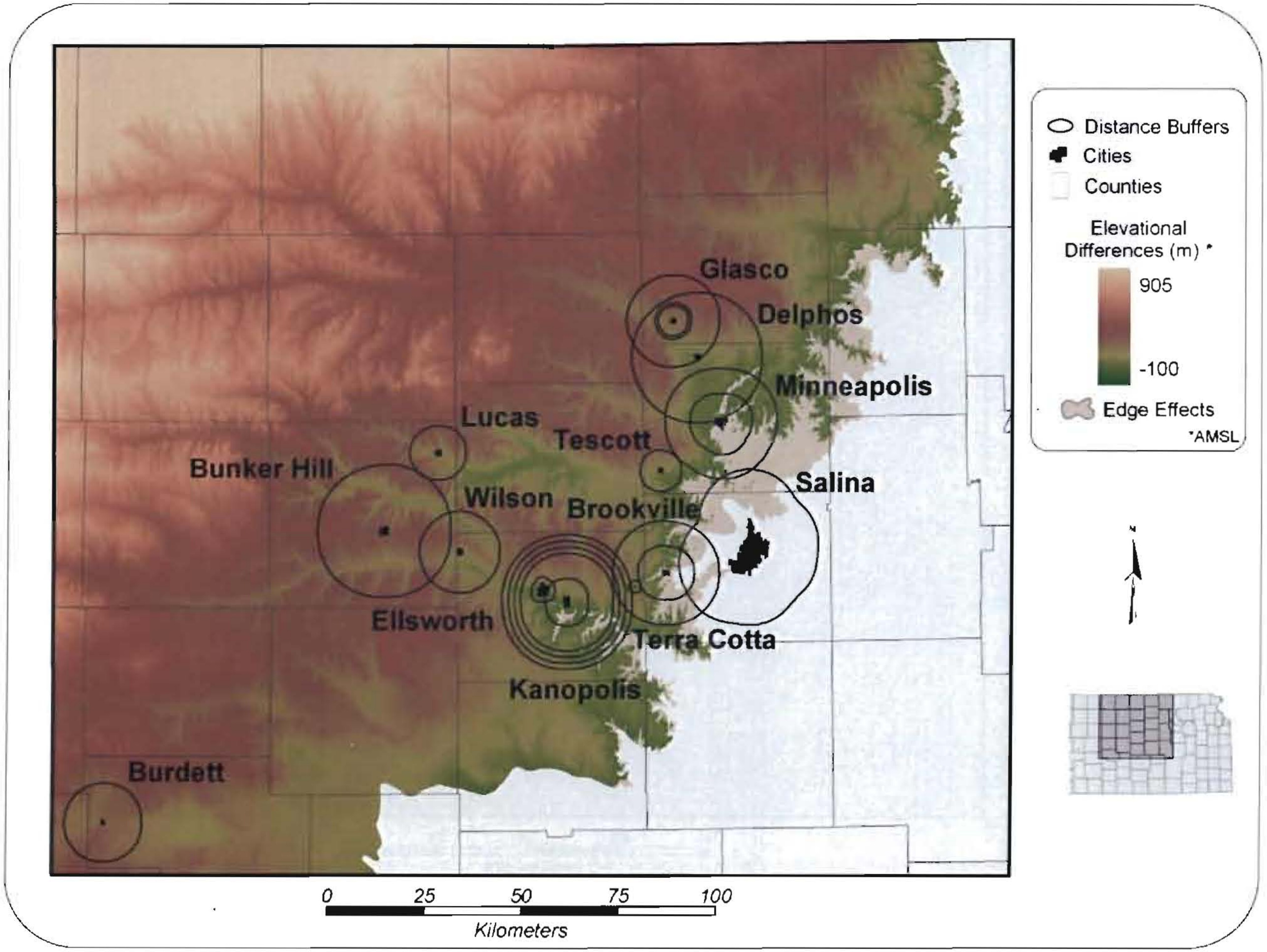

Figure 55: Edge Effects on Distance Collection Site Locations' Kiowa Formation Derived Dakota Formation Thickness Elevations. Map of the edge effects near and involved in the Distance Collection Sites Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas.

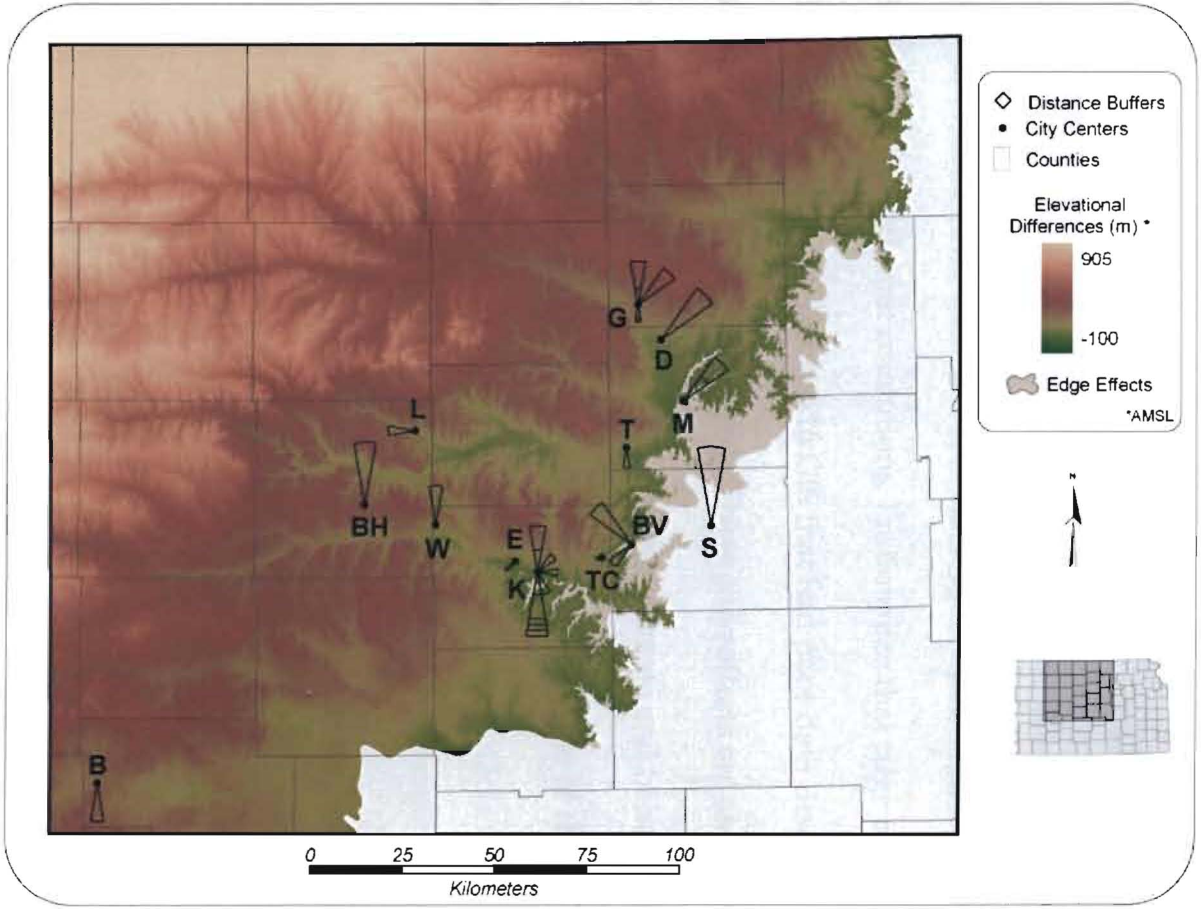

Figure 56: Edge Effects on Limited Distance Collection Site Locations' Kiowa Formation Derived Dakota Formation Thickness Elevations. Map of the edge effects near and involved in the Limited Distance Collection Sites Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

Therefore, the DB elevations has some areas in which there are negative values where the aquifer outcrops at the surface and that the topography of the TKW has some areas in which there are negative values where the formation outcrops at the surface. In the discussion of input data, a table was presented that in addition to listing the datasets and where it was obtained included the scale/resolution of the dataset (Table 4 on pg 85). This supports the fact that the NED and TKW datasets were not originally compiled with the same resolution. Because of the different resolutions, I rationalize that edge effects or areas along the edge of the grid produced in GIS that had poor data distribution or lack of data caused errors (Figure 57-59). These edge effects are also contributing to the negative values on the ADB # 2 thickness estimate and because the DB elevations would have similar edge problems, I assume that some of the negative values of the ABD # 1 thickness estimate are also due to edge effects.

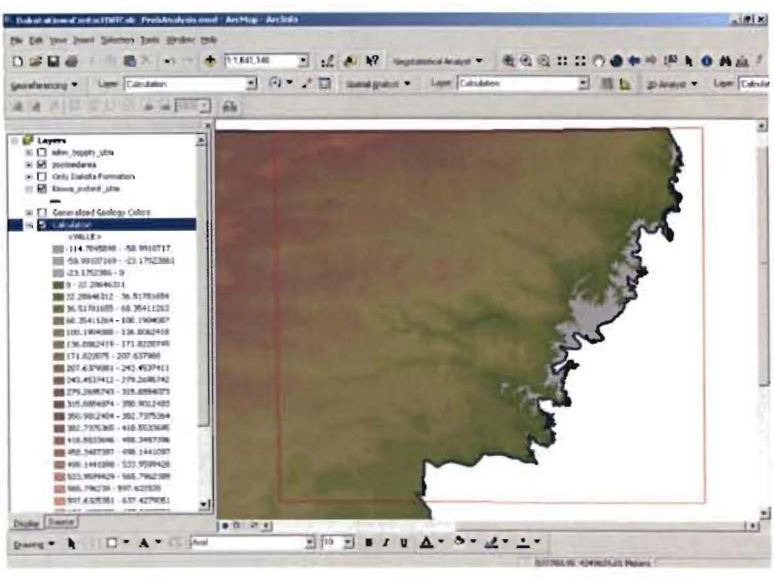

Figure 57: Edge Effects Caused by Dakota Formation Thickness Estimates Explanation Area. ArcGIS map view screenshot showing the ABD # 2 thickness estimates area (red box) used to illustrate edge effects (gray areas) explanation.

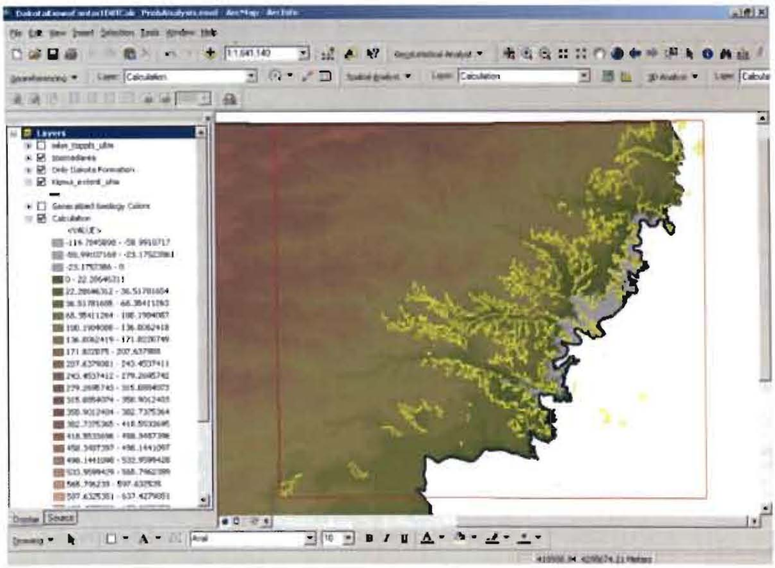

Figure 58: Dakota Formation Thickness Estimates Edge Effect in Relationship to Outcrop. ArcGIS map view screenshot showing the ABD # 2 thickness estimates edge effect explanation area with the Dakota Formation outcrop indicated (yellow outlined area).

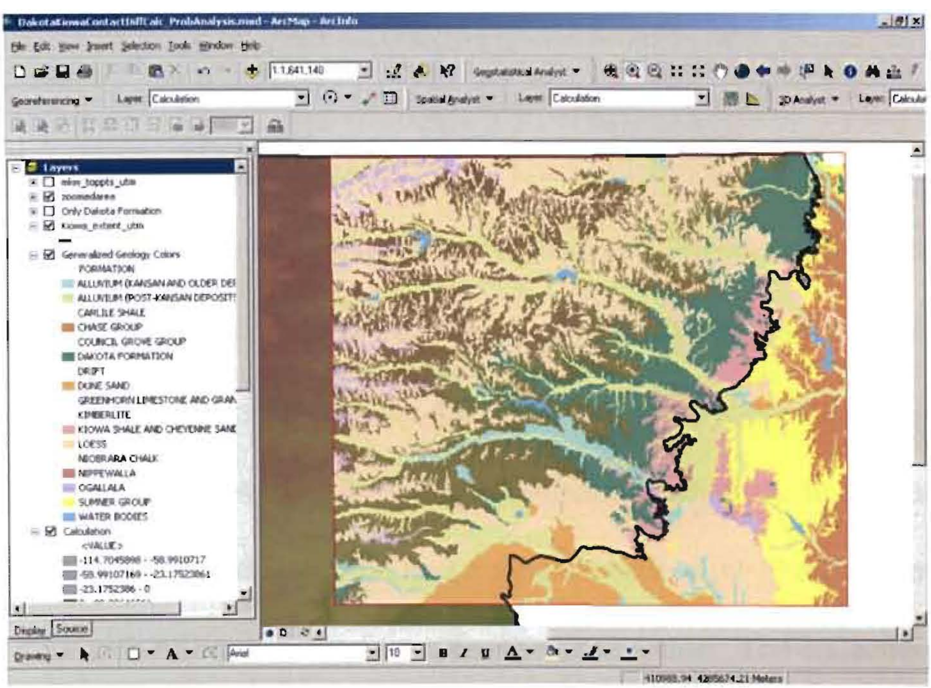

Figure 59: Surface Geology's Relationship to Edge Effects On Dakota Formation Thickness Estimates . ArcGIS map view screenshot showing how edge effects areas are probably the cause of negative values in the ABD # 2 thickness estimates and how it relates to the outcrops of the Kiowa Formation (yellow), Dakota Formation (pink), and Graneros Shale (green).

Geographic Locations of Collection Sites

After winnowing, the numerous available publications and specimen labels on the Dakota, produced many collection site descriptions that were too vague to be used (approximately collection sites). Hundred's of collection site descriptions were defined as only a county, State, or fraction of a State and therefore were not specific coordinates or small enough to obtain adequate control on the coordinates for GIS analyses. The publications and specimen labels that did contain usable collection site descriptions consisted of 71 collection sites, that while not specific coordinates, were small enough to obtain adequate control on the coordinates for GIS analyses. When these usable collection site descriptions were categorized, 51 were designated distance-related and 30 were designated legal descriptions. The 51 distance-related collection site descriptions could be further grouped as 21 Distance Collection Sites and 30 Limited Distance Collection Sites. Although, some of the 21 Distance Collection Sites were obtained by using only the distance from a city specified in a collection site description that also had directional information. In addition, one Distance Collection Site description had a range specified (8-10 miles) for the distance and each full mile was plotted for the description. The collection site legal descriptions resulted in 20 PLSS Collection Sites of which six were considered Problematic PLSS Collection Sites. While some limitation of the six Problematic PLSS Collection Sites could be limited to more likely sections based on surficial geology, the limitation is not ideal; therefore, I usually just use the 20 PLSS Collection Sites as a group in discussing the collection sites with legal descriptions.

The first analysis of locations was to determine what trends might exist among the Public Land Survey System described historic fossil collection sites (Figures 44 and 48–49). These graphical illustrations point out that some collection site locations are described more completely and therefore more accurately known than others are known. The PLSS Collection Sites also are clustered mainly in northeastern Ellsworth County.

The second analysis of locations was to determine what trends might exist among the specified direction and distance historic collection sites (Figures 48 and 49). Those collection sites listed as being a specified distance and direction from a city are often times overlapping and likewise clustered. While the two types of collection sites described as distances from cities are clustered, they do not exhibit quite the Ellsworth County bias. Instead, they tend to be biased as being north of the Saline River.

Although initially the exact location of Sternberg's Ranch was not known, the PLSS Collection Sites, the Distance Collection Sites, and the Limited Distance Collection Sites seem to indicate that the description of it being approximately 10 miles south of Fort Harker is correct due to their distribution. This was confirmed when the actual location of the Sternberg Ranch was determined by consulting with the Ellsworth County Historical Society (Ellsworth County

Historical Society, 2005). This is easily seen when comparing the location of Fort Harker and Sternberg Ranch to the Ellsworth County collection sites (Figure 30).

Surficial Geology

The comparisons of the collection sites with the surface geology results suggest that some of the locational descriptions of the collection sites are not accurate enough (*i.e.* not as accurate as one would like them to be) to be very useful (Figures 46–49). This assumption appears likely, as some of the non-problematic collection sites did not have any Dakota Formation directly within their polygonal shape. However, some of the more problematic descriptions, like the one in Saline County, could be limited to one section instead of multiple sections based on where outcrops are present showing that limitation by this method might be possible (Figure 47).

Additionally, there were the limitations of the Dakota Formation outcrop to those areas that had historic fossil flora collection sites. While there is still a sizeable area remaining for ground searching the location of collection sites, when the directionality is factored in, the directionality of the buffers surrounding the cities limits it considerably (Figure 50).

The location of collection sites in relation to surficial geology appears to help limit search areas, especially for those collection sites with less complete PLSS descriptions as exemplified by Saline County's Township 6 S, Section 6 description, appearing to be limited to just one of five sections. However, there are also those collection sites in which the polygon representing the location of the collection site does not appear to contain the Dakota Formation outcrop. Ottawa County's Township, Range, and Section description or the description of a specified number of miles north of Bunker Hill exemplifies this condition of lack of outcrop.

Areas that do not appear to have outcrops of the Dakota Formation seem to be located mainly near streams and/or rivers. Therefore, it appears that:

1. The specimens collected in that area were washed out of the Dakota strata onto other formations.
2. The surficial geology was improperly mapped and is therefore incorrectly mapped in the surficial geology coverage.
3. There could be a very thin and patchy cover of Quaternary deposits overlying the Dakota strata such that localized areas of Dakota strata are exposed.

However, a fourth possibility exists that should be considered. Because most of the collections were made in the late 1800s and early 1900s, the possibility exists that the collection site description was not accurate enough to be useful in the relocation process. This possible inaccuracy of the description could also have been intentional, because Sternberg was selling the specimens and therefore would not have wanted the location known by others who might collect from his collection sites and compete with him for sales. A fifth possibility exists since the Dakota Formation polygon coverage was obtained from DASC is a State scale surficial geology map for Kansas, there is the potential of cliff exposures and other small-scale exposures existing in places not indicated in the maps. Especially in areas near rivers and creeks exposures of the Dakota in historical or modern cut banks could exist that are not mapped. However if these limitations are kept in mind utilizing the results of the GIS analysis to help limit where to look for historical collection sites should be a reasonable idea for determining places to search in the field.

It might be argued that if the limited distance collection sites were portrayed differently they could be smaller thereby further limiting the search area. This is a valid argument; as such, a portrayal is theoretically possible; there are, however problems with carrying this out. It would be possible for each limited distance collection site to consist only of the arc at the end of the buffer; however, this assumes that the distance measurement is accurate. In addition, fossil collection sites are usually areas not a single point or line, therefore what the area of the collection site is would need to be determined in order to create a relatively accurate representation. The arc itself could be buffered to take into account the possibility of the inaccuracy but then you would need to know by how much to buffer the arc. Any of these solutions to the argument of a further precision being obtained by limiting the Limited Collection Sites would undoubtedly encounter, if not exaggerate, the problem of the polygon representing the collection site location does not always containing Dakota Formation outcrops and probably would not really help limit much more.

Elevations

One of the fundamental questions of this thesis was determining if their were spatial relationships between the collection site locations , the surface elevations above mean sea level (AMSL), and/or the elevations above the base of the Dakota (ABD). The intent was to determine if the collection sites were clustered at certain elevations AMSL or ABD. For the purpose of this thesis, a cluster is considered to be three or more collection sites of similar elevation (within 20 meters). This simplistic explanation of what constitutes a cluster is only intended for statistical analyses on the data. It may not be useful in the field for site relocation. An individual site description may only limit a search area to a relatively large area (*e.g.*, 40 acres). If the total local relief within that 40-acre tract is 20 meters, then confining the search to a 20 meter range of elevation does not constrain the search area. However if there happened to be 40 meters of relief within that 40-acre tract then confining the search to only 20 meters of elevation range might be very helpful. Macfarlane, *et. al.* (1989a) indicated that the Dakota Formation in Kansas is typically 200–300 feet or 61.0–91.4 meters. However, most of the Dakota Formation is in the subsurface, therefore to determine if the clusters determined by analyses are helpful in constraining search areas two questions need to be answered:

1. Does a cluster consist of multiple collection sites with the same overlapping location descriptions?

2. Does the elevation range of a cluster limit the search area for a particular collection site or cluster?

Therefore, once ArcView was used to summarize the zones of the polygons outlining each likely collection site, the results were arranged from West to East (those collection sites at the same longitude were arranged from South to North) in order to search for clusters. The data were diagramed as box and whisker plots. In these diagrams, the box represents the mean plus or minus one standard deviation (STD), while a line depicts the range for the lower to upper most elevation values in each polygon (Figure 60). The collection site zone summaries do appear to contain some clustering however, the clusters are not as distinct as hoped (Table 9).

Summary statistics for the AMSL elevations indicate that at most collection site locations, regardless of type (PLSS, Distance, or Limited Distance), 68% of the elevation observations within a polygon (mean ± 1 STD) fall between 400 and 550 meters (Figures 60–62). In addition, there appears to be two clusters—one that centered at about 420 meters and another at about 480 meters. There seems to be some geographical component to these clusters, with the lower cluster being on the eastern side of the study area and the higher cluster on the western side of the study area. This clustering is most apparent in the surface elevation data from the zone summaries of the Distance Collection Sites (Figure 60).

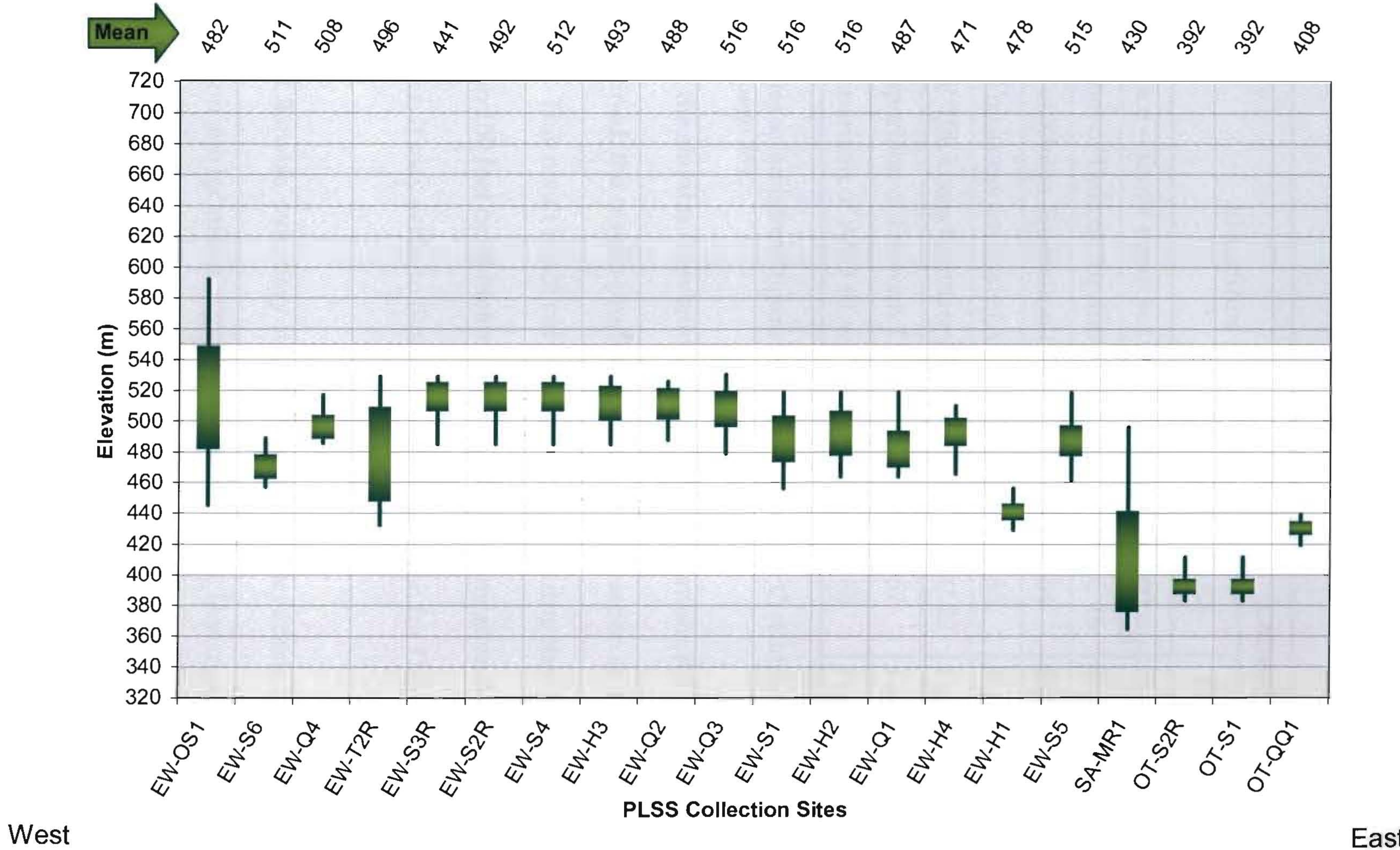

Figure 60: Surface Elevation Statistics for PLSS Collection Sites. Statistics of the surface elevations of the PLSS Collection Sites are depicted as a box and whisker plot. The shaded areas on the graph are outside of the 400-550 meter range of surface data as discussed in the text.

Table 9: Summary of Collection Site Elevational Statistics Graphs. Because graphs were created for all three types of collection sites as they were analyzed with regard to five elevational surfaces and two comparisons of surfaces, a listing was created here for connivance.

Elevations	Collection Site Type		
	PLSS	Distance	Limited Distance
Surface—above mean sea level (AMSL)	Fig. 60	Fig. 61	Fig. 62
Bottom of Dakota Aquifer (DB)	Fig. C 16	Fig. C 17	Fig. 63
Top of Kiowa Formation (TKW)	Fig. 64	Fig. C 18	Fig. C 19
DB Thickness Estimate (ABD # 1)	Fig. 65	Fig. C 20	Fig. C 21
TKW Thickness Estimate (ABD# 2)	Fig. C 22	Fig. C 23	Fig. 66
Comparison of DB with TKW	Fig. 67	Fig. C 24	Fig. C 25
Comparison of ABD #1 with ABD #2	Fig. 68	Fig. C 26	Fig. C 27

* Indicates an additional figure located in "Appendix C: Additional Figures" starting on page 269.

When the standard deviation of the AMSL elevations for each collection site is determined, the results produced a standard deviation of 10-20 meters (Figures 60-62). This result is not very surprising considering that local relief is typically less than 150 feet or 45 meters (Personal Communication Macfarlane, 2005) however; it may serve to limit the search elevation for Dakota Flora collection sites.

Likewise, summary statistics for the DB elevations indicate that at most collection site locations, regardless of type (PLSS, Distance, or Limited Distance), 68% of the elevation observations within a polygon (mean ± 1 STD) fall between 320 and 440 meters (Figures 63 and C 16-C 17).

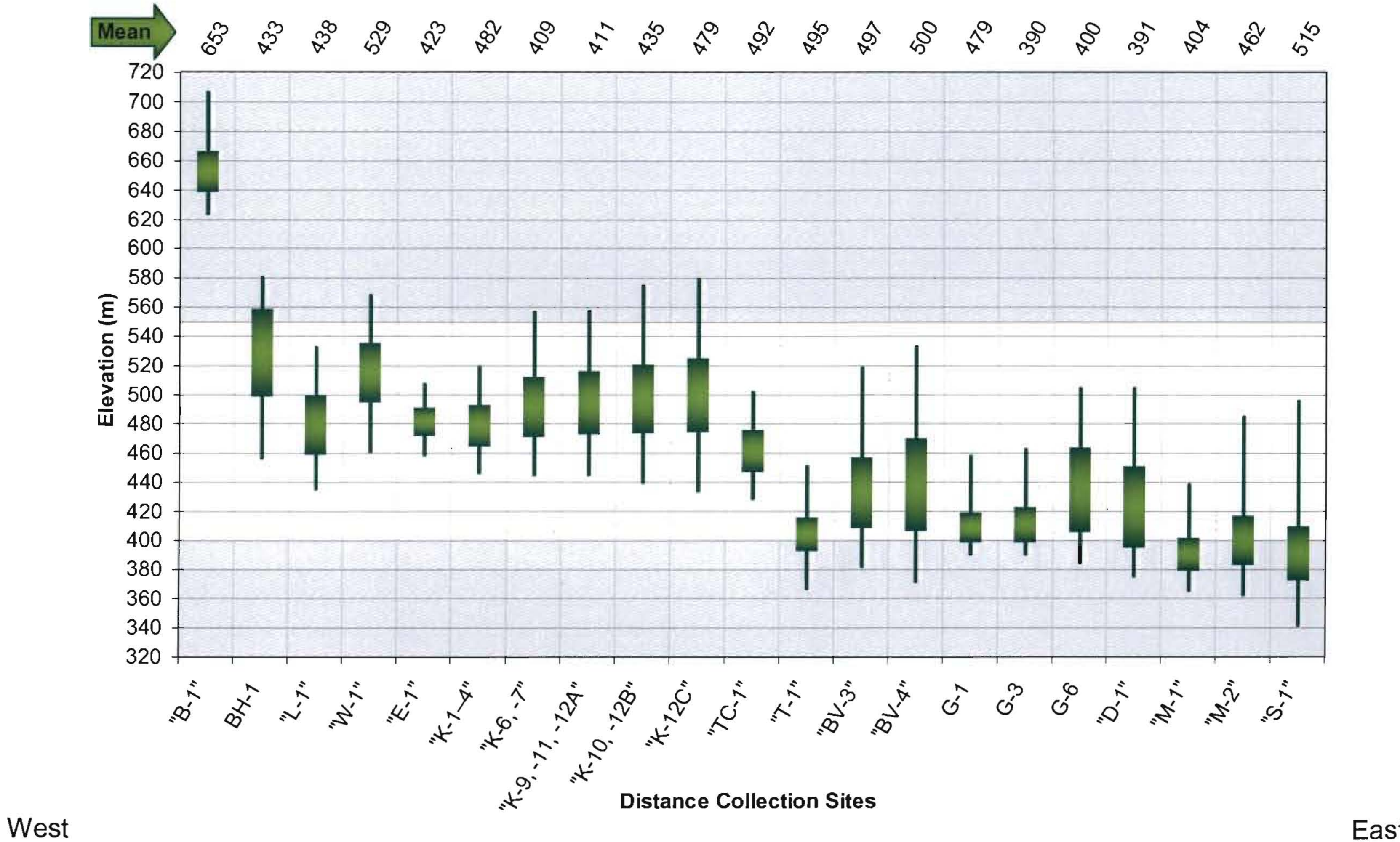

Figure 61: Surface Elevation Statistics for Distance Collection Sites. Statistics of the surface elevations of the Distance Collection Sites are depicted as a box and whisker plot. The shaded areas on the graph are outside of the 400-550 meter range of surface data as discussed in the text.

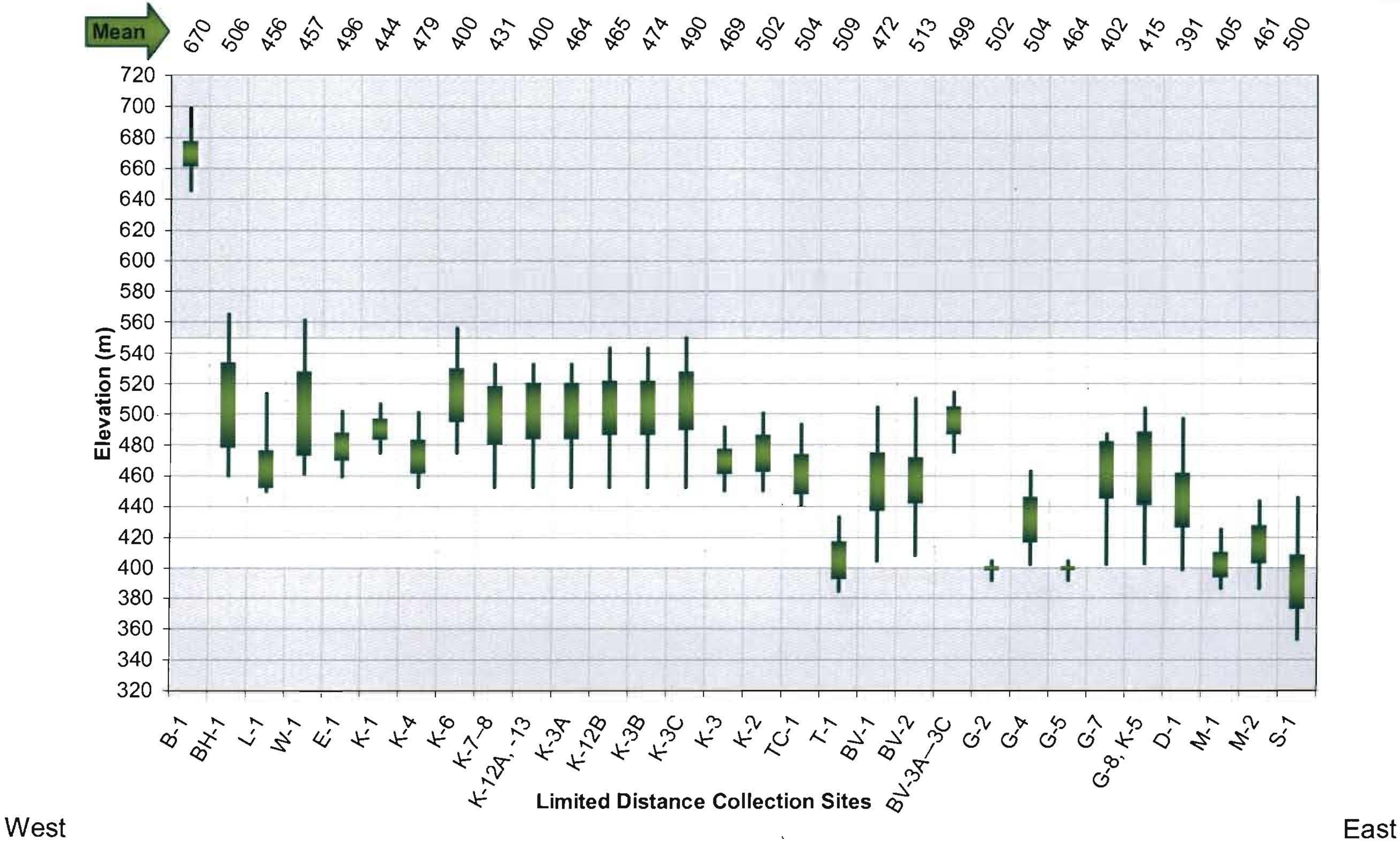

Figure 62: Surface Elevation Statistics for Limited Distance Collection Sites. Statistics of the surface elevations of the Limited Distance Collection Sites are depicted as a box and whisker plot. The shaded areas on the graph are outside of the 400-550 meter range of surface data as discussed in the text.

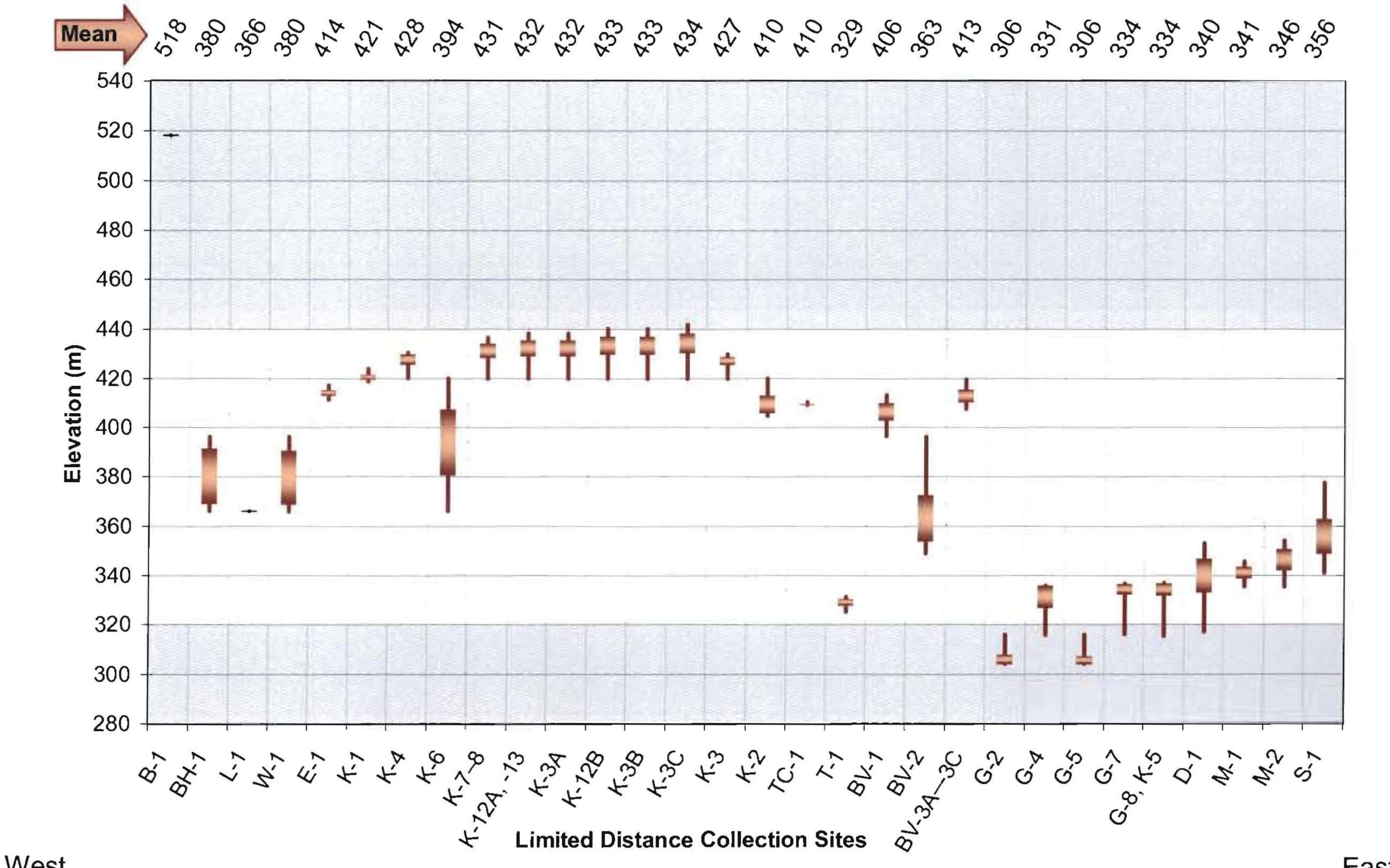

Figure 63: Dakota Aquifer Base Elevation Statistics for Limited Distance Collection Sites. Statistics of the Dakota Aquifer base elevations of the Limited Distance Collection Sites are depicted as a box and whisker plot.

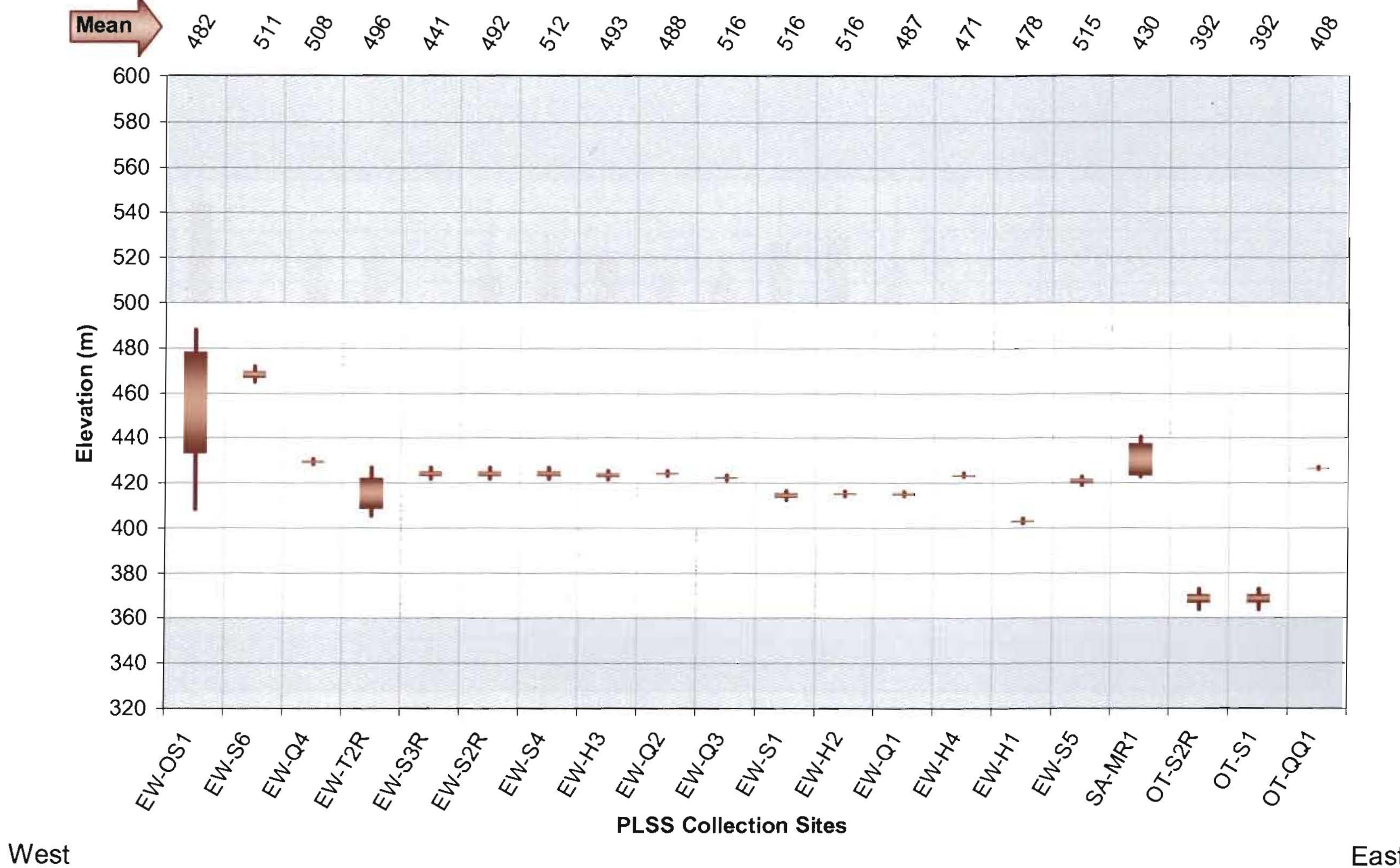

Figure 64: Dakota-Kiowa Contact Base Elevation Statistics for PLSS Collection Sites. Statistics of the Dakota-Kiowa contact elevations of the PLSS Collection Sites are depicted as a box and whisker plot.

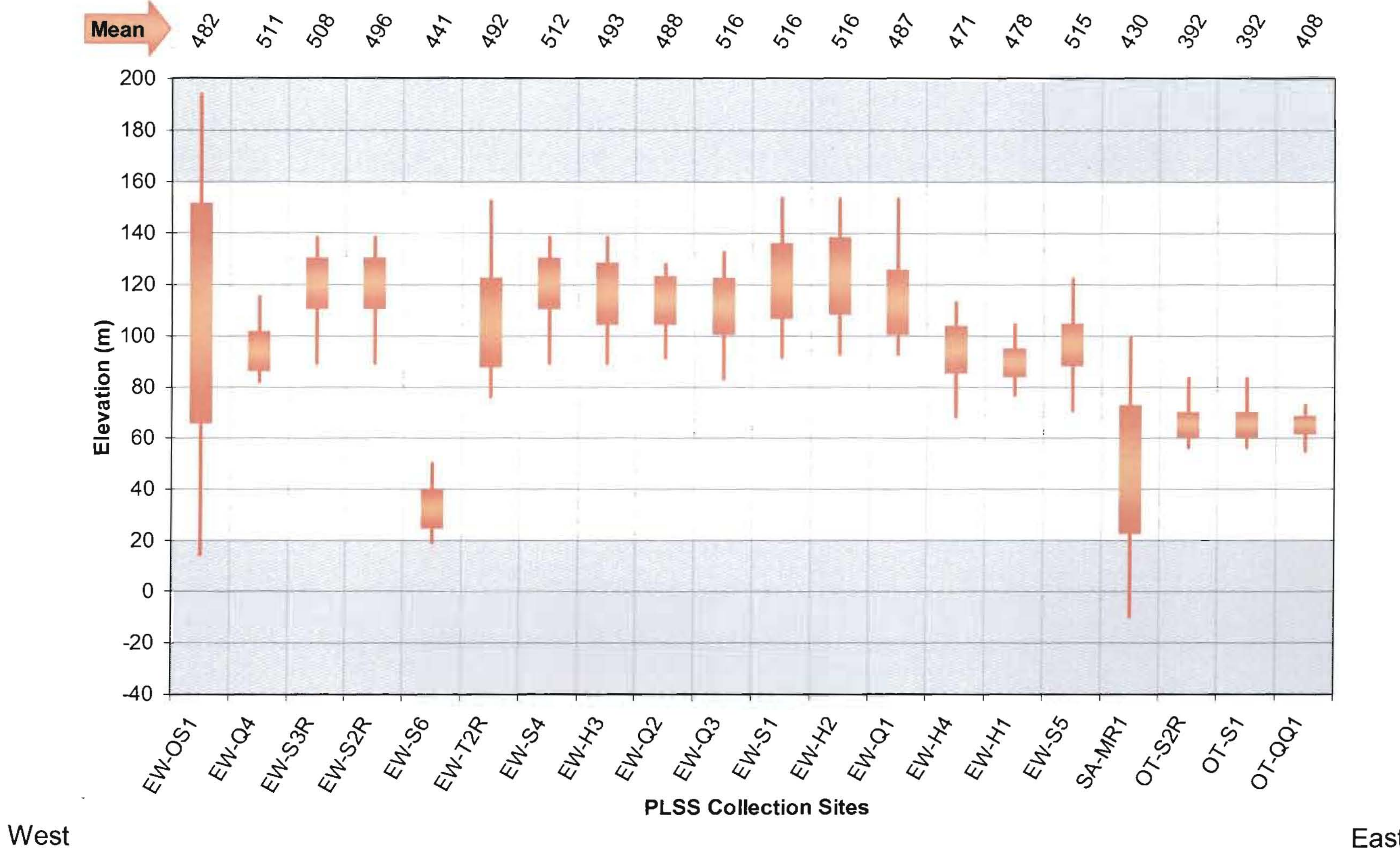

Figure 65: Dakota Aquifer derived Dakota Formation Thickness Estimate for PLSS Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas for the PLSS Collection Sites are depicted as a box and whisker plot.

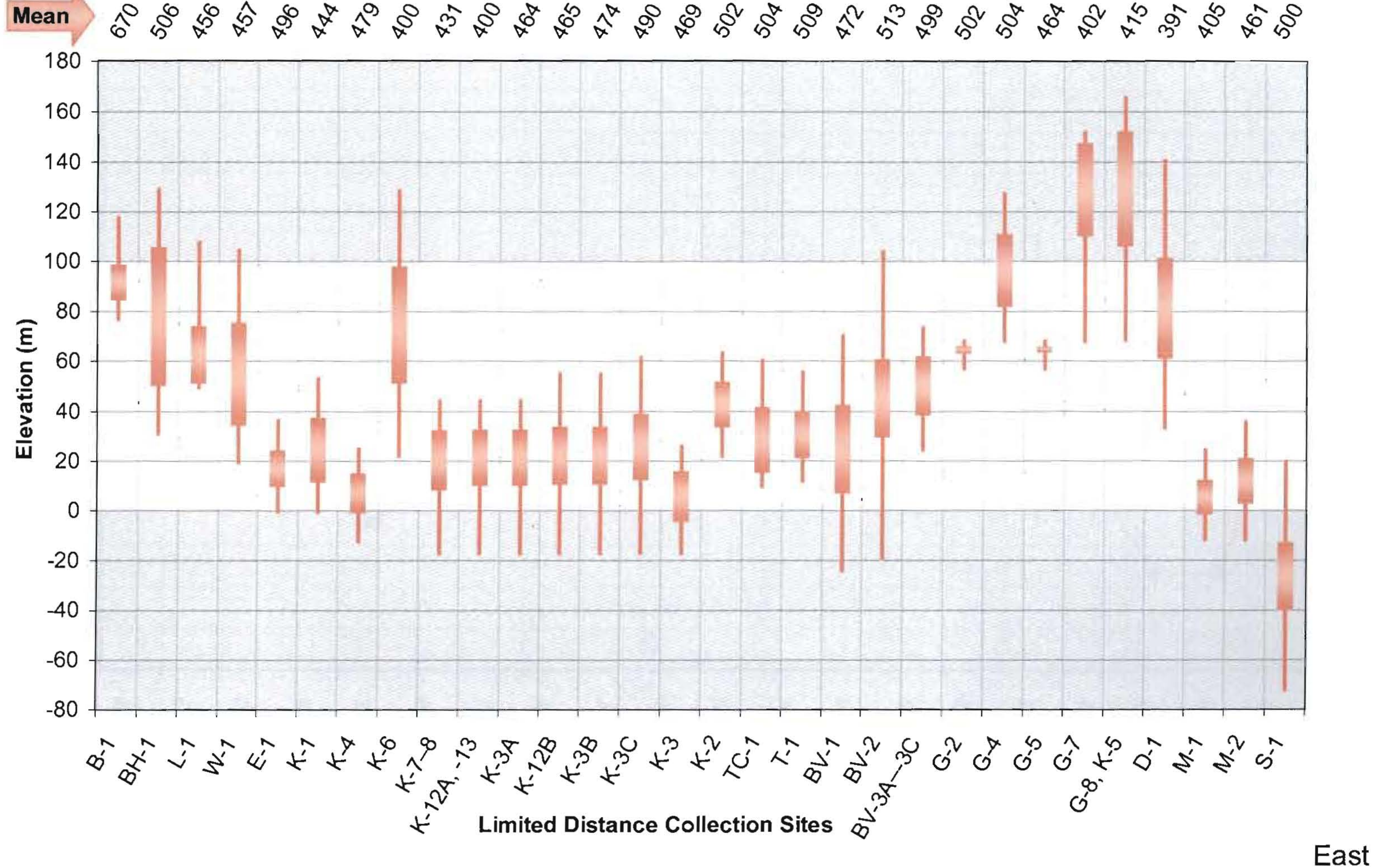

Figure 66: Kiowa Formation derived Dakota Formation Thickness Estimate for Limited Distance Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas for the Limited Distance Collection Sites are depicted as a box and whisker plot.

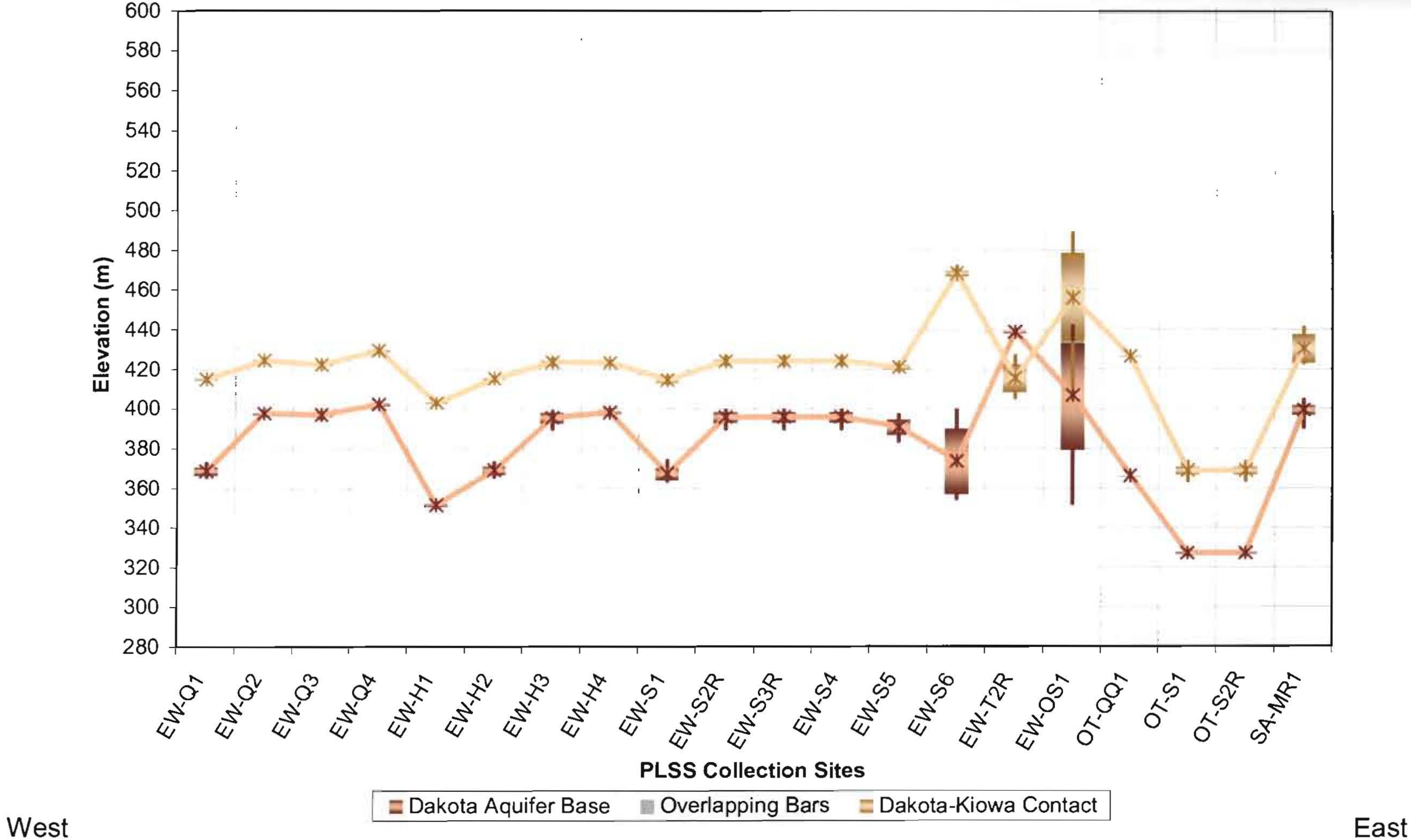

Figure 67: Comparison of Dakota Aquifer Base and Dakota-Kiowa Contact Elevations for PLSS Collection Sites. Statistics of the Dakota Aquifer base elevations and the Dakota-Kiowa contact elevations for the PLSS Collection Sites are depicted as a box and whisker plot for comparison.

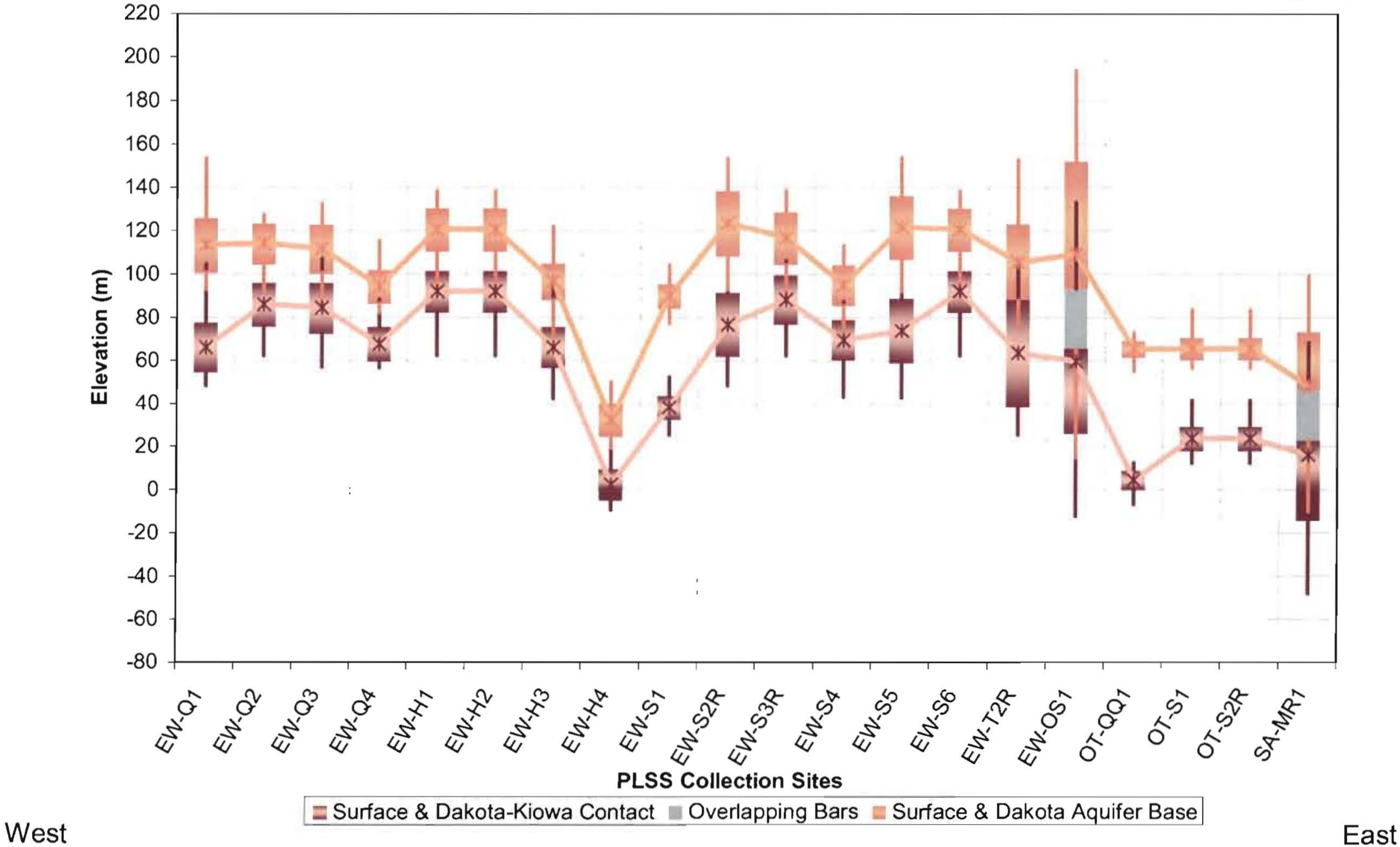

Figure 68: Comparison of the Estimated Formational Thickness for PLSS Collection Sites. Statistics of the Dakota Aquifer derived Dakota Formation thickness estimate and the Kiowa Formation derived Dakota Formation thickness estimate for the PLSS Collection Sites are depicted as a box and whisker plot for comparison.

Otherwise there does not appear to be any clustering for the DB elevation data except for the Limited Distance Collection Sites for which a clustering around 430 meters is observable (Figure 63). A standard deviation of less than 15 meters was calculated for the DB elevation at each of these collection sites (Figures 63 and C 16–C 17). Similarly, summary statistics for the TKW elevations indicate that at most collection site locations, regardless of type (PLSS, Distance, or Limited Distance), 68% of the elevation observations within a polygon (mean ± 1 STD) fall between 380 and 500 meters (Figures 64 and C 18–C 19). The ranges for the TKW elevations at each collection site, regardless of type (PLSS, Distance, or Limited Distance), appear smaller than the other elevations analyzed however, they are most limited and clustered (around 420 meters) in the results for the PLSS Collection Sites (Figure 64). The TKW elevation for each collection site also has a standard deviation of below 15 meters (Figures 64 and C 18–C 19).

The two different Dakota Formation thickness estimates (ABD) have some similarities in values even with edge effects present (Figures 65–66 and C 20–C 23), but there also appears to be some noise or erroneous values. Part of the problem with using the ABD estimates comes from the fact that not all of the collection sites in this study are unaffected by edge effects. However, when the two ABD estimates and their sources are compared, they follow similar patterns (Figures 67–70). Considering that the two surfaces (DB and TKW) are at different elevational planes in the subsurface, it appears that there is some topographic control to these two surfaces.

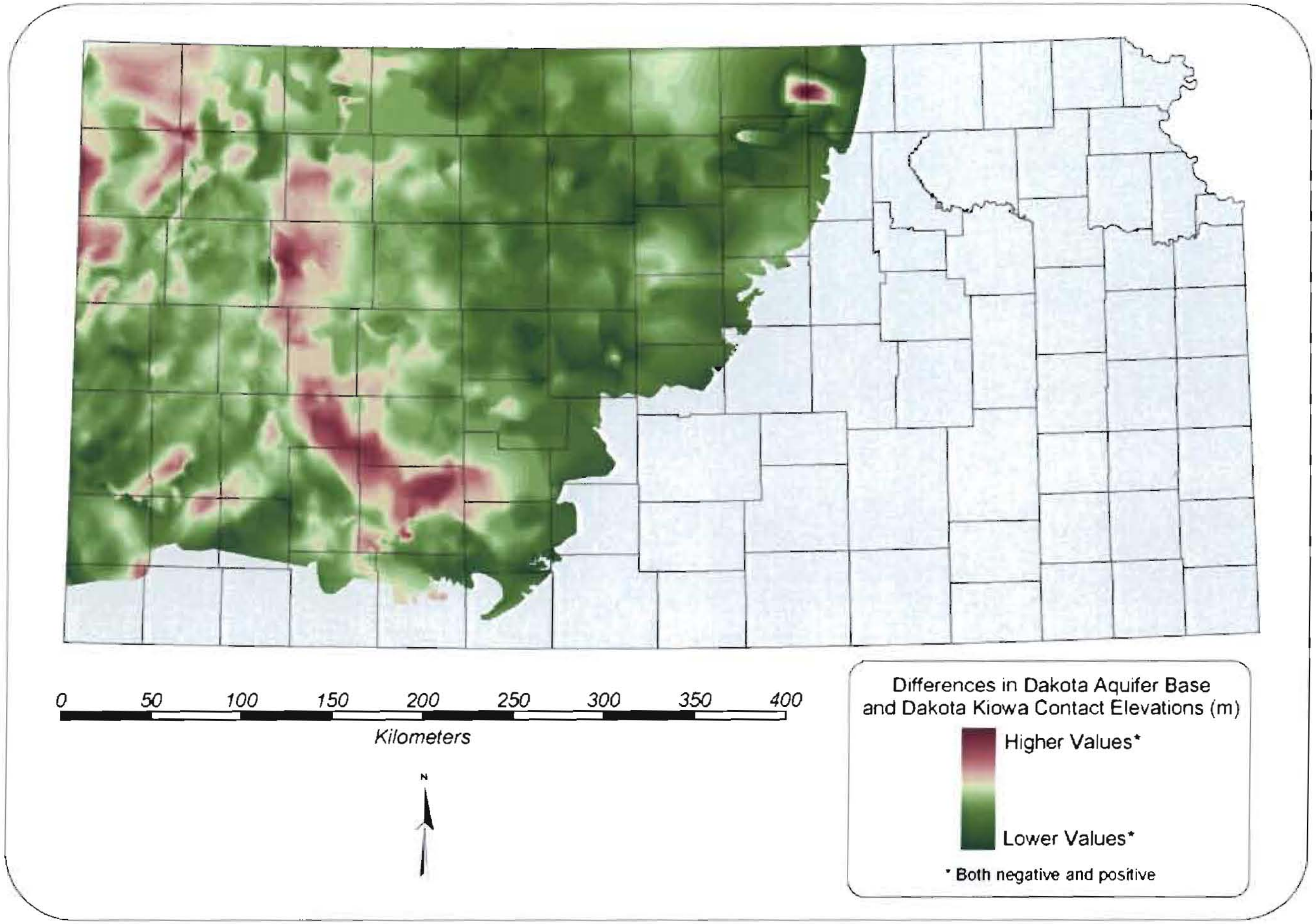

Figure 69: Comparison of the Dakota Aquifer Base and the Dakota-Kiowa Contact Elevations. Results of subtracting the Dakota-Kiowa contact elevations from the Dakota Aquifer base elevations plotted as the deviation from zero with the higher values depicted in pinks and the lower values depicted in greens on the map created to depict the differences.

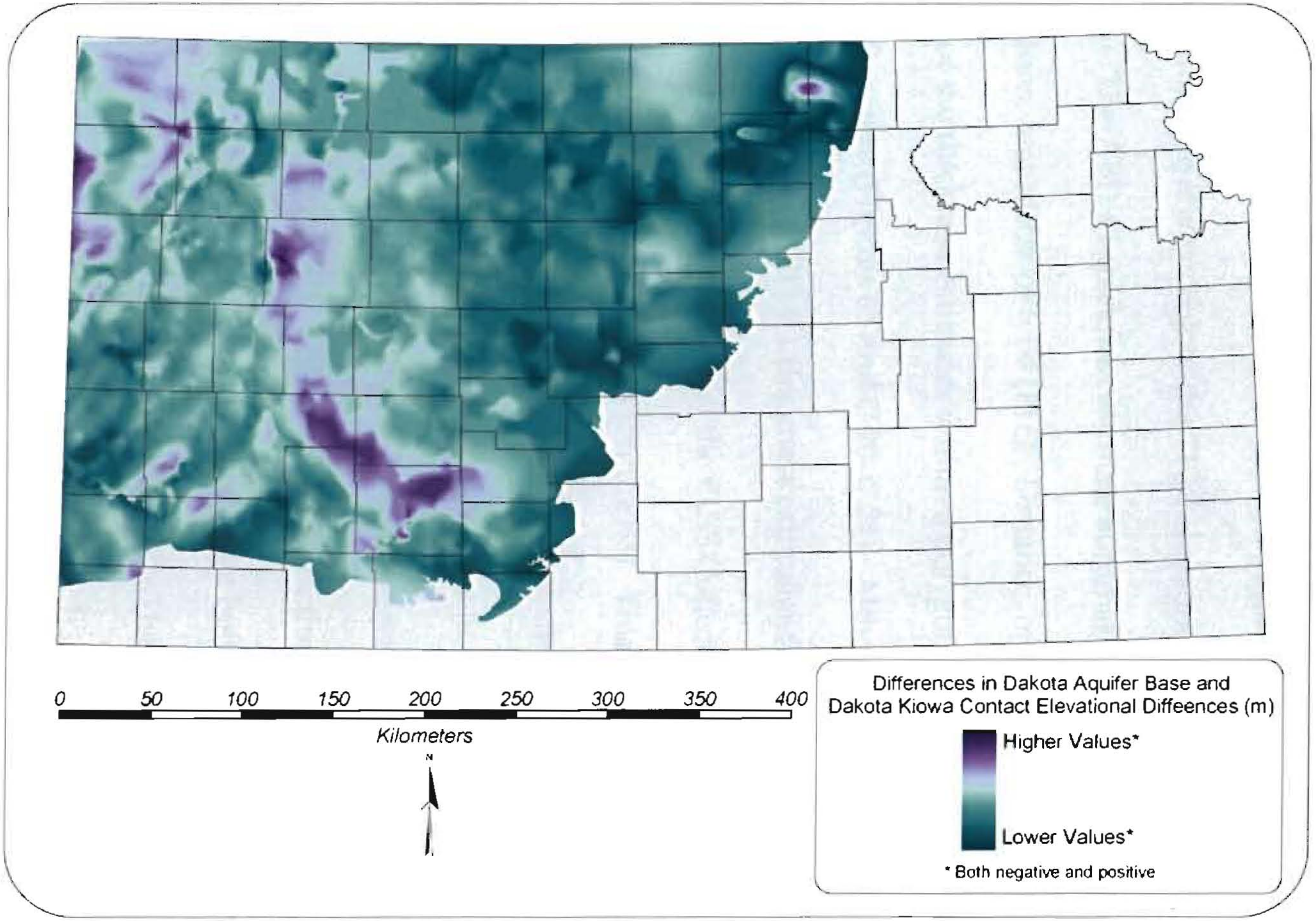

Figure 70: Comparison of Dakota Formation Thickness Estimates. Result of subtracting the Kiowa Formation derived Dakota Formation thickness estimate from the Dakota Aquifer derived Dakota Formation thickness estimate plotted as the deviation from zero with the higher values depicted in purples and the lower values depicted in teals on the map created to depict the differences.

When the two ABD estimates are compared, one collection site for each collection site type (PLSS, Distance, or Limited Distance) causes the lines representing the mean values to cross (Figures 67 and C 24–C 25). However, when just the DB elevations and the TKW elevations are compared the DB elevations are always below the TKW elevations (Figures 68and C 26–C 27).

The ABD #1 thickness estimate summary statistics at most collection site locations, regardless of type (PLSS, Distance, or Limited Distance), indicates that 68% of the thickness estimates within a polygon (mean ± 1 STD) fall between 20 to 160 meters (Figures 65 and C 20–C 21). Although the results of the zone summaries of the ABD # 1 thickness estimates for all of the collection sites generally exhibited no clusters, the PLSS Collection Site data seem to show a cluster around 100–120 meters (Figure 65). This corresponds to a standard deviation of 15–20 meters for each collection site (Figures 65 and C 20–C 21). The edge effects were present to varying degrees in each collection site type (Figures 51–53). The PLSS Collection Sites have no descriptions that are affected by the edge effects (Figure 51). The Distance Collection Sites have two buffers that have edge effects present at the outer edge of the buffer, but all are less than 1/16 of the circumference of the buffer (Figure 52). The Limited Distance Collection Sites have no affected collection sites (Figure 53). It is not surprising that the larger areas have more edge effects present. In addition to edge effects, there are the effects of the eight collection site polygons that do not remain in the grid area.

These polygons outside the grid area will be discussed in more detail under the known errors section ("Why the Errors in the Results?" on page 194).

The ABD # 2 thickness estimate summary statistics at most collection site locations, regardless of type (PLSS, Distance, or Limited Distance), indicate that 68% of the thickness estimates within a polygon (mean ± 1 STD) fall between 0 to 100 meters (Figures 66 and C 22–C 23). While the ABD # 2 thickness estimates contains considerable variability, there appear to be zones of similarity like those of the Limited Distance Collection Sites around Fort Harker (collection sites with a "K" prefix) at about 20 meters (Figure 66). This creates a standard deviation for the ABD #2 thickness estimate of less than 25 meters for each collection site (Figures 66 and C 22–C 23). The ABD # 2 thickness estimate also contains the negative values due to inclusion of areas with edge effects (Figures 54–56). The PLSS Collection Sites only have two of the descriptions that are affected by the edge effects and both are problematic descriptions. One problematic description results in 10 possible sections that contain Dakota outcrops of which only two are affected and neither is the most likely candidate for the "true" collection site location. The other problematic description results in only one possible section that includes any Dakota outcrop (Figure 54). The Distance Collection Sites have 11 buffers that have edge effects present at the outer edge of the buffer, but of these most (all but 5) are less than 1/16 of the circumference of the buffer (Figure 55). The Limited Distance Collection Sites also have 11 affected collection sites however, of those 11 only one has edge effects at the arc end (Figure 56). Even though the source of the edge effects was different for this value, it is still not surprising that the larger areas have more edge effects present. In addition to created edge effects, there are the effects of the five collection site polygons that do not remain in the grid area. These polygons outside the grid area will be discussed in more detail under the known errors section ("Why the Errors in the Results?" on page 194).

A single cluster for a single analysis is probably not significant, however if multiple analyses using different datasets produce clusters containing similar collection sites then these patterns of similarity may indicate useful relationships. It appears that some collection sites are at similar elevations. Perhaps future additional study will allow the collection sites to either be correlated stratigraphically or relocated based on this similarity of elevations. Nevertheless, it should also be observed that dissimilarities were detected when the differences in elevation statistics were compared. These varied considerably and I believe will need further analysis in another study to understand whether there are any spatial, topographic, or stratigraphic patterns and what they may or may not indicate (Tables 8-9). This could be due to a variety of factors. These factors include, but are not limited to: incomplete grid cells in the zone of the collection site location polygon that change the results, the sloping nature of both the surficial elevation and the Dakota Aquifer base elevation, the fact that the slope of the surface and the slope of the base are perpendicular to each other (Personal Communication Macfarlane, 2005), and the negative values indicating a data error or difference in coverage area. Unfortunately, in this study there is insufficient data to understand fully what the patterns of similar variation mean to the Dakota strata or why one collection site of each type (PLSS, Distance, or Limited Distance) causes the formation thickness estimate's mean lines to intersect.

I recognize that the collection site polygons are bigger than the actual size of the collection sites. Therefore, there is a certain amount of uncertainty in the elevational statistics because they are not constrained to the actual collection site boundary but the collection site polygon boundary that was derived from the GIS processing of the collection site descriptions. Hence, the clusters of similar AMSL, DB, and TKW elevations and the ABD #1 and ABD #2 thickness estimates may be an artifact of the analysis method itself. Additionally, as previously explained some of the GIS collection site polygons were essentially the same location or at least overlapping locations, especially in Ellsworth County.

Field elevations obtained with a Garmin GPS 12XL Personal Navigator at Dakota Formation outcrops in the vicinity of historically described collection sites were analyzed to determine if the GIS results of the AMSL elevation analyses were useful. However, these field observations of elevations at sandstone lithologies of the Dakota Formation outcrops containing plant fossils are also problematic. The 400-550 meter range of surface elevations is also present in the GPS-derived elevation measurements (Figures 71 and 72).

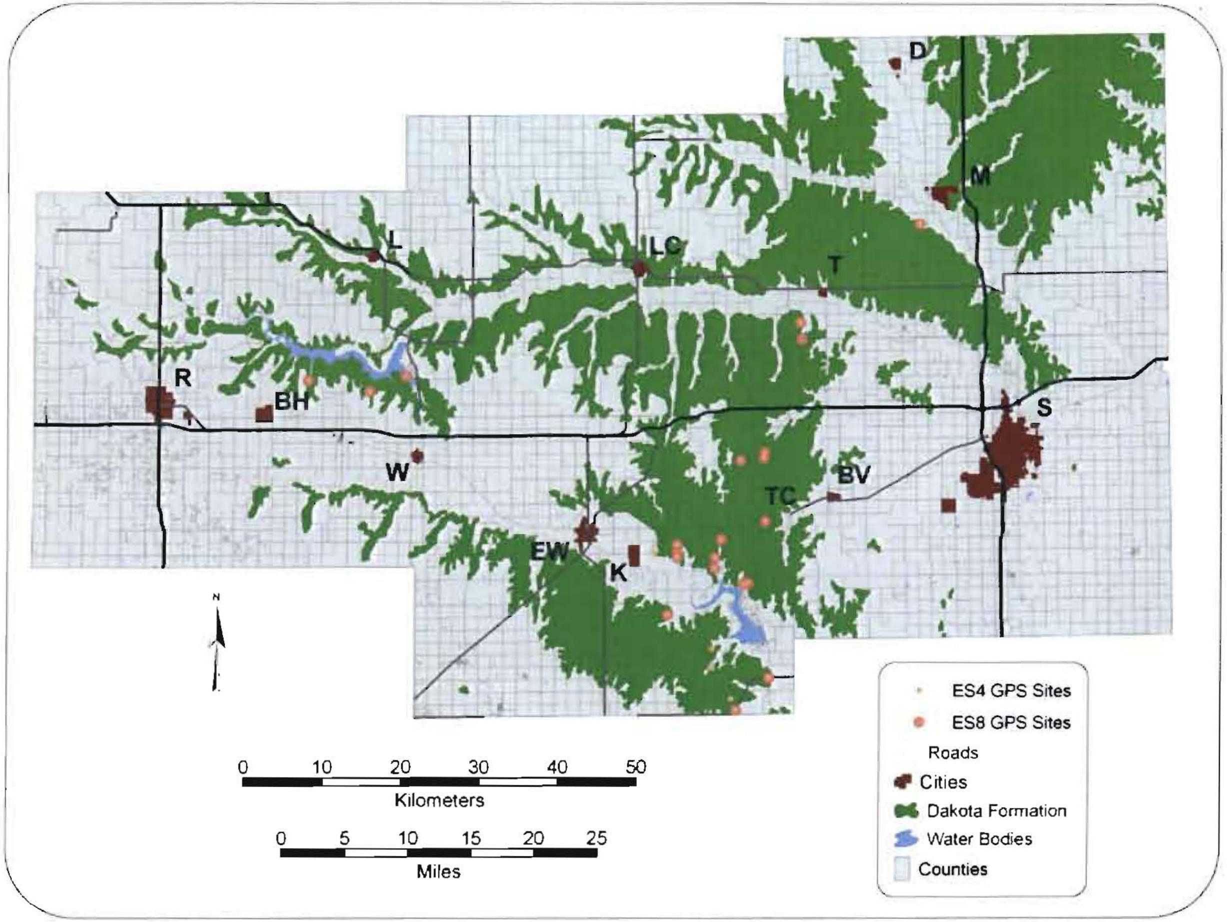

Figure 71: GPS Locations. Locations of GPS readings obtained during the summer of 2004. Most locations were Dakota sandstone outcrops, most although not all contained plant fossils. (City abbreviations are: BH=Bunker Hill, BV=Brookville, D= Delphos, EW=Ellsworth, K=Kanopolis, L=Lucas, LC=Lincoln Center, M=Minneapolis, R=Russell, S=Salina, T=Tescott, TC=Terra Cotta, and W=Wilson).

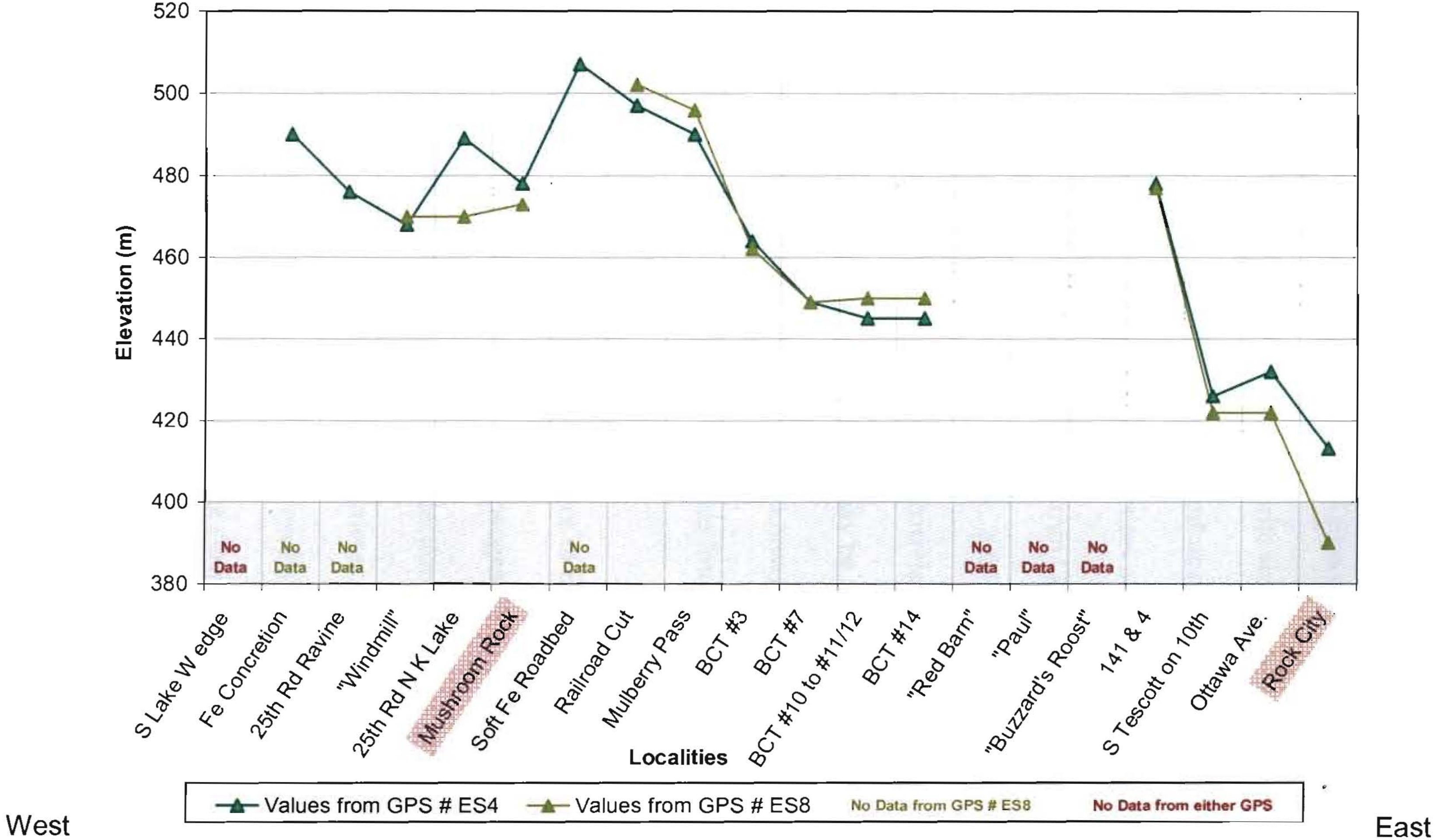

Figure 72: Elevation Similarities Among GPS Locations. GPS readings obtained in the field during summer of 2004 of Dakota sandstone outcrops. The gray shaded area on the graph is outside of the 400-550 meter range of surface data as discussed in the text. No Data labels indicate where GPS elevation readings were not taken. All GPS site locations but the ones shaded brown contain plant fragments.

It should be mentioned that while this range is the same in both analyses, the GPS elevations were obtained prior to the GIS analysis processing of the surface elevations. Additionally, while these GPS sites contain tentatively identifiable taxa of Dakota Flora or plant fragments quite similar to those described in published data there may not be a sufficient number of specimens to correlate these GPS sites to the historical collection sites absolutely. However, since the generally accepted elevation error for Garmin GPS 12XL Personal Navigator is 30 meters (Personal Communication Schaffer, 2005), its precision and accuracy may not be sufficient for reliable stratigraphic correlation of these GPS sites with other known collection sites. Nevertheless, it may be possible to gain more precise elevation readings of the GPS sites on the known outcrops of Dakota Formation to evaluate the similarity of the GIS analysis findings with the GPS elevation analysis findings in a future study.

Due to the results of the GIS analyses of the NED derived AMSL elevations and the GPS elevations, the hypsographical data for the area in Central Kansas containing most of the collection sites were analyzed to determine if it followed the same 400-550 meter clustering of collection site locations. The hypsography comparison results also indicated that the similarities from the surface elevation zone summaries and GPS site readings probably have merit. The 400–550 meter hypsography when compared with the most limited collection site data show that all but four of the collection sites are within this interval (distance and direction delineated data in Figure 73).

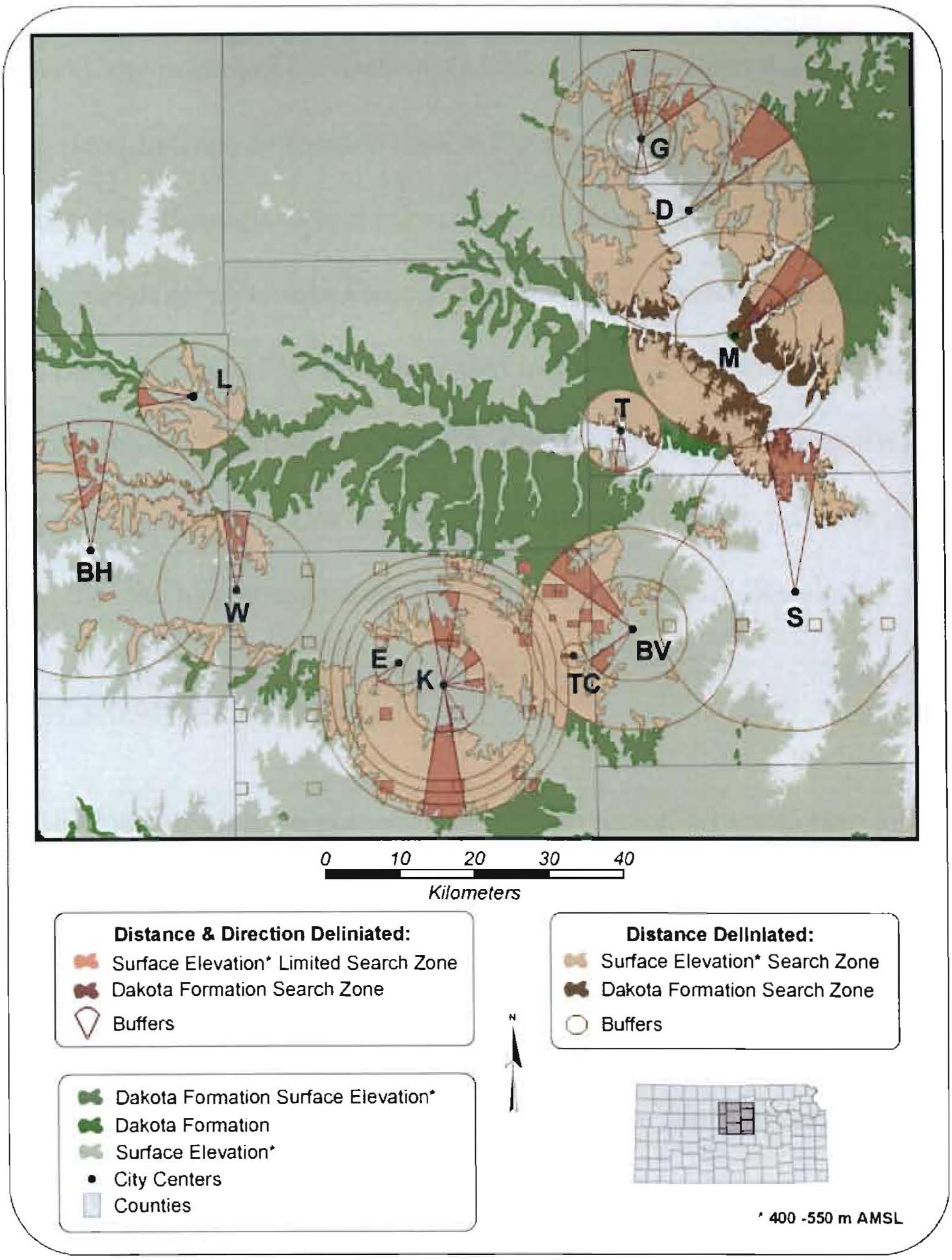

Figure 73: Relationship Between Elevations of Dakota Formation Outcrop and Collection Sites. This map attempts to illustrate the complexity of analyzing the Dakota Formation Collection Sites strictly by surface elevations. Much of the Dakota Formation Outcrop is within the 400–550 meter AMSL range. However, when the Dakota Formation outcrop is limited by both the 400–550 meter AMSL range and either the combined Distance and PLSS Collection Sites or by the combined Limited Distance and PLSS Collection Sites the approximation of collection site areas are more precise.

If one accepts the idea that only some of the collection site area must fall within this interval, the number of collection sites that are not within the interval drops to one or two (distance delineated data in Figure 73). Further stratigraphic control obtained through field checks of known Dakota Flora collection sites may help limit search zones within Dakota strata polygons to elevation ranges less than 150 meters (Figure 73). It is likely that inclusion of more detailed surface elevation in the analysis might help further limit search areas, because when the hypsography of the entire Dakota Formation outcrop is observed there is enough variation that the hypothesis might have some merit (Figure 74).

Why the Errors in the Results?

GIS datasets all have potential for inherent error, which in turn affects the results. While these error values vary among the input data used in this study, the resulting error is at least as great as those of the input datasets are. Because the GIS datasets used for these analyses have these inherent errors the results may not accurately portray the collection sites as they are in the real world. Therefore, while the locations of the Dakota Flora collection sites obtained in this study are more limited and useful than when the study was begun they are still not as accurate as modern collection site descriptions that include accurate GPS readings.

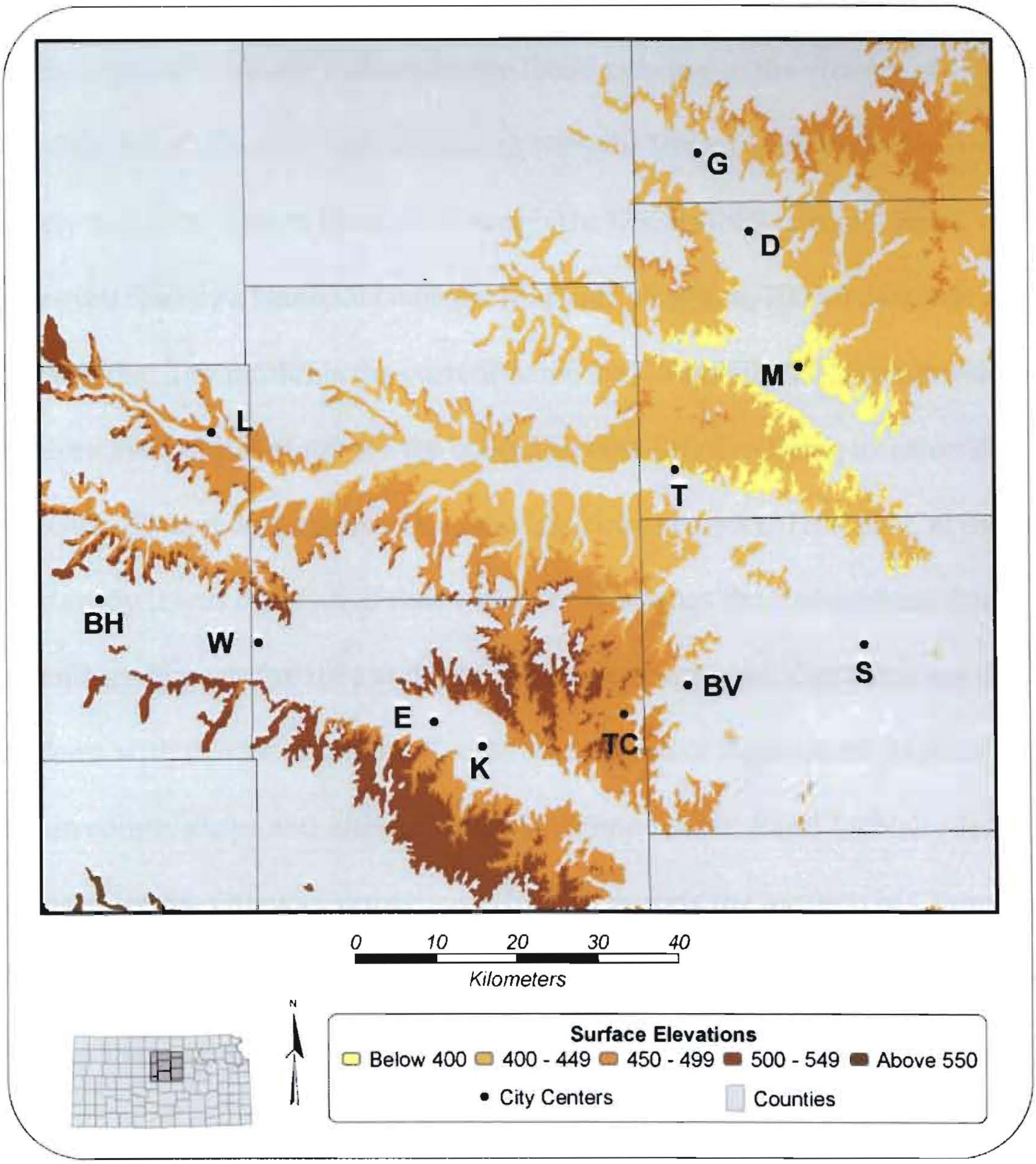

Figure 74: Dakota Formation Outcrop Hypsography. Colors are used to show spatial variation in Dakota Formation outcrop elevation in 50-meter intervals.

Additionally the collection site data for both the Distance Collection Site and the Limited Distance Collection Site listed as being in the vicinity of Churchill, KS (Collection Sites beginning with the letter T), are probably not entirely accurate. This is because although the USGS GNIS (United States Geological Survey's National Geologic Mapping Program, 2000a) database indicates that Tescott, KS is the current name for Churchill, KS. Tescott was therefore used in this study for the collection sites listed as being located near Churchill, KS as it was assumed that the USGS was correct. However, at the end of the study it was discovered that when one examines the Kansas State Board of Agriculture Reports for 1884 and 1888, just four years apart, that there are some problems with this assumption. Kansas State Board of Agriculture Reports contain county maps and although the same map maker, Rand McNally & Co., was used for the Ottawa County maps in both reports the location of Churchill, KS in 1884 (pg 308) and Tescott, KS in 1888 (pg 368) are not in the same position (Figures 18-19 on pages 90-91). The location of Churchill, KS in 1884 is south of the river while the location of Tescott, KS in 1888 is located north of the river (Figures 18-19 on pages 90-91). While cities, especially in the early days of settling the west, changed names and locations the collection sites based off of directions from Tescott, KS as a proxy for Churchill, KS which is the location Sternberg used in the collection site and locality descriptions would be off.

The values obtained from the GIS ArcView Summarize Zones command may also be a source of error. When ArcView summarizes a zone, it uses the entire feature as a footprint to use for the data summary. Therefore, any collection sites that do not have their entire footprint within the grid in question (either the Dakota Aquifer base or the Dakota-Kiowa contact and the differences derived from them) cause erroneous values to be included in the analysis. This is due to the zone summary using a value (usually zero) for the cells within the area outside of the grid in question and using them as part of the total cells used in the calculation. Therefore, the results for collection sites, if included, should be used cautiously although they seem to follow the pattern of agreement. These collection sites are few (2 Distance Collection Sites) in the Dakota Aquifer derived estimate and more numerous in the Dakota Kiowa derived estimate (2 PLSS Collection Sites, 11 Distance Collection Sites, and 11 Limited Distance Collection Sites). Because general observations showed that the data derived from these sources had more variability than the surface data, it was decided to keep these points in and use the generalities in the discussion of results (Dakota Aquifer related on page 186 and Kiowa Formation related on page 187).

Chapter 4: Conclusions

Answers to Research Questions

The goals of this study were to find answers to four main questions. In the following paragraphs, the questions will be restated and the answers reached in this study summarized.

Question 1 was: Can existing location descriptions be used to create a GIS dataset that represents the collection sites as polygons of various shapes? In the case of the Dakota Flora specimens examined for this study, this question does not have a single answer. Among the numerous specimen collection sites examined were descriptions that included legal descriptions and distance and direction from known points that allowed GIS analyses techniques to be used. However, other descriptions gave only counties, States, or partial States thus did have enough detail for GIS analysis techniques. Therefore, whether GIS analyses will be useful in documenting localities derived from specimens collected prior to the mid-1900s depends on two factors. Those factors are the degree of details about the individual specimen collection site provided by the original collector and the conditions under which the specimen has been maintained.

Question 2 was: Can GIS analyses be used to refine these collection site polygon locations to smaller polygons that could be more useful for relocating specific historical collection sites? For the Dakota Flora collection sites examined for this study, GIS analyses were shown to be useful. The degree of utility of the techniques depends on the descriptions that are available for those collection sites and the GIS datasets that are available for the relevant area(s). GIS analyses of the Dakota Flora collection sites which were reasonably well described based on distance and direction or legal descriptions resulted in identification of more narrowed areas of origin for the specimens collected prior to the mid-1900s, rather than a single coordinate as would be obtained with a GPS reading for modern specimen collection sites. This study has made future revisitation of the studied historic Dakota Flora collection sites more feasible. Such revisitations and their resulting data may allow refinement of the polygons assigned in these GIS analyses. These GIS techniques should be helpful in researching other historic specimen collections.

Question 3 was: Do spatial analyses of the relationships between the derived collection site polygon locations and other GIS datasets indicate that specimens were collected from a single well-defined geographic area or from a widespread geographic area? Looking at collection site descriptions, both historical and modern, and the results of this study the specimens appear to come from clusters of collection sites. Ellsworth County, Kansas has the majority of collection sites (especially among the historically collected specimens) though there are clusters in Ottawa County, Kansas and in other States including Nebraska and Minnesota. Additionally, the similarity in present day surface elevations determined by the GIS analyses indicate that some collection sites may be have similar strata, although there were other collection sites that did not fit the same elevational groupings. The latter collection sites will require a new study to answer this question definitively. This study does not rule out that the Dakota Flora should not be treated as a single well-defined geographic area because there are still regional stratigraphic relationships to be examined and explained as well as a reappraisal of species by modern standards. While this study found that some collection sites cluster, others do not cluster. Initially, the Dakota Flora and the strata from which it comes seem confusing and complex. When collection site descriptions are examined, some of the reasons for confusion become apparent. The Dakota Flora is not, as presently defined, a centralized locality, but rather areas that are widespread among many counties and even States. Thus, in reality it is a single well-defined geographic area covering a widespread area. Therefore, although it was possible to separate the collection sites to a degree this indicates but does not prove that they come from multiple localities. Because some separation was possible, the single well-defined geographic area of the historically defined Dakota Flora is probably more accurately a widespread geographic area. However, separating collection sites to multiple localities is much simpler than documenting specifically whether the specimens come from multiple horizons, especially for historically collected fossils.

Question 4 was: After relocation, do analyses indicate that the collection sites are dispersed within similar enough stratigraphic units to indicate that they were extant contemporaneously or not? Unfortunately, because paleobotanists have difficulty recognizing the allostratigraphic relationships of the Dakota Formation and its equivalents in the field, the "Dakota Problem" has not been adequately resolved and therefore this question cannot be answered definitively. There are indications that strata with different lithologies have produced plant specimens that have been assigned to the Dakota Flora over the years. While these observations are indicative of the time transgressive nature of the Dakota Formation as an allostratigraphic unit, paleobotanists have been slow to accept this definition of the Dakota. New studies of the relationship of the collection sites to the strata will be necessary to resolve the issues inherent in the "Dakota Problem." These new studies will require fieldwork to determine both regional stratigraphical correlations and field locations containing Dakota Flora specimens *in situ*, especially in sandstones. Additionally, some sort of field methodology for Dakota fossil collectors, especially those working in the sandstones, will need to be established to determine where in the Dakota Formation the fossils were collected.

What Has This Study Told Us That Can Be Used Elsewhere?

Locating historic collection sites is important for both researchers and museum curators. The results of locating collection sites in this study indicate areas likely to be more productive for obtaining new specimens that in turn may aid in depositional studies or in paleoenvironment reconstructions.

Although based on a small number of collection localities, this study indicates that GIS is a useful tool for reconstructing the localities of the Dakota Flora. Of the numerous collection site descriptions that were available, many were too vague. Twenty-one Distance Localities (and an additional 30 when all the directions for the Limited Distance Localities) and 20 PLSS Localities were available as input data. The most complete descriptions came for the specimen labels. Further studies, including museum visits and historical document study, may provide more localities for an extended dataset for new GIS analyses. This will give more locations of collection sites, however it may not aid in answering the stratigraphical questions, since this information was usually not recorded in sufficient detail.

The use of GIS has proven to be a powerful tool of geographical analysis that can help narrow the ground area to search for the historic collection sites using surficial geology and current elevation in the analyses. GIS may be beneficial in answering questions about some of the relationships among collection sites although much additional data will be required to refine the coverages as well as additional types of collection sites. It is important to remember that the GIS analysis results rely on the input datasets, and still must be confirmed by fieldwork. The potential exists for GIS to help provide solutions to both stratigraphical questions and paleoenvironmental conditions if appropriate stratigraphical and locational data is available. This is of limited help with the Dakota Flora since much of what is known comes from the historical specimens with little or no stratigraphical information. To a limited degree, GIS may yet help with locating potential collection sites for modern studies once the "Dakota Problem" is fully resolved for the entire single well-defined geographic area of Dakota Flora specimens.

While much has been done over the years to sort out the stratigraphy of the Dakota Formation, there are still problems with the relationships among the strata containing the historically collected Dakota Flora. Until the relationships among these strata are understood for the entire Dakota strata (as opposed to just study by study and region by region), additional collection sites would be useful from the standpoint of distribution, but not entirely helpful in determining depositional conditions of the Dakota Flora macroflora. Therefore, full depositional and environmental information of the historically described Dakota Flora is not likely to be possible based on only the methods utilized in this study. Nor is it currently possible to obtain the depositional and environmental information using other methods, since insufficient data is available from the historical specimens. Instead, new specimens from the sandstone will have to be collected to explain the depositional and environmental information of the Dakota Flora in the sandstones. With this in mind, this study is helpful in defining where to look for possible future collection sites.

Suggestions for Future Projects on the Dakota Strata and Flora

The Dakota Flora is a well-known Cretaceous fossil flora consisting mainly of angiosperms. The Flora is represented around the world in many paleontology/paleobotany collections, including most of the larger natural history museums and some of the smaller ones. The notoriety, occurrence, geologic history, and importance of the strata and flora of the Dakota warrant more research. Having a clearer idea of the Dakota's distribution and relationships should aid the scientific community in investigating a wide variety of geological, botanical, and paleontological questions. The Dakota's strata and flora distribution and relationships are especially important now that systemists are questioning the validity of the rich diversity supposedly present in the Dakota Flora and debating the importance of the Dakota Flora. This debate arises from the Dakota Flora being lumped into a single well-defined geographic area as opposed to separated into the actual individual localities where it has been collected.

The strata of the Dakota are a rich source of plant and animal fossils. The true importance of Dakota fossils is in the well-preserved and richly diverse leaves, regardless of how diverse it is on a collection site by collection site basis.

The Dakota Flora has not taken its deserved place in paleobotany for two reasons. First, differences in terminology; unclear stratigraphic and sedimentological history; and diversity differences with contemporaneous floras make its study complex and confusing. Second, many modern paleobotanists have partially discounted the abundant diversity claimed for the Dakota Flora. The entire Dakota Flora has not been re-investigated in an all-encompassing large-scale way since Lesquereux's 1874, 1883, and 1892 monographs, in part because of the aforementioned problems but also because of the overwhelming size of the task. The present research of others supports the need to seriously re-examine the diversity Lesquereux reported as individual taxa/species. Still lacking is a location-based examination of Lesquereux's individual taxa/species and a reexamination of those taxa/species descriptions with modern ideas of taxa/species. Wang's (2002) research on flora from specific collection sites of Dakota strata supports the idea of a higher than normal diversity in the Dakota Flora. Wang's flora is similar to that of what Lesquereux suggested comes from five localities. Wang (2002) found a greater 20–25 species per locality; a diversity exceeding that suggested by others as the standard early Cretaceous angiosperm diversity.

Since the Dakota Flora is an important paleobotanical collection from the mid-Cretaceous when angiosperms are still just beginning to diversify, it deserves to be fully understood and respected. Lesquereux's publications on the flora (1874a; 1883; 1892), he describe 6 ferns, 12 cycads, 15 conifers, and 437 angiosperms. If the 437-angiosperm species diversity appearing in the Dakota Flora is correct, it suggests an earlier time of evolution. This gives more credence to a late Jurassic evolution of the angiosperms, as is suggested by ongoing research. The Dakota Flora also has more angiosperm species than contemporaneous floras that have only 20-30 species (Lidgard and Crane, 1988). The context and composition of the Dakota Flora therefore may be an important key to early angiosperm evolution. The Dakota Flora needs to be studied with the-cutting-edge technology and modern theories from the paleobotany science sub-specialties of both geology and biology.

If the similarities in elevations and thickness estimates found in this study are an artifact of the analysis methods, it is because both the Distance Collection Site locations and the Limited Distance Site locations utilized buffers to portray the polygon representing the collection site. These polygons included the entire "circle" of the specified distance for the Distance buffer and the entire "wedge" of the specified Distance and direction for the Limited Distance buffer. If the buffers were constructed differently, they potentially could be smaller and thereby probably could more accurately depict the location of the collection sites thus further limit the search area for relocation purposes. In order to portray construct these different buffers each Distance Collection Site could be buffered as a "ring" of a specified width at the appropriate distance from the city and each Limited Distance Collection Site could be buffered as a specified width from only of the arc at the end of the current buffers. However, assumptions about the accuracy of the distance measurement would need to be made in addition to determining what the area of the collection site might have been to determine what the specified width for the rings and arc buffers should be in order to create a relatively accurate representation. These limitations of the buffers were not attempted in this study. However, during analyses of the results it was observed that they would be an additional extension of what has already been done here to be carried out in a future study. Additionally, field checks in the Dakota Flora search zones determined by this study could help determine how useful this method actually is for fieldwork planning and perhaps even provide data to help refine the GIS processing and analyses.

I believe that GIS will also begin to play a role in the study of the Dakota Flora and other paleontological studies when fossil researchers see the utility that various coverages/layers have for analyses and interpretations, especially those of environment of deposition. This will require the creation of a 3-D model of the modern field environment to aid in interpreting the complex interactions that produced the fossil collection sites both for the Dakota and for other paleontological studies. In addition, a 3-D model of the reconstructed paleoenvironments should also be created to understand the depositional processes that produced the fossil floras and faunas and to aid in interpretations of the floras and faunas. If these 3-D models are created, historic collection sites, modern collection sites, and future collection sites can be properly located and analyzed in relation to each other.

Both the information needs and the GIS software capabilities must be better understood by such individuals before GIS can become a viable tool for paleontological researchers and museum curators. Paleontological data about the specimens must be available in a format compatible with the GIS software, as is true for any museum collection. To achieve this, the following things will have to happen:

1. Museum catalog information must be organized into a database format to utilize fully the capabilities of the GIS software programs.
2. Organizational emphases in museum catalogs must be structured to deal with the GIS information needs of researchers and curators, such that the data contained in them can be related to databases.
3. Specific locality data must be transferred from individual specimen labels in the museum collections into a centralized computer system.
4. Standard formats must be implemented for museum catalogs and/or databases will need some sort of standardization so that data from multiple museums can be combined to form the datasets needed for the GIS input.
5. International policies for using and safeguarding of paleontological localities must be established by the international museum and paleontological communities. Such policies must permit GIS analyses without jeopardizing the collection sites and must include how specific locating instructions of localities will or will not be distributed and who will maintain which types of data.

6. Consortiums or working groups will need to develop paleontological GIS resources and/or locality data clearinghouses (similar to DASC for Kansas related data).

Many museums are now putting their collection catalogs into databases. However, they are not generally readily accessible to researchers, nor are all the museum collection's specimens included. Collections that are in databases are not usually structured to provide the GIS information needed by researchers and curators. Some researchers are beginning to develop the processes for associating GIS data with pre-existing museum databases. How well these processes for pre-existing museum collection databases will facilitate GIS analyses remains to be seen, but the future looks promising for research combining GIS analyses with museum collections.

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Appendix A: Glossary of Selected Terms

This glossary contains only the most commonly confused terms and abbreviations used in this thesis. It is assumed that the reader has a general understanding of both stratigraphic and GIS terms. For comprehensive definitions of stratigraphic terms the *North American Stratigraphic Code* (North American Commission on Stratigraphic Nomenclature, 1983) and the *International Stratigraphic Guide: A Guide to Stratigraphic Classification, Terminology, and Procedure* (Salvador, 1994) are good sources. The textbooks *Introduction to Geographic Information Systems* (Chang, 2002) or *Getting Started with Geographic Information Systems* (Clarke, 2003), are good sources for GIS terms.

ABD: Elevations that are above the base of the Dakota Formation whose elevational values were determined by subtracting a subsurface elevation (base of the Dakota Aquifer or top of the Kiowa Formation) from the surface elevation derived from the NED or hypsography.

AMSL: Elevations that are above mean sea level that were derived from the NED or hypsography downloaded from DASC.

Anschutz Library: Anschutz Science Library located at the University of Kansas located in Lawrence, Kansas.

Cambridge Museum: Cambridge Museum of Comparative Zoology of Harvard University located in Cambridge, Massachusetts.

Cluster: Three or more collection sites of similar elevation (within 20 meters).

Collection Site: Actual position on the outcrop in the field from where the fossil specimen was obtained. <**NOT** to be confused with the terms *Locality* or *"Single, well-defined geographic area."*>

Current Studies: Any first-hand data I gathered, any data from studies published since 1994, and any modern specimen label—unless it was written before 1970.

CWIS: Cretaceous Western Interior Seaway; the epicontinental sea present during the Cretaceous in North America, which at one point connected the Gulf of Mexico to the Artic Ocean.

Dakota Flora: The primarily angiosperm leaf megafossil specimens that have been described in museums and the literature as coming from sandstones attributed to Dakota strata.

Dakota Formation: The fossiliferous and non-fossiliferous Cretaceous sediments in Kansas, which are older than the Graneros Shale and younger than the Kiowa Formation; <u>except</u> in quotes from other authors where an attempt will be made in the text near the quote to establish the meaning.

"Dakota Problem": The use of the term Dakota to designate many Cretaceous strata in the Western Interior of the United States without regard to the guidelines in the North American and International stratigraphic codes, mainly perpetuated today because of paleobotanists' misunderstandings of stratigraphical concepts because they are using the historically collected fossil leaf specimens to view the strata as a lithostratigraphic unit; while, stratigraphers view the strata by using modern stratigraphic concepts as an allostratigraphic unit.

Dakota sandstone: Any sandstone of the Dakota Formation especially if it contains fossils of the historically collected Dakota Flora. <**NOT** to be confused with the term *Dakota Sandstone* in quotes from other authors where an attempt will be made in the text near the quote to establish the meaning.>

Dakota strata: Reference to the strata that make up the Dakota Formation when the terminology might otherwise bog down the discussion.

Dakota strata and flora, The: Sparingly used when discussing the Dakota in general. This term should be taken to include the Dakota Flora, the sediments the fossil flora comes from, and the Cretaceous sediments in Kansas assigned to the Dakota.

DASC: Kansas Data Access and Support Center located at KGS, which is an online source of GIS datasets for the State of Kansas.

Distance Collection Site: Collection site that is described as a certain distance from a city (even if it has a directional component) that is represented as the entire buffer of the distance around that city limit.

DOQQs: Digital Orthophoto Quarter Quadrangles or digital aerial photographs that have been georeferenced.

DRGs: Digital Raster Graphics or digital images of topographic maps that have been georeferenced.

ESRI: Environmental Systems Research Institute located in Redlands, California.

ESU: Emporia State University located in Emporia, Kansas.

FHSU: Fort Hayes State University located in Hays, Kansas.

Fipscodes: United States Census Bureau derived Federal Identification Processing Standard Codes used by the United States government and many GIS users to identify specific features.

FLMNH: The Florida Museum of Natural History at the University of Florida located in Gainesville, Florida.

GEOLEX: Geologic Names Lexicon of the USGS that is an on-line lexicon of stratigraphic names.

GIS: Geographical Information Systems.

GNIS: Geographic Names Information System of the USGS that is an on-line lexicon of place names.

GPS: Global Positioning Systems.

Harvard: Harvard University located in Cambridge, Massachsetts.

Historical Data: Data or previous studies that I obtained from the literature published before 1994 or historical specimen labels—those labels that are not the current label or that were written before 1970.

Historical Collection Site: A collection site that was discovered and collected in the late 1800s and early 1900s by any Dakota Flora worker.

Historical Specimen Labels: Those labels that are not the current label or those that were written before 1970.

JGM: Johnston Geology Museum at Emporia State University located in Emporia, Kansas.

KGS: Kansas Geological Survey located in Lawrence, Kansas at the University of Kansas.

KU: University of Kansas located in Lawrence, Kansas.

KU NHM: The University of Kansas Natural History Museum located in Lawrence, Kansas.

LEO: Common reference to the *LEO II* computer utility/program, which is the Kansas Automated Reference Conversion Utility used to transform PLSS data to a GIS compatible form; for additional information see the KGS publication (Ross, 1991) listed in reference section of this thesis.

Limited Distance Collection Site: Collection site that is described as a certain distance from a city and have a directional component, represented by a directional wedge from the city center-point of the distance around the city in which the distance is obtained from the Distance Collection Site buffer (sometimes abbreviated as Limited Distance Site).

Locality: Usually a location of the outcrop that contains the collection site. <**Not** to be confused with the term *Collection Site* or *"Single, well-defined geographic area."*> Except in stratigraphic discussions it means the position of the outcrop that the stratigraphic description is describing. <See also *"Single, well-defined geographic area."*>

Modern Data: <See *Current Studies.*>

Modern Collection Site: A collection site that was recently (since about 1970) discovered collection site by any Dakota Flora worker.

Modern Specimen Label: Any recently created specimen label, even if it is just a typed version of an older label—unless it was written before 1970.

NAD: North American Datum.

NADCON: North American Datum Conversion utility used to transform the datums of projections for GIS.

NED: National Elevation Dataset.

PLSS: Public Land Survey System; the legal description of a piece of land using township, range, and sections that can be further subdivided in to varying levels of quarter-sections and/or half-sections.

PLSS Collection Site: Collection site that is described as a legal description using the Public Land Survey System.

"Single, well-defined geographic area": The overall extent of the historically (late 1800s to early 1900s) collected and described Dakota Flora when taken as a whole—the overall extent of this geographic area consists mainly of the Dakota strata on the eastern margin of the Cretaceous Western Interior Seaway, this mainly includes: Kansas, Nebraska, Iowa, and Minnesota.

Smathers Library: The George A. Smathers Library (science library) located at the University of Florida in Gainesville, Florida.

Smithsonian: The Natural History Museum of the Smithsonian Institute located in Washington, D. C. .

SMNH: The Sternberg Museum of Natural History at Fort Hays State University located in Hays, Kansas (also abbreviated *Sternberg Museum*).

Sternberg Museum: The Sternberg Museum of Natural History at Fort Hays State University located in Hays, Kansas (also abbreviated *SMNH*).

TIGERfiles: Topologically Integrated Geographic Encoding and Reference files (county boundaries, roads, railways, cities, etc.) generated from United States Census data.

TIN: Triangulated Irregular Network used for depicting elevations.

UF: University of Florida located in Gainesville, Florida.

UTM: Universal Transverse Mercator projection.

USGS: United States Geological Survey.

WAW Library: William Allen White Library located at Emporia State University in Emporia, Kansas.

Appendix B: GIS Processing Methods

General Comments on GIS Processing Used in This Thesis

A wide variety of software programs were utilized in the organization and processing of data in these analyses. The Microsoft® Office 2000 suite consisting of Word, Excel, and Access was used to record and organize data. Additionally, Adobe® Photoshop 6.0, Microsoft® Notepad, and Kansas Automated Reference Conversion (LEO II and hereafter referred to as LEO) were used to enable transfer of data to GIS applications. ArcView 3.3 (hereafter referred to as ArcView), ArcMap/ArcView 8.3/ArcGIS 8.3 (hereafter referred to as ArcGIS), and ArcInfo/Workstation (hereafter referred to as ARC/INFO) were the GIS programs used. The discussion of GIS methods contained in this appendix assumes the reader is familiar with common GIS terminology, jargon, and abbreviations however, "Appendix A: Glossary of Selected Terms" (starting on page 224) contains the definitions and abbreviation for those used in the chapters of this thesis.

The GIS data processing for the collection sites had several sub-projects. The collection sites were subdivided into Distance Collection Sites and PLSS Collection Sites. To understand these collection sites it was also useful to understand where each collection site is in relation to Sternberg's residence (Fort

Harker was initially used as a proxy because the exact location of the Sternberg ranch was not known; see appropriate sections beginning on pages 111, 113, 246, and 249 respectively). The surficial geology of the collection site and surface elevation of each collection site were used to help refine locations. Therefore, for this study, data processing needed to be carried out for: the collection sites (both those specified as being a certain direction and distance from a city and those described by legal descriptions), the location of Fort Harker, the location of Sternberg Ranch, the surficial geology, the Dakota Aquifer base elevations, the Dakota-Kiowa contact elevations, and the surface elevations (including DEM and hypsography based models).

Detailed Collection Site Data Processing Overview

After historic fossil collection site data were compiled from publications, specimen labels, and information written directly on the specimens, the collection site data were recorded such that it could be categorized and used in ArcView, ArcGIS, and ARC/INFO. Therefore, as each collection site description was obtained it was entered into an Excel spreadsheet and categorized by type (*i.e.* too vague, outside of Kansas, PLSS, Distance, Limited Distance). Each category was grouped and put into a systematic list to determine what types of GIS coverages would be needed to best estimate the GIS coordinates for each collection site (Tables 5 and 6 starting on page 97).

From the information obtained on collection sites (total of 228), some data were deemed insufficient for use in creating GIS datasets (97 collection sites in Kansas and 28 collection sites in other States). Descriptions such as Ellsworth County, Kansas or just Kansas, as well as those described as vicinity of Fort Harker or Near Ellsworth were too vague to be used and were discarded for these analyses. Additionally because this project limited the collection site data to those within Kansas, any collection site that was outside of Kansas was not used (31 collection sites). The remaining historic collection site descriptions (71 collection sites) were divided into two main categories. These categories were those described by legal descriptions (PLSS Collection Sites listed in Table 5 starting on page 97) and those specified as being a certain direction and/or distance from a city (Distance Collection Sites and Limited Distance Collection Sites listed in Table 6 starting on page 100).

The fossil collection sites classified as Distance Collection Sites and Limited Distance Collection Sites seem to be concentrated around eleven cities in Central Kansas: Brookville, Burdett, Delphos, Ellsworth, Glasco, Fort Harker (Kanopolis), Minneapolis, Salina, Churchill (Tescott), Terra Cotta, and Wilson. Due to complications in determining where the boundary of Fort Harker was located, the city of Kanopolis, KS was used for any description that specified a distance from Fort Harker in this study (further explanation can be found in the sections "Processing Location of Fort Harker" on page 111). The collection sites with descriptions given from a city were first examined as just a distance from the city (Distance Collection Sites) and then as both the distance and direction from the city (Limited Distance Collection Sites). The legal descriptions included entire sections as well as half sections and quarter sections. Only one workable description was of a quarter-quarter section.

Detailed Processing of Distance and Limited Distance Collection Sites

Processing for the Distance Collection Sites and Limited Distance Collection Sites was performed using ArcView, ArcGIS, and ARC/INFO. TIGER 2000 files, DOQQs, and DRGs were downloaded from DASC and unzipped. Then the TIGER 2000 files were imported into ArcView utilizing the Import 71 utility. Only the TIGERfiles for cities were processed, although the county boundaries were used in making many of the maps. In ArcView, the cities theme was added to a view to allow it to be manipulated. The theme was then queried such that an individual city was selected. Once the city was selected, it was converted to a shapefile of its own (Figure B 1).

Four cities (Blackwolf, Carnerio, Crawford, and Terra Cotta) were not part of the TIGER 2000 files. These cities are either very small or they no longer exist; therefore, they were not collected as part of the data in the 2000 census. In order to determine the location of these cities, DOQQs and DRGs for Ellsworth and Rice counties were added to the view in ArcView containing the TIGER 2000 files. All the cities not in the TIGERfiles (except for the city of Crawford, KS in Rice County) are in Ellsworth County.

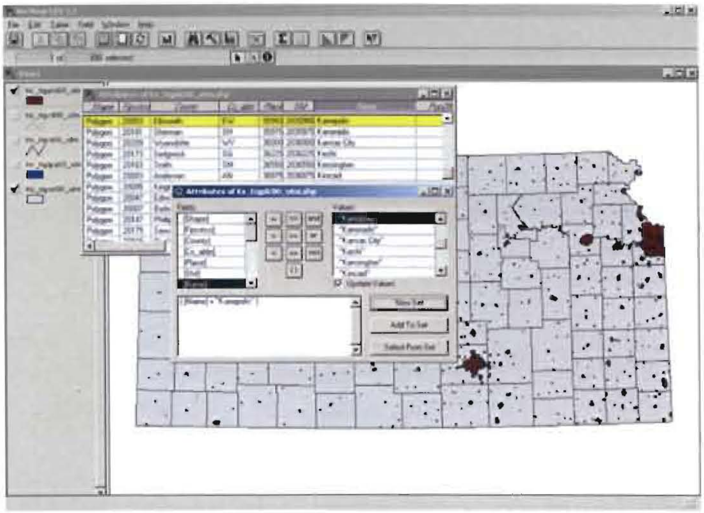


Figure B 1: Querying Kanopolis, KS Polygon. A view screenshot from ArcView in which the Kansas TIGERfiles cities, downloaded from DASC, are queried in order to select a city (in this example Kanopolis) to convert it into its own shapefile.

Heads-up digitizing of city boundaries were undertaken to add these cities to the TIGER 2000 cities shapefile (Figure B 2). To add each city, it was located on the appropriate DRG and compared to the county mosaic DOQQ for the appropriate area. A determination of an appropriate position for the city boundary was made and then added with the "Draw Polygon" tool.

Terra Cotta, KS is said to have been a railway-siding town that no longer exists; however, the name still appears on the map of Ellsworth County and the Venango 7.5 minute quadrangle (Figure 22 on page 107). The name on the map, the location of the railroad, and the traces of roads in the area were used to digitize a small square where Terra Cotta appears to have existed. In all probability, the town boundary of the time was bigger. However, until further information is available and another study is done, the small square was used as the city boundary of Terra Cotta.

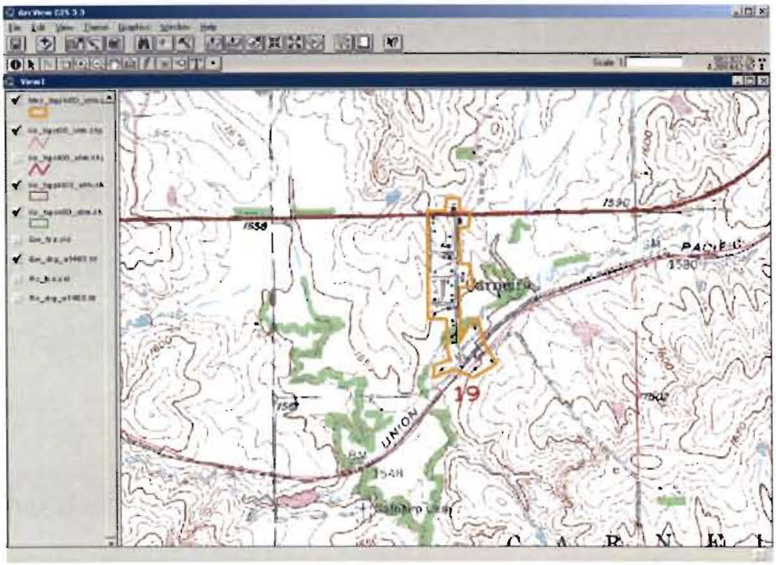


Figure B 2: Digitizing Carnerio, KS. A view screenshot from ArcView in which the Ellsworth County DRG downloaded from DASC is zoomed into Carnerio, KS with a digitized polygon shapefile (orange polygon) to illustrate heads-up digitizing method.

Once digitization was complete, the county name, the county abbreviation, the fipscode (Federal Information Processing Standard Codes) for the county, the fipscode for the place, and the city name were added to the attribute table manually. All fipscodes used were obtained from the GNIS (United States Geological Survey's National Geologic Mapping Program, 2000b). These digitized files were also created as separate shapefiles. The city shapefiles were converted into coverages utilizing ARC/INFO. The commands utilized were <SHAPEARC>, <CLEAN>, <REGIONPOLY>, <BUILD>, <PROJECTDEFINE>, and <BUILD> again. This procedure allowed the polygons for each city to be subdivided into any component parts they might have had (Figure 23 on page 107).

The coverages were then added to a view in ArcView to ensure that the coverages were double-checked to ensure that they were correctly portraying the shape of the city. Any city coverage that had multiple entries in its attribute table was converted back into a shapefile using the "Convert to Shapefile" (Figure 23 on pg 107 and Figures B 3 and B 4). These shapefiles were then edited to include just the main entry. This both simplifies the buffering process and factors in the assumption that outliers are probably later additions to the city than the city boundaries that existed in the late 1800s and early 1900s.

Four cities (Clay Center, Concord, Larned, and Salina) had internal polygons and therefore required a union followed by a dissolve to create a single entry in which the internal polygon was added to the main polygon (Figure 23 on pg 107 and Figures B 3 and B 4). Note that Salina had both external and internal polygon components and therefore it was processed first for external and then for internal polygons (Figure 23 on pg 107 and Figures B 3 and B 4).

Once editing of these shapefiles was complete, they were converted to coverages using ARC/INFO (see above). At this point coverages were double-checked to ensure that they were in the proper coordinates/projection (UTM, Zone 14 N, meters, NAD83).

Once a coverage was created for each city, the attribute tables were examined to ensure that they reflected what was present in the TIGER 2000 files attribute tables.

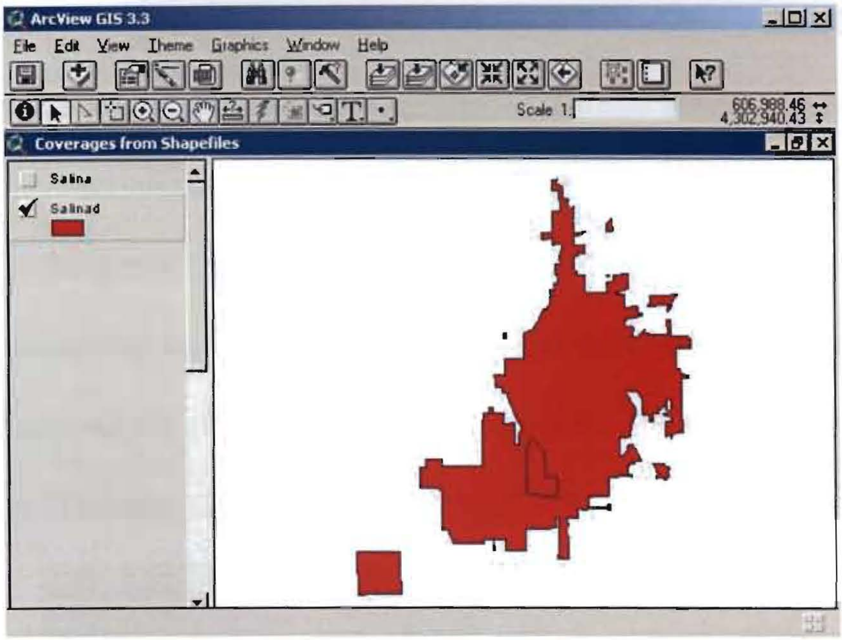


Figure B 3: Example of External and Internal Polygons. A view screenshot from ArcView in which the TIGERfiles cities, downloaded from DASC, shows both external and internal polygon for Salina, KS.

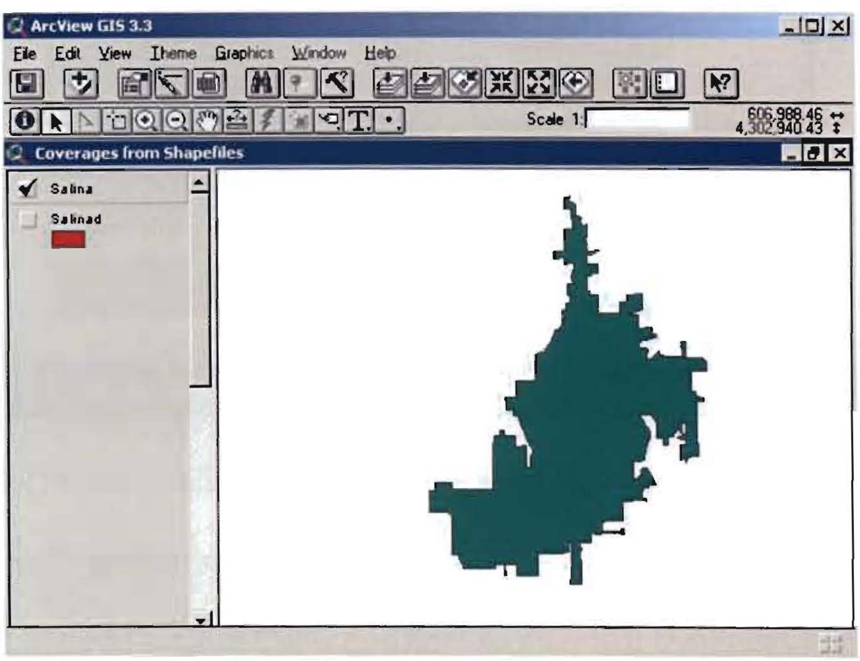


Figure B 4: Example of Removed External and Internal Polygons. A view screenshot from ArcView in which the external polygon for Salina, KS has been removed from the TIGERfiles cities, downloaded from DASC.

After this processing, the city coverages were added to a view in ArcGIS. Each coverage was processed the appropriate number of times based on whether or not multiple collection sites were described as directions and distances from the city with the "Buffer Wizard." The specifications within the Buffer Wizard were to create outside-only buffers of the city polygon at the appropriate number of miles distance from the city as shapefiles (Figure B 5). This produced what are referred to as "Distance Collection Site."

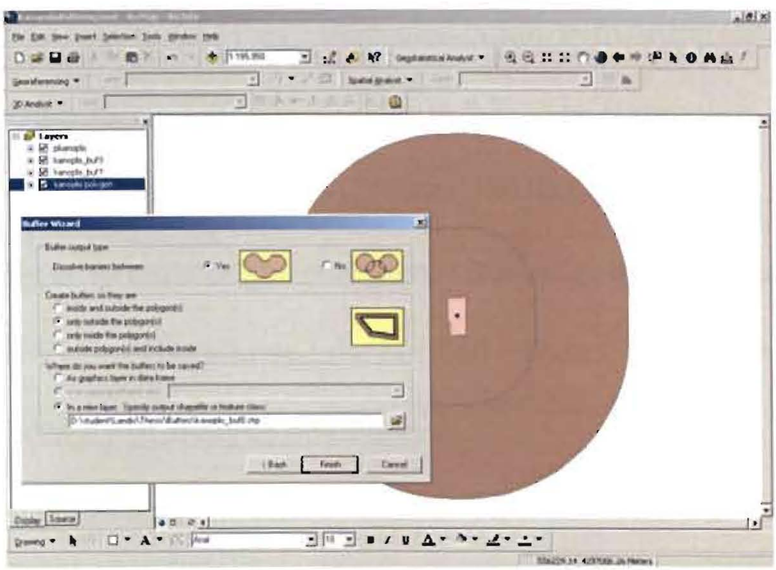


Figure B 5: Buffering Kanopolis, KS. Map view screenshot from ArcGIS in which outside the polygon buffers of specified distances are being created.

The Distance Collection Site buffers were limited to the direction specified in a collection site description by a variety of means in ArcGIS. I use the term "Limited Distance Collection Site" to refer to a Distance Collection Site whose description specified a certain distance and direction from a city. I used GIS methods to create a directional wedge of the buffer within the specified distance from the city. In order to limit the city buffer into a directional wedge of the buffer, a new polyline shapefile for each limited distance collection site based on direction had to be created in ArcCatalogue. Once the Shapefiles were added to the map view that contained the buffer, they could be edited with the editor units set to North Azimuth. The "sketch" tool was used to draw two lines with angles that represented the twenty degrees assigned to each compass direction (Table 7 on page 109 and Figure B 6). Then the "trace" tool was used to trace the buffer's arc between those two lines. The three lines were then examined at a scale of 1:1,000 to ensure that they intersected before converting them into polygon coverages using ARC/INFO (Figure B 7). The commands utilized in ARC/INFO consisted of <SHAPEARC> lines, <BUILD> lines, <TABLE>, <KILL> specific table parts of line coverage, <BUILD> polygons, and <PROJECTDEFINE>. This allowed the Limited Distance Collection Site to be used more effectively in analysis operations.

Each coverage was also added into ArcView 3.3. This was done so that the "XTools" extension's "Centroid to Point" process could be run (Delaune, 2003). This process converts the centroid of a polygon into a point shapefile. The point shapefile allows the directionality of search to be specified. The city polygon coverages were then consolidated into a single coverage by appending them all together in ARC/INFO.

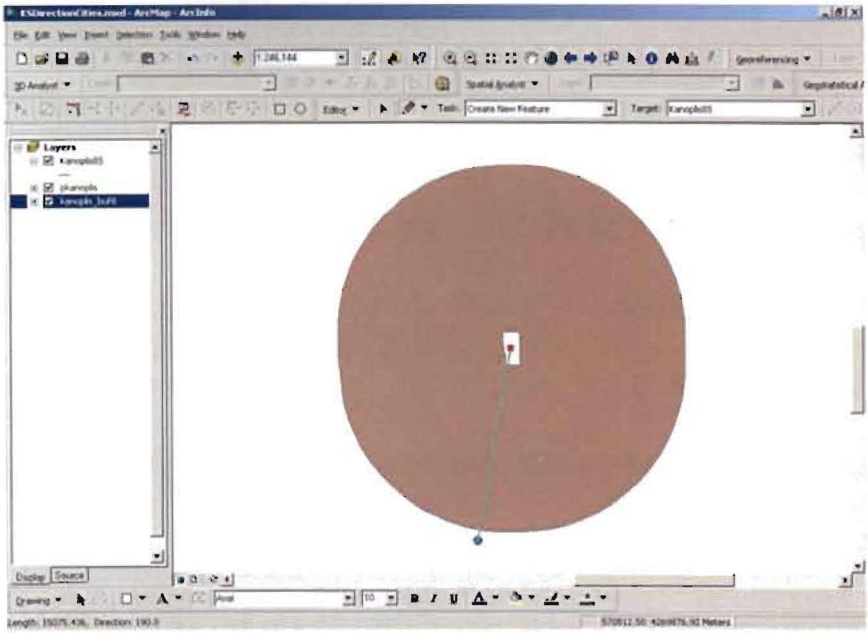


Figure B 6: Drawing a Direction-Limiting Line. ArcGIS map view screenshot illustrating the distance buffer being limited to a specified direction by drawing three different lines.

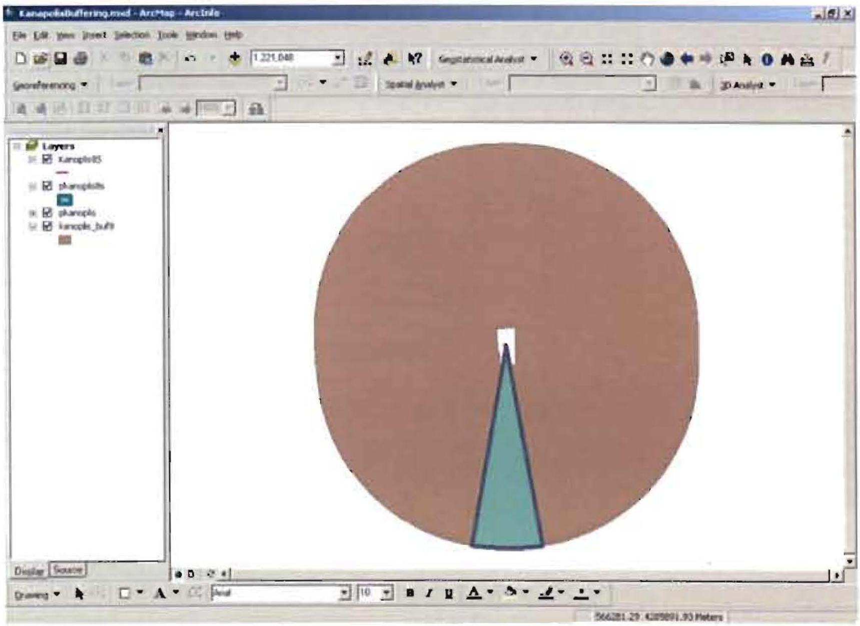


Figure B 7: Directional Distance Polygon. Map view screenshot from ArcGIS showing the completed limited distance buffer polygon.

Detailed Processing PLSS Collection Sites

Processing for the PLSS Collection Sites was performed using ArcView, ArcGIS, ARC/INFO, Notepad, Excel, and LEO. First, the PLSS file was downloaded from DASC and unzipped. Then the PLSS file was imported into ArcView using the Import 71 Utility. In ArcView, the PLSS theme was added to a view in order to allow it to be manipulated. The theme was then queried such that a specific section of a township and range was selected (Figure B 8). Once the section representing the query results was selected, it was converted to a shapefile of its own.

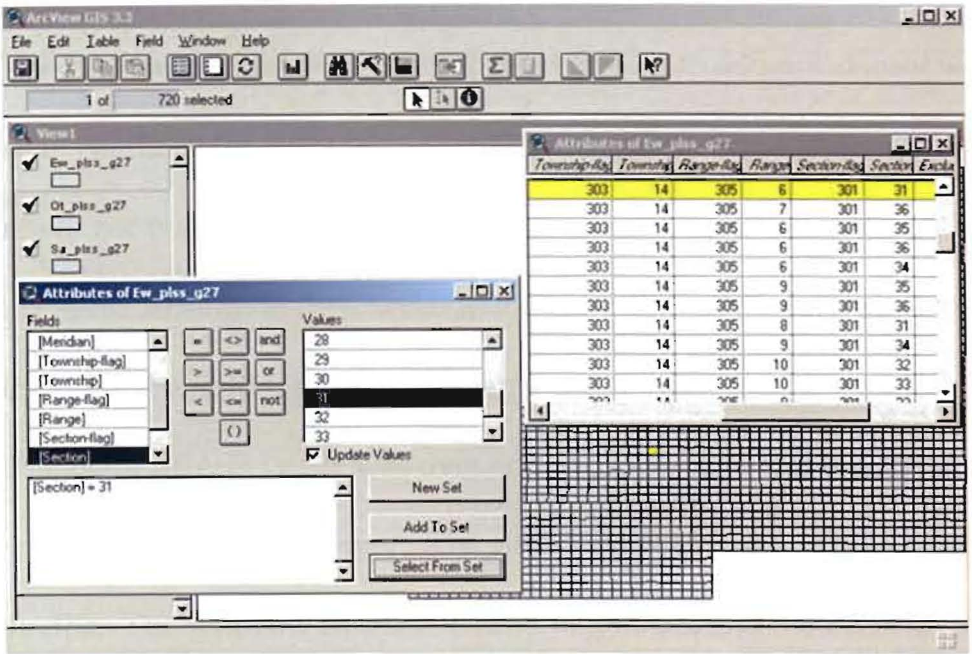


Figure B 8: PLSS Section Selected. ArcView screenshot showing the Kansas PLSS grids, which were downloaded from DASC, being queried in order to select a specific section (this example is Township 14, Range 6, Section 31) to convert into its own shapefile.

Collection sites that specified a half, quarter, or quarter-quarter section were transcribed into a format compatible with LEO. This was accomplished by transforming the township, range, section, half section, quarter section, or quarter-quarter-section into a series of letters, numbers, and spaces (Figure B 9). For example the Southeast quarter of Section 33 in Township 14 South, Range 6 West would be transcribed as 14 S 6 W 33 d. In addition, to make drawing the parcels easier, the township, range, and section for each was listed as a separate entry in the input file for LEO. After processing with LEO, this resulted in an output file in which each entry was converted to a latitude and longitude coordinate for the center of each legal description parcel entry.

The LEO output file was then imported into an Excel spreadsheet where the column headings for latitude and longitude were reversed (a necessary requirement because of a quirk in LEO) and the header and footer were deleted. The Excel spreadsheet was then saved as a dBASE IV file to be compatible with GIS software in the ESRI family of programs.

The point dBASE IV file was then added to ArcView and brought into a view by adding an "Event Theme." The added event theme was then converted to a shapefile. The shapefile of latitudes and longitudes and the PLSS theme were then added to a map in ArcGIS (Figure B 10). ArcCatalogue was opened and a new polygon shapefile was created with an appropriate name for each of the half, quarter, or quarter-quarter sections described collection sites. In the ArcGIS map view each half, quarter, or quarter-quarter shapefile was added.

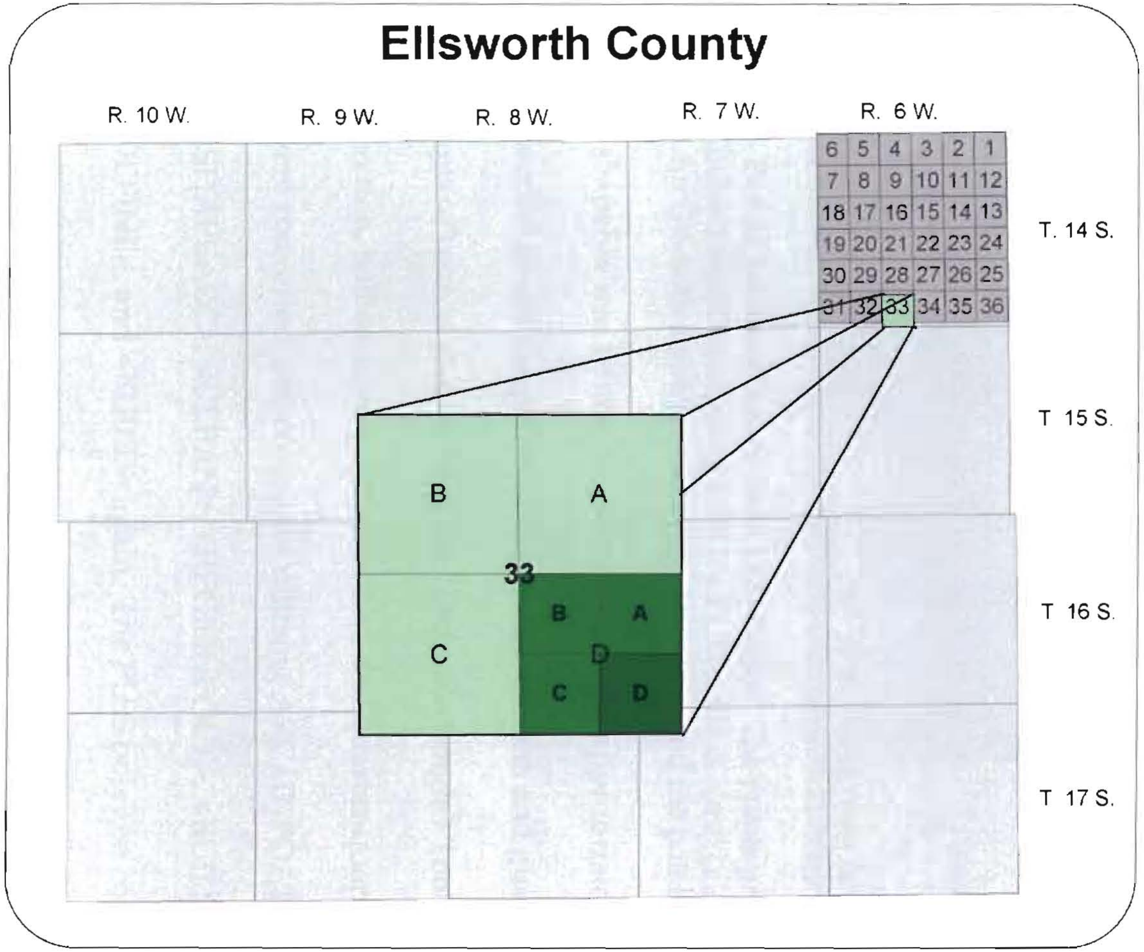


Figure B 9: LEO Subdivisions Naming Conventions. Ellsworth County, KS map created to depict the SE ¼ of the SE ¼ of the SE ¼ of Sect. 33 in T. 14 S, R. 6 W and explain the naming conventions of LEO Subsection divisions (14 S 6 W 33 ddd). The LEO translations for the quarter sections are: NE is A, NW is B, SW is C, and SE is D.

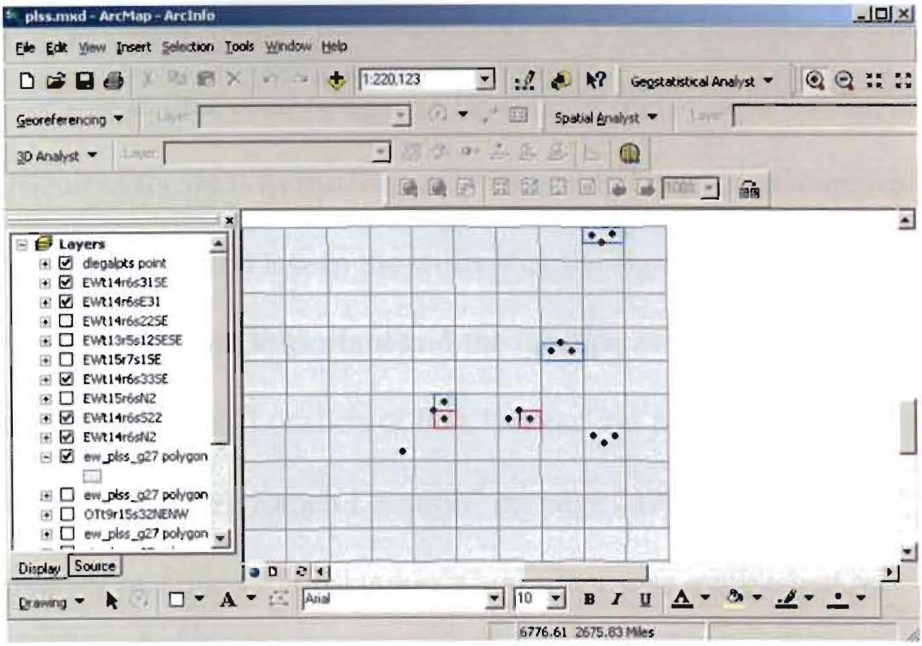


Figure B 10: Partial Sections Drawn from LEO Points. The points produced by the LEO output coordinates along with the PLSS grids in a map view screenshot from ArcGIS with a polygon shapefile drawn around the point.

Then each shapefile was edited by zooming into the appropriate township, range, and section to use the points of the section centers and quarter sections to draw the "square" parcel shapes with the "Draw Rectangle" Tool (Figure B 10).

The section, half section, quarter section, and quarter-quarter section shapefiles were converted into coverages utilizing ARC/INFO. The commands used were <SHAPEARC>, <CLEAN>, <REGIONPOLY>, <BUILD>, <PROJECTDEFINE>, and <BUILD> again. The PLSS polygon coverages were then consolidated into a single coverage by appending them in ARC/INFO.

Detailed Processing For Fort Harker Location

Processing for the location of Fort Harker was performed using Photoshop and ArcGIS. Because the location of the Sternberg family ranch was initially uncertain (it probably was 2.5 miles south of Fort Harker (Sternberg, 1990: 6)), Fort Harker was at first used as a proxy location in this study (discussion on why it was difficult to locate is in the section "Processing Location of Fort Harker" on page 111). It was realized late in the study that the significance and location of the ranch was even more important and the location of the Sternberg Ranch was determined ("Processing Location of Fort Harker" on page 111 and "Detailed Processing For Sternberg Ranch Location" on page 249).

First, the location of Fort Harker's boundary was established by consulting an archaeological report by King (1997). In her report, King (1997: 3) included a figure similar to Figure 25 on pg 112 in which the boundary of historical Fort Harker was drawn on a topographical map. Since the location of Forth Harker would be useful in the analysis of the results, the location of Fort Harker was processed to be compatible with the ESRI family of GIS Programs.

Because the topographical map was the same as the DRG of Ellsworth County, a flatbed scanner and Photoshop were used to scan in the figure from King (1997) and convert it into a digital image compatible with GIS. Then the digital image was added to a map in ArcGIS that contained the Ellsworth County DRG. Because neither the image nor the DRG of the area around Kanopolis were transparent, a shapefile was created from the DRG of Fort Harker boundary image of key road intersections (Figure B 11). This enabled the Fort Harker boundary image to be rectified to the DRG using the georeferencing tool in ArcGIS (Figure B 12).

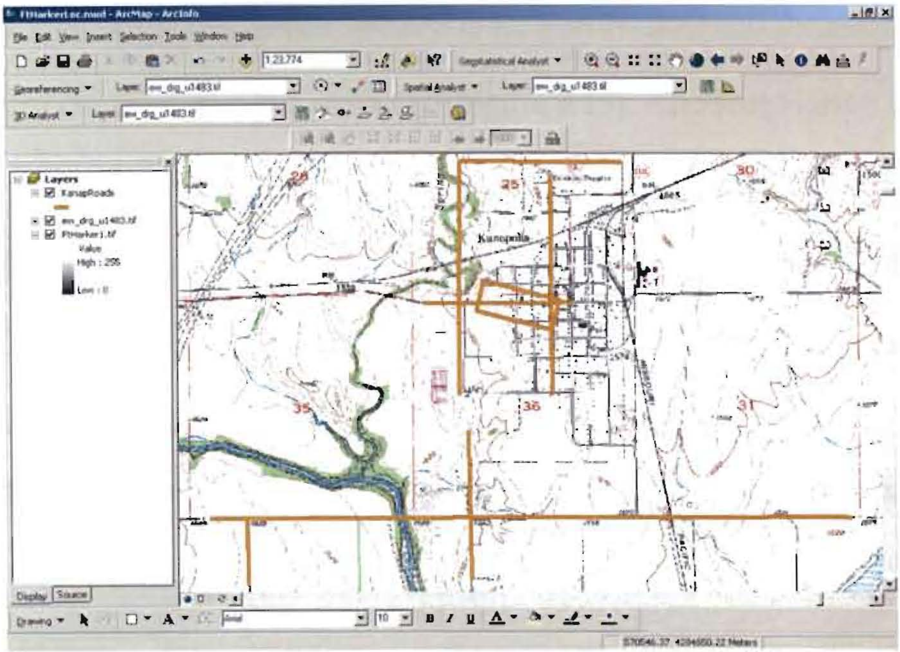


Figure B 11: Key Roads Digitized for Georeferencing. ArcGIS map view screenshot showing the digitized key roads (in orange-brown) used for georeferencing the image of Fort Harker's location.

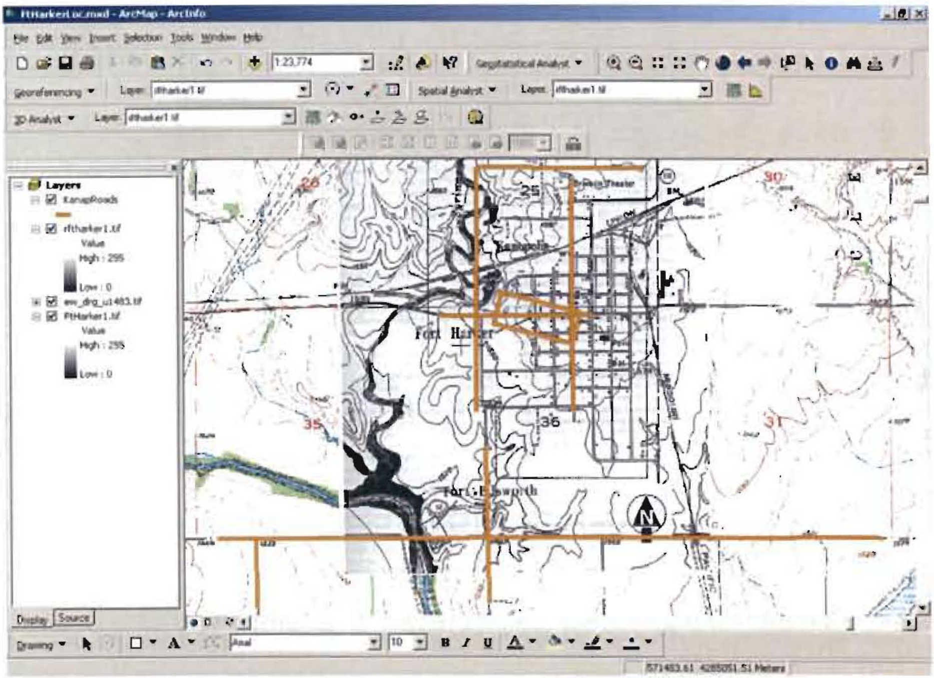


Figure B 12: Georeferencing the Archaeological Image. ArcGIS map view screenshot showing the georeferenced image of Fort Harker's location.

Finally, a shapefile was created in ArcGIS for Fort Harker and the boundary digitized for conversion into a coverage (Figure B 13). The Fort Harker boundary shapefile was then converted into a coverage utilizing ARC/INFO. The commands used were <SHAPEARC>, <CLEAN>, <REGIONPOLY>, <BUILD>, <PROJECTDEFINE>, and <BUILD> again. The Fort Harker polygon coverage was opened in ArcView to make sure that it was complete.

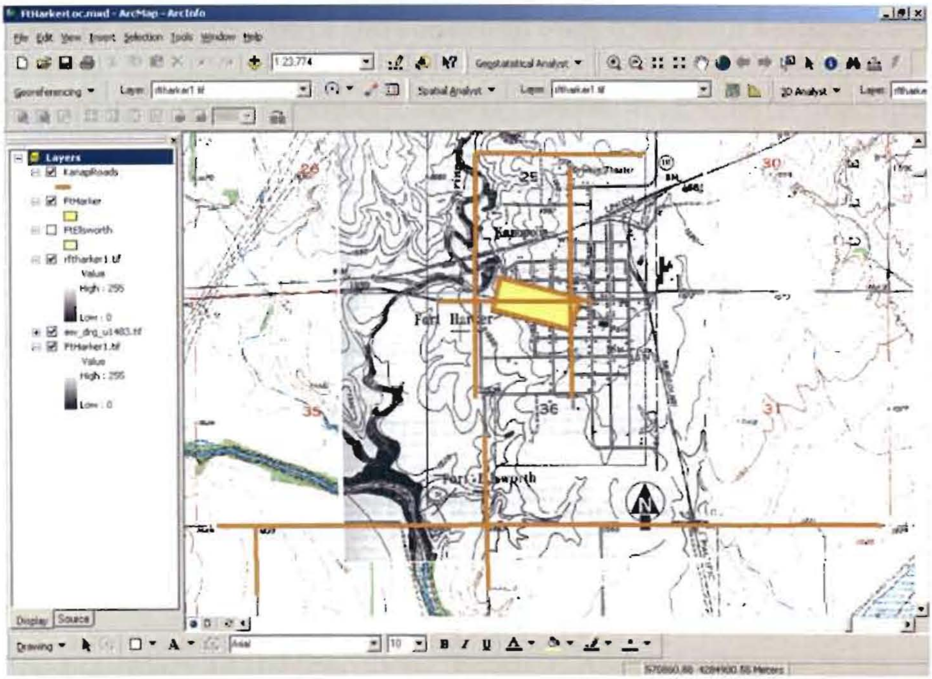


Figure B 13: Fort Harker, KS Coverage. ArcGIS map view screenshot in which the location of Fort Harker (yellow box) has been digitized.

Detailed Processing For Sternberg Ranch Location

Processing for the location of the Sternberg family ranch was performed in ArcView and ARC/INFO. Initially the location of the Sternberg family ranch was only known as 2.5 miles south of Fort Harker; therefore, Fort Harker was originally used as a proxy location for this study (Sternberg, 1990: 6). However when the significance of the location of the ranch was truly realized, further clarification was obtained through consultation with the Ellsworth County Historical Society. The actual location of the Sternberg Ranch was obtainable at the county courthouse in Ellsworth County from a plat map of land ownership of the time period when C. H. Sternberg was said to be collecting Dakota Flora specimens (Personal Communication Ellsworth County Historical Society, 2005). The analyses of relationships of the collection sites to known features of the time needed the location of the Sternberg Ranch. Therefore, the legal description of the location of the Sternberg Ranch needed to be digitized to be usable with the ESRI family of GIS Programs.

The Ellsworth County Historical Society (Ellsworth County Historical Society, 2005) supplied a legal description in PLSS format. Therefore, the PLSS dataset from DASC (2004) was opened in ArcView and a shapefile was created to digitize the Sternberg Ranch boundary. The legal description was then used to digitize the boundary of the Sternberg Ranch in ArcView (Figure B 14). The Sternberg Ranch boundary shapefile was then converted into a coverage utilizing ARC/INFO. The commands used were <SHAPEARC>, <CLEAN>, <REGIONPOLY>, <BUILD>, <PROJECTDEFINE>, and <BUILD> again. The Sternberg Ranch polygon coverage was opened in ArcView to make sure that it was complete.

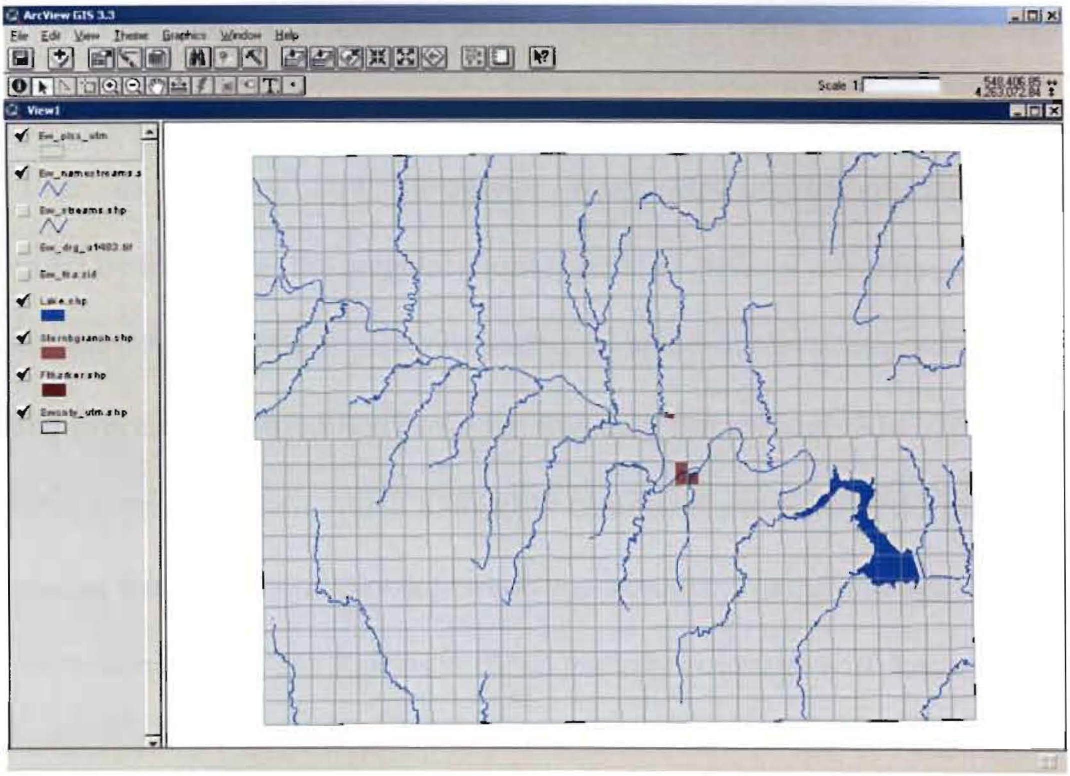


Figure B 14: Digitized Sternberg Ranch Location. ArcView screenshot showing the digitized location of the Sternberg Ranch (in brown). Sections are shown in a blue-green colored grid.

Detailed Processing of Surficial Geology

Processing for the surficial geology was performed using ArcView and ARC/INFO. First, the surficial geology coverages for every county in Kansas were downloaded from DASC and unzipped. Then each county's polygon file was imported using ARC/INFO's <IMPORT> command. All county coverages were then joined with the <APPEND> command in ARC/INFO followed by the <DISSOLVE> command to eliminate the county lines. The <DISSOLVE> command dissolved the individual county surficial geology into an entire coverage for Kansas based on the form-id field.

At this point, ArcView was used to open the surficial geology coverage in a view. The attribute table was queried to look for form-ids that were blank. For any form-ids that were blank, the polygon was located and the appropriate value obtained by looking at the original county surficial geology coverage for the area in question. Most of these polygons ended up being slivers produced by the joining process. The modified coverage was then run through ARC/INFO's dissolving process again. A <JOINITEM> command was then performed with form-id as the relate item in order to add the formation name and age based on the form-id number. The Kansas surficial geology coverage with known formation names was then added to a view in ArcView so that the Dakota Formation could be queried out and converted to a shapefile of its own (Figure B 15). At this point, the Dakota Formation shapefile was converted into a coverage utilizing ARC/INFO. The commands used were <SHAPEARC>, <CLEAN>, <REGIONPOLY>, <BUILD>, <PROJECTDEFINE>, and <BUILD> again.

Detailed Dakota Aquifer Base Elevation Processing

Processing for the Dakota Aquifer data was performed using ArcView, ArcGIS, and ARC/INFO. The Dakota Aquifer data downloaded from DASC were unzipped. Then the Dakota Aquifer data were imported into ArcView using the Import 71 Utility. Only the Dakota Aquifer base data were processed, although other data were examined to aid in its processing.

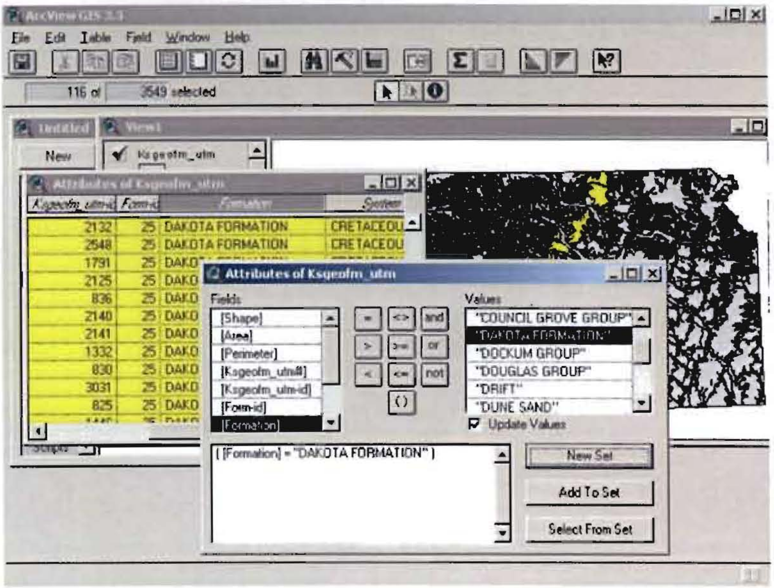


Figure B 15: Selecting Only Dakota Formation. ArcView screenshot in which the Kansas surficial geology coverage, downloaded from DASC, is queried in order to select the Dakota Formation to convert into its own shapefile.

The Dakota Aquifer base elevation contours were added to a view and examined (Figure 26 on page 116). The observation was made that the base contours included the surficial extent lines, which included the northern and western edges of Kansas, as well as a subsurface fault line. Therefore, the Dakota Aquifer base elevation coverage was converted to a shapefile and edited to delete all lines that were not bedrock elevation contours (Figure 27 on page 116). A field with altitude in meters was added to the attribute table by performing a field calculation conversion using the field containing the altitude in feet.

The edited Dakota Aquifer base contours were then transformed into a coverage in ARC/INFO. Commands utilized were <SHAPEARC> and <BUILD> lines. Then a TIN of the base was created using ARC/INFO's

<CREATETIN> command with the contour lines and altitude/elevation in meters as the inputs (Figure B 16).

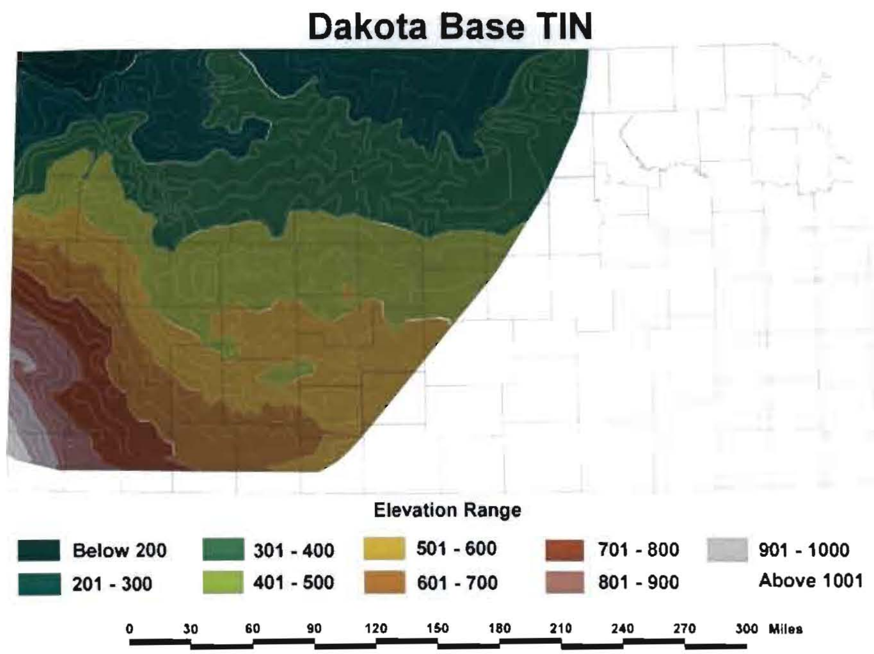


Figure B 16: Dakota Aquifer Base Elevation TIN. The Dakota Aquifer base elevation after it has been converted from a coverage into a TIN.

The TIN was converted into a grid via the <LATTICETIN> command in ARC/INFO. This was done to facilitate the use of the Dakota Aquifer base elevations in further analyses and calculations with other datasets (Figure B 17). Therefore, the grid or cell size of the lattice was set at a relatively small value—160 square-meters—to match with other grid data. The cell size value used for the lattice was determined through trial and error in trying to optimize the model using the smallest possible cell size that the data and GIS software would allow.

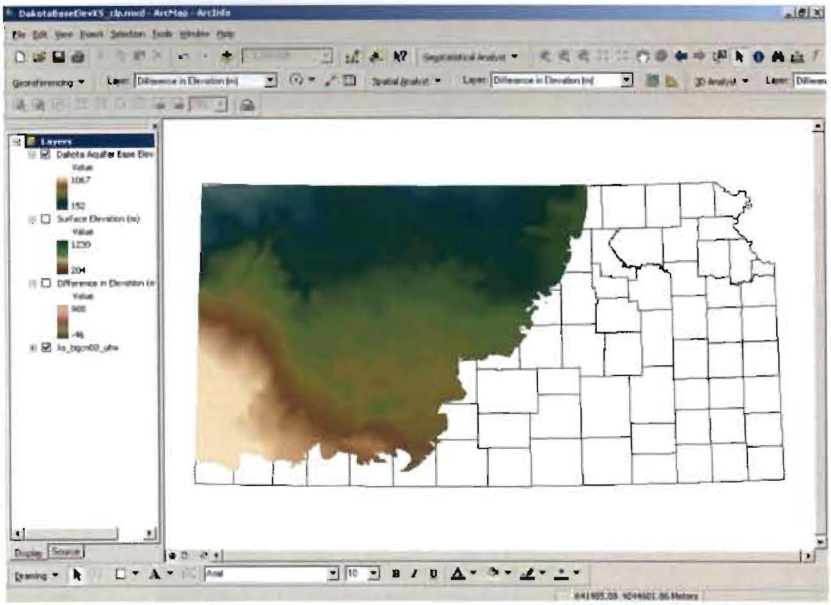


Figure B 17: Dakota Aquifer Base Grid. The Dakota Aquifer base elevation after it has been converted into a grid in ArcGIS (screenshot).

Detailed Dakota-Kiowa Contact Elevation Processing

Processing for the Dakota Aquifer data was performed in ArcView, ArcGIS, and ARC/INFO. The Dakota-Kiowa contact data was obtained by scanning the *Top Configuration of the Kiowa Formation* map from the *Dakota Aquifer Annual Report of 1989* (Macfarlane, *et. al.*, 1989b: Plate 5), and using ArcGIS to georeference the resulting image to the map projection used in the Dakota Aquifer coverages obtained from DASC (Figure B 18). The georeferenced images of the Dakota-Kiowa contact elevations were opened in ArcView and the contours representing the top of the Kiowa Formation were then digitized into a Dakota-Kiowa contact elevation shapefile (Figure 28 on page 118).

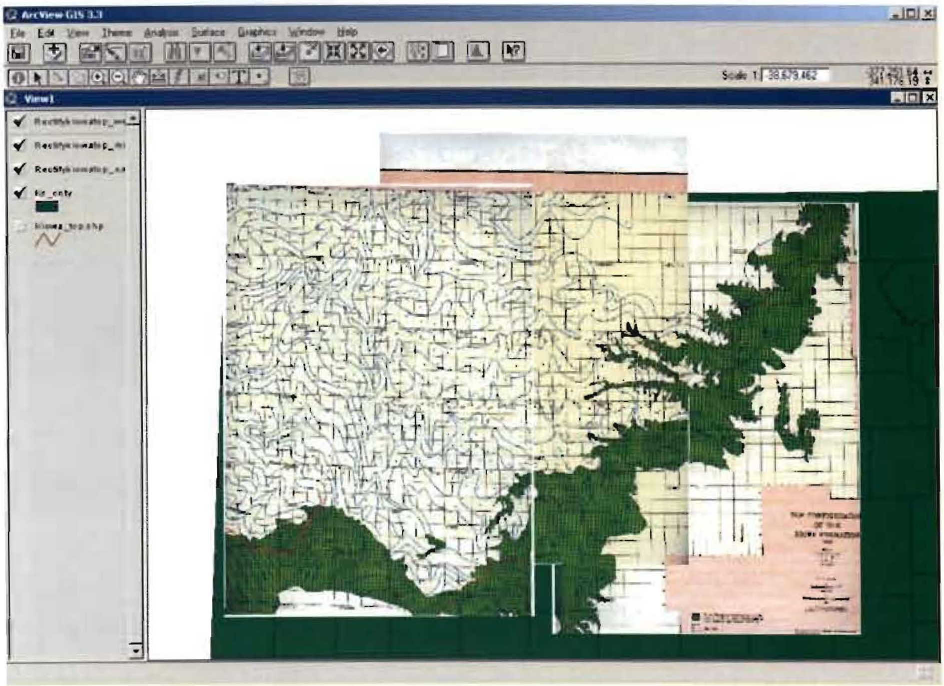


Figure B 18: Scanned and Georeferenced Kiowa Formation Contours Source. The Kiowa Formation top elevation (in the subsurface) after it was scanned and rectified prior to digitizing as seen in an ArcView screenshot.

The attributes for the contours in meters were then added to the shapefile before the Dakota-Kiowa contact elevation file was transformed into a coverage in ARC/INFO. The Dakota-Kiowa contact elevation coverage was viewed in ArcView to check that the processing had been accomplished correctly (Figure B 19).

The Dakota-Kiowa contact contours were then transformed from lines to points in ArcView using the "poly2pts" extension (Huber, 2002) because insufficient data was present along the edge to produce a TIN or grid of the entire area (Figure B 20). Once the contours were present as points, locations where additional points would be need to create a grid for the entire area were determined and added to the edge (Figure 29 on page 119).

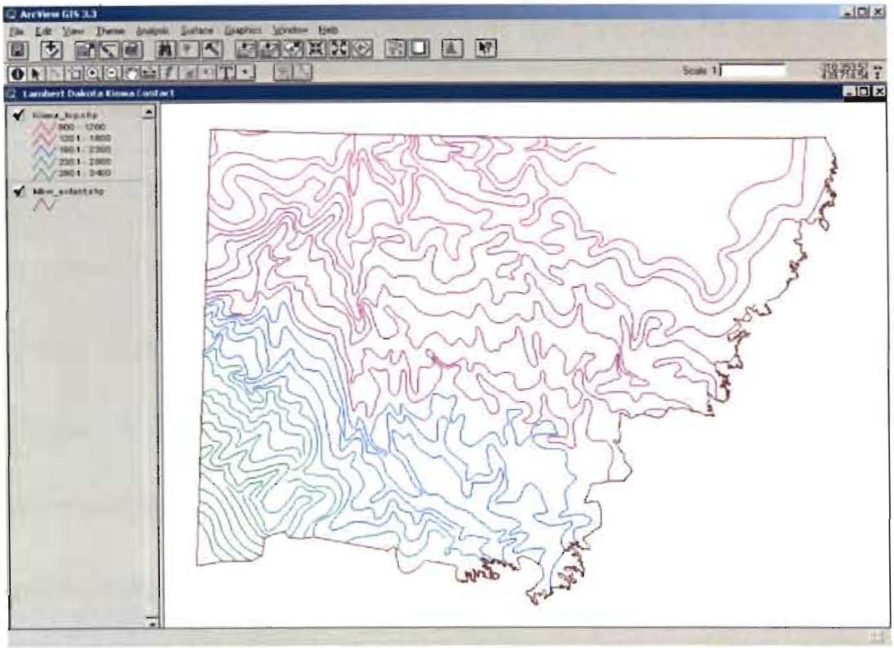


Figure B 19: Digitized Kiowa Formation Contours. The Kiowa Formation top elevation (in the subsurface) contours after digitized as seen in an ArcView screenshot.

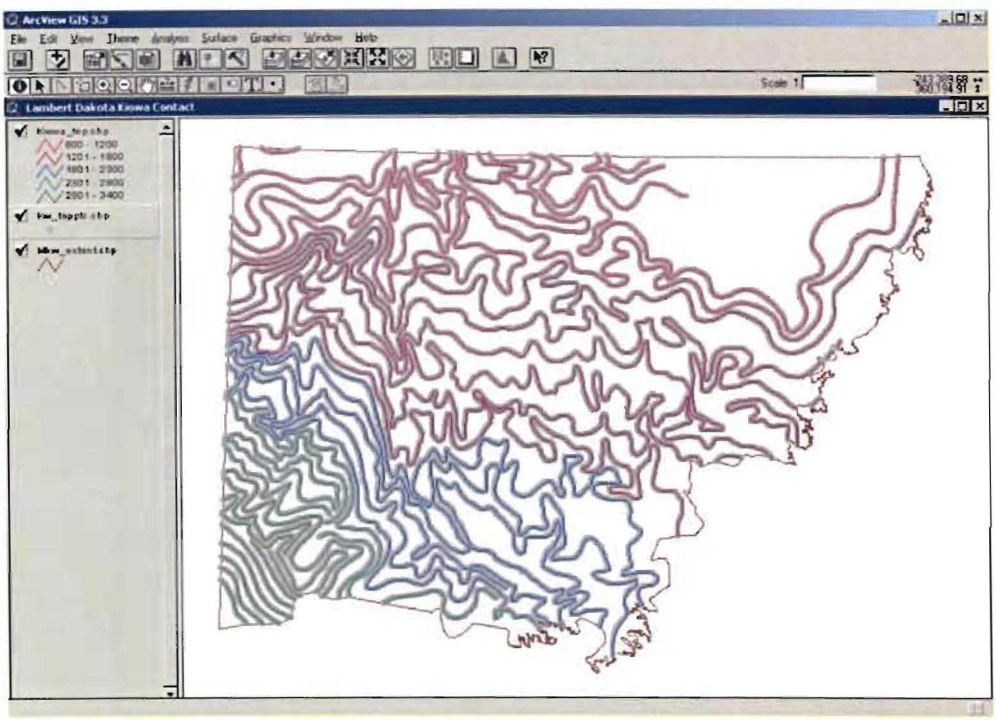


Figure B 20: Dakota-Kiowa Contact Contours as Converted to Points. The Dakota-Kiowa contact elevation coverage after the contours are converted to points as seen in an ArcView screenshot.

Based on comparison with the placement of the contours of both the Dakota-Kiowa and Dakota Aquifer base these additional points were assigned approximate elevational values in meters.

The edited Dakota-Kiowa contact "contour" points were then transformed into a coverage in ARC/INFO. Commands utilized were <SHAPEARC> and <BUILD> lines. A TIN representing the topography of the Dakota-Kiowa contact was created using ARC/INFO's <CREATETIN> command with the contour lines and altitude/elevation in meters as the inputs.

The TIN was converted into a grid via the <LATTICETIN> command in ARC/INFO. This was done to facilitate the use of the Dakota-Kiowa contact elevations in further analyses and calculations with other datasets (Figure B 21). Therefore, the grid or cell size of the lattice was set at a relatively small value—160 square-meters—to match with other grid data already processed.

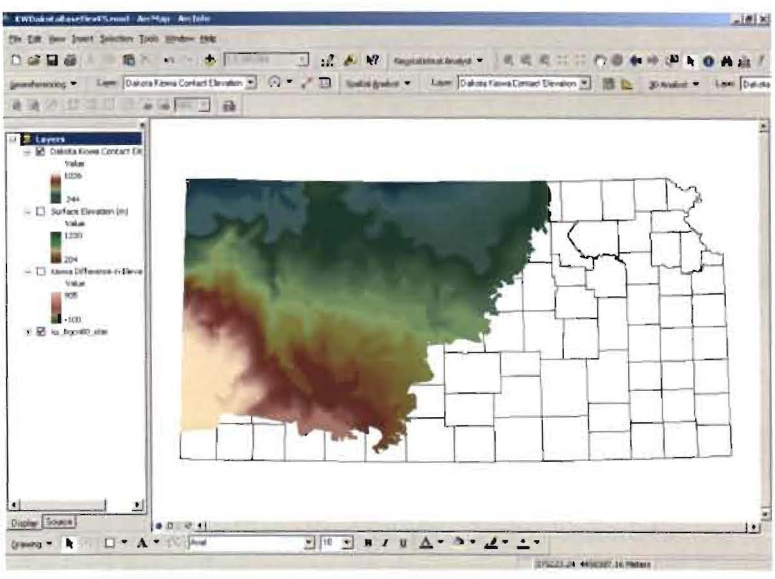


Figure B 21: Dakota-Kiowa Contact Grid. The Dakota-Kiowa contact elevation after it has been converted into a grid in ArcGIS as seen in a screenshot.

Detailed Surface Elevation Processing

Processing for the surface elevation as represented by the NED was accomplished using ArcGIS and ARC/INFO. First, the four NED parallel grids that covered parts of the study area were downloaded from DASC and unzipped. Then they were added to an ArcGIS map view. Spatial Analyst's options were set such that it would provide an extent that was the union of the inputs and such that the cell size/resolution matched the Dakota Aquifer base's and Dakota-Kiowa contact's 160 square-meters (Figure B 22). Finally, the four grids were combined with the merge command in Raster Calculator and made into a permanent grid.

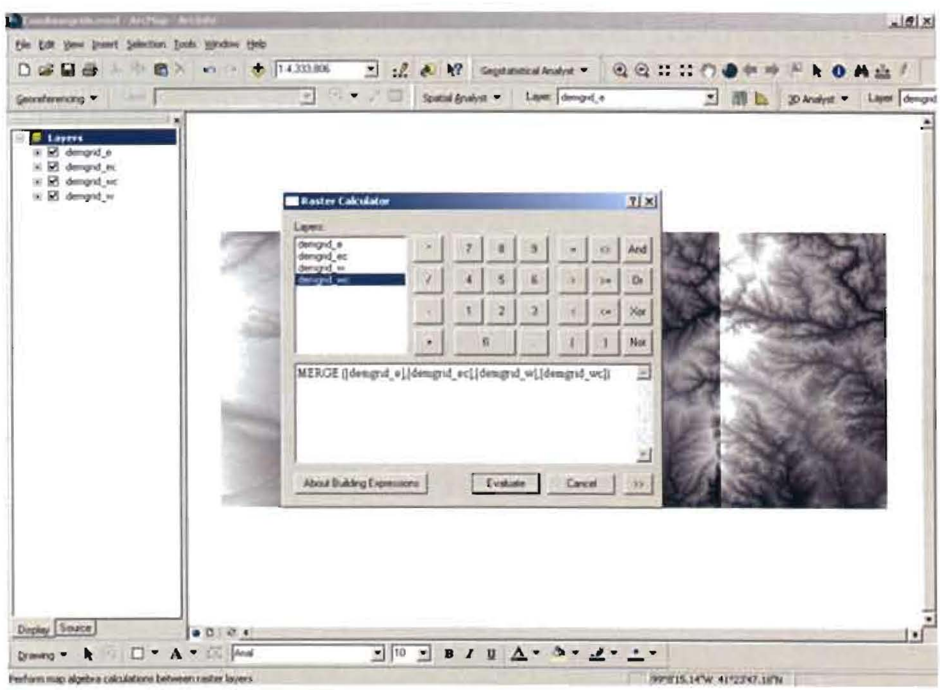


Figure B 22: Merging Surface Elevation Grids. Raster Calculator expression used to merge the four grids that makes up the surface elevation of Kansas into one grid in an ArcGIS map view screenshot.

Detailed Processes for GIS Analysis

After the initial processing for the collection sites and the surficial geology used for this investigation, the data were then processed to determine where the Dakota Formation and the collection sites overlapped. First, all of the layers/coverages were added to a map view in ArcGIS. Then the collection sites were symbolized as outlines only and the entire State's surficial geology coverage was displayed as unique values for each formation. This allowed a general idea about the spatial relationships among the different types of data to be formed.

As part of this, the location of Fort Harker was compared with the locations of collection sites. This allowed for a visual confirmation of the bias of the collection sites to an approximation of the primary collector's residence (Figure 30).

The Dakota Formation, the combined Distance Collection Sites, the combined Limited Distance Collection Sites, and the combined PLSS Collection Sites coverages were added to the same view in ArcView (Figure B 23). The Geoprocessing Wizard was used to clip the Dakota Formation separately by the combined Distance Collection Site data, the combined Limited Distance Collection Site data, and the combined PLSS Collection Site data.

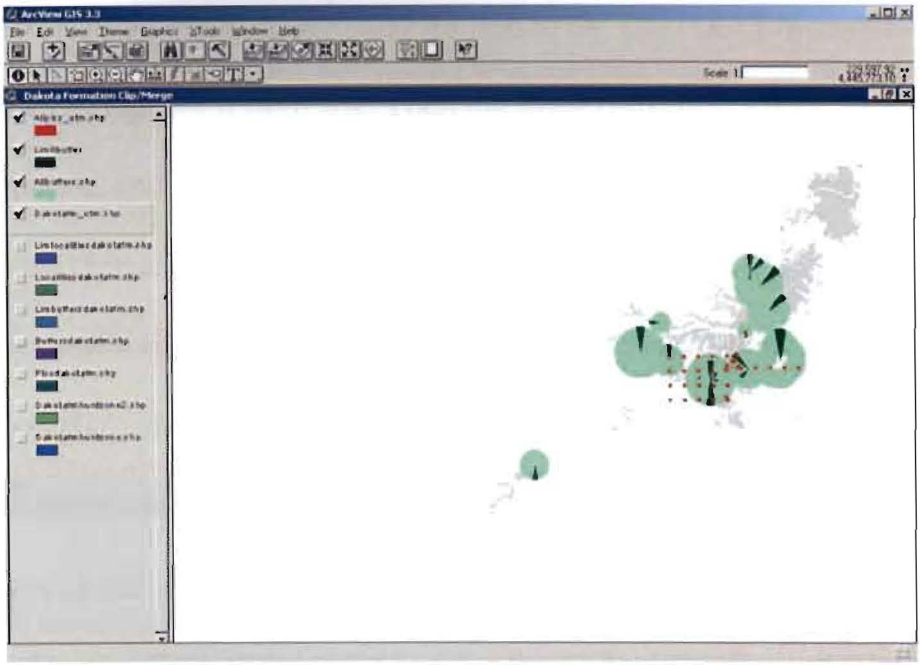


Figure B 23: Combined Dakota Flora Collection Sites. ArcView screenshot showing the locations of all of the collection site before they were combined.

Then separately, the two versions of the distance clipped Dakota Formation were each combined with the PLSS clipped Dakota Formation using the Merge function of the Geoprocessing Wizard. This was followed by a dissolve function of the Geoprocessing Wizard where the Dakota Formation was the dissolve item in order to eliminate the lines produced by the outlines of the city boundaries visible in some of the collection sites.

Analysis of the elevation data compared the surface topography with both the Dakota Aquifer base and the Dakota-Kiowa contact topographies and formational thickness estimates derived from these datasets and the NED surface using ArcView, Excel, and ArcGIS. First, in ArcGIS, both the Dakota Aquifer base elevation grid was subtracted from the surficial grid and limited to the Dakota Aquifer base elevation area and the Dakota-Kiowa contact elevation was subtracted from the surficial grid and limited to the Dakota-Kiowa contact elevation area (Figures B 24–B 28). Then the three collection site types—those of PLSS, Distance, and Limited Distance—were analyzed in relationship with elevation and formation thickness.

ArcView's summarize zones module was employed to obtain statistics about the surface elevation, Dakota Aquifer base elevation, and the two different estimates of formation thickness at each collection site (Figure B 29). To make this process easier, each collection site type was combined into a single shapefile using the "Merge Theme" command under the "XTools" extension (Delaune, 2003). The summarize zone command was then run from the "Analysis" Menu. Because the themes had been merged together, the field containing the source theme could be used as a unique identifier for this process.

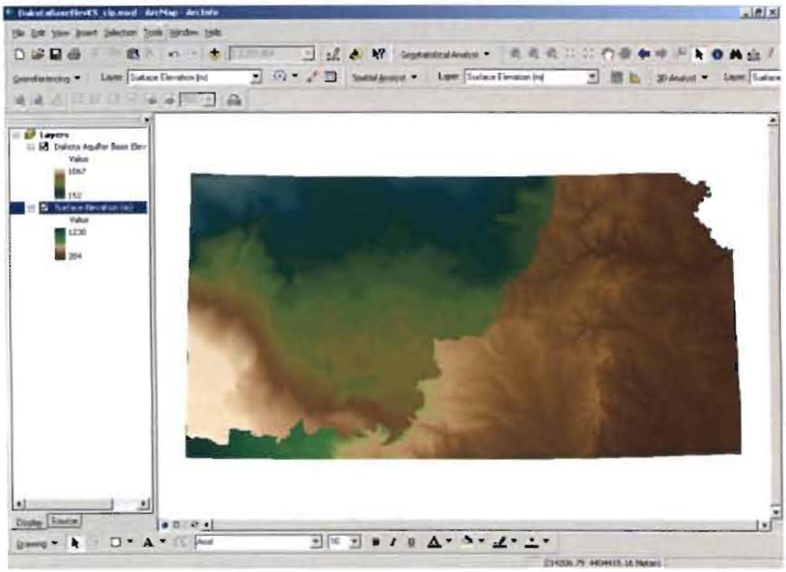


Figure B 24: Difference in Surface Elevation and Base Elevation Inputs. Map view screenshot from ArcGIS with both the Surface Elevation grid and the Dakota Aquifer base elevation grid present.

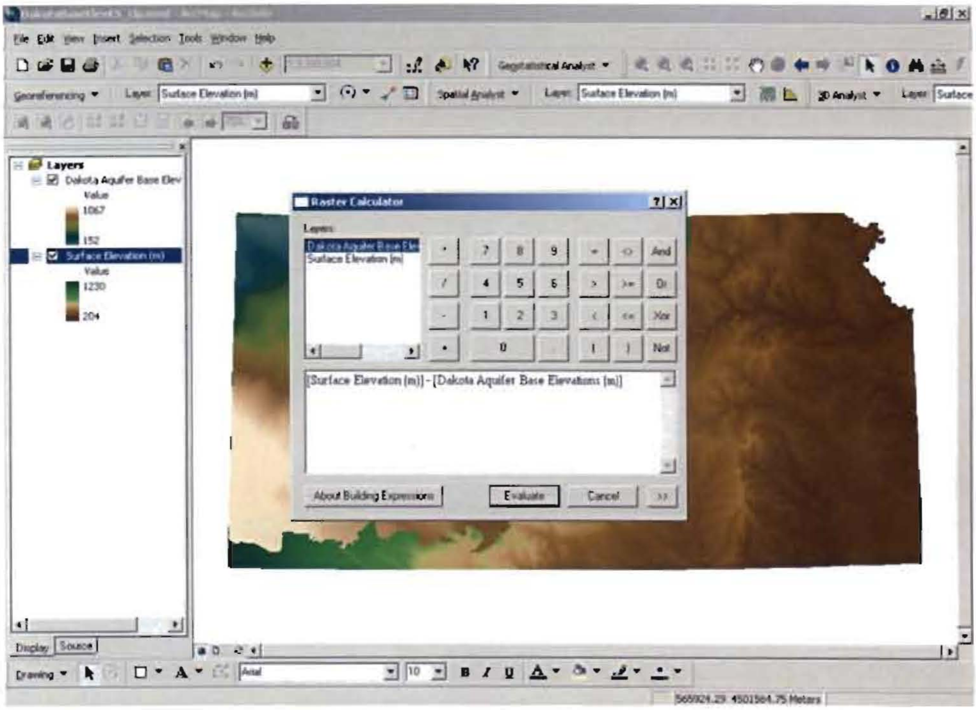


Figure B 25: Difference in Surface Elevation and Base Elevation Calculation. Map view screenshot from ArcGIS with both the Raster Calculator is being used to subtract the Dakota Aquifer base elevation grid from the Surface Elevation grid.

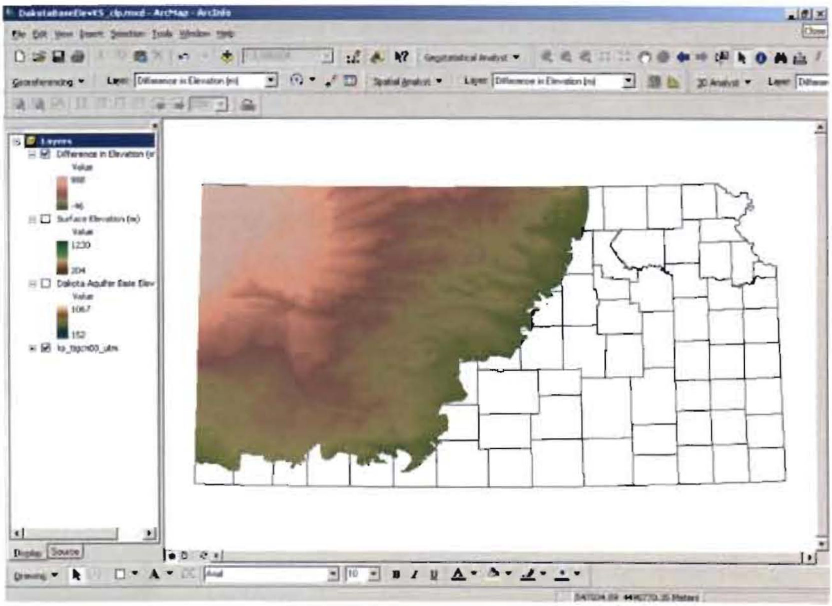


Figure B 26: Difference in Surface Elevation and Base Elevation. ArcGIS map view screenshot showing the difference in elevation grid produced by the Raster Calculator.

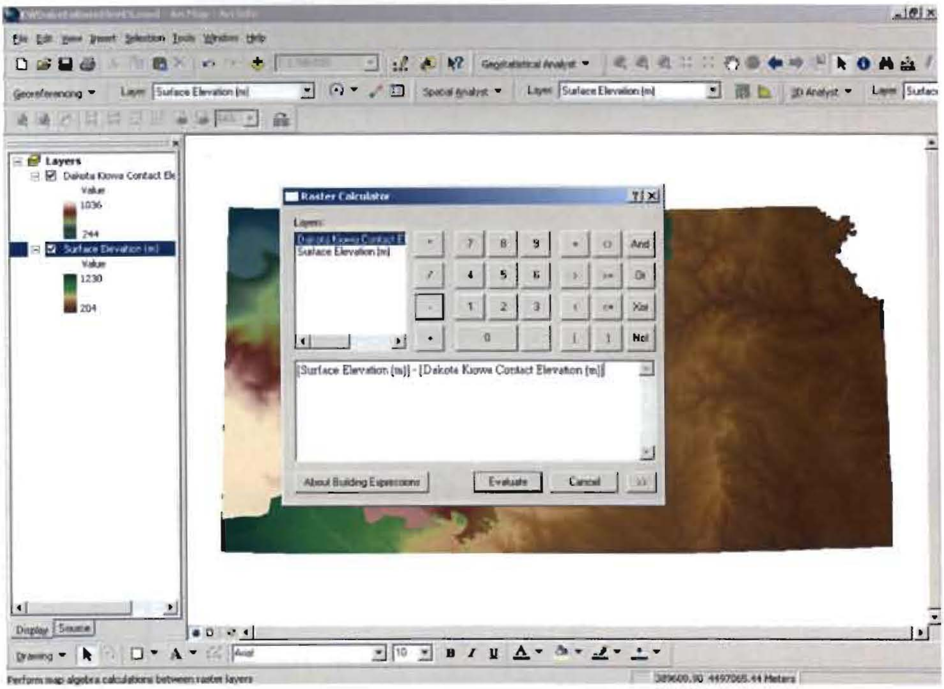


Figure B 27: Difference in Surface Elevation and Contact Elevation Calculation. Map view screenshot from ArcGIS with both the Raster Calculator is being used to subtract the Dakota-Kiowa contact elevation grid from the Surface Elevation grid.

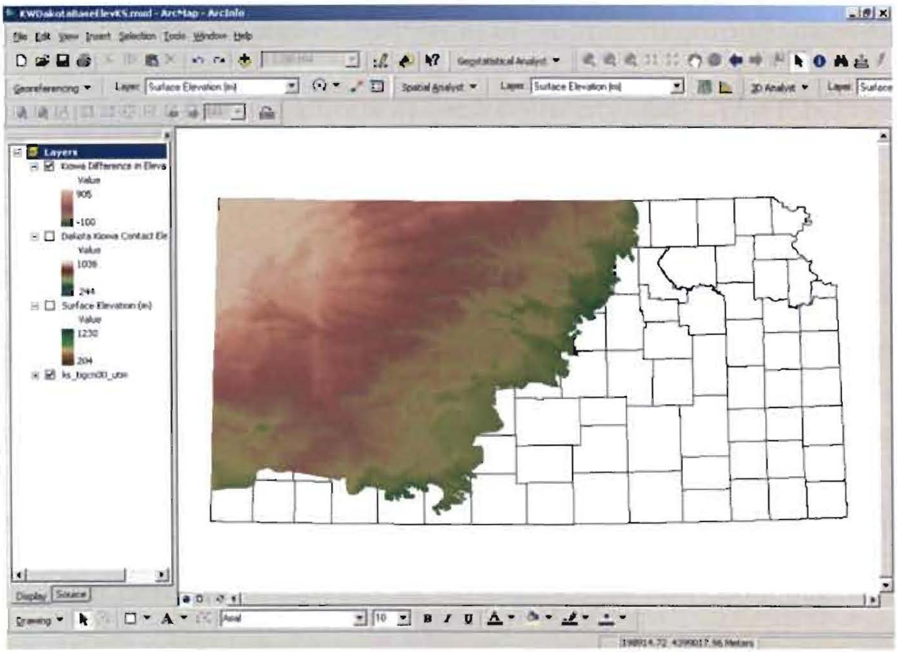


Figure B 28: Difference in Surface Elevation and Contact Elevation. ArcGIS map view screenshot showing the second difference in elevation grid produced by the Raster Calculator.

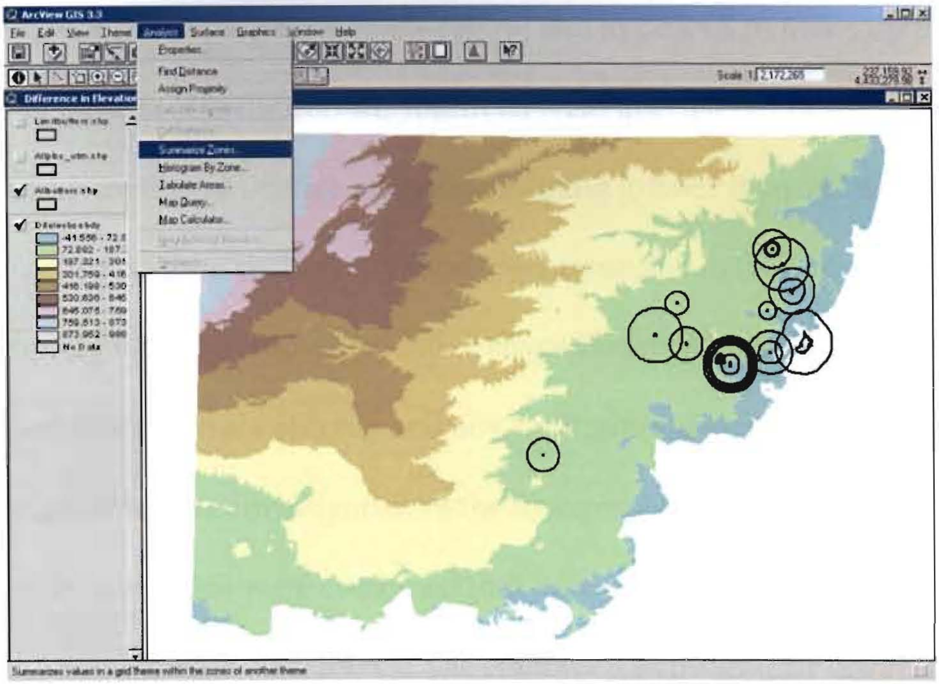


Figure B 29: Example of Summarize Zone. View screenshot from ArcView with an elevation grid and Distance Collection Sites performing a summarize zones.

The zone summaries process produced a table that contained, among other things, the mean elevation, minimum elevation, maximum elevation, and standard deviation of the elevations at each collection site. The tables were then exported from ArcView as a dBASE IV file. The tables were then opened in Excel for analysis of the values generated by the summarize zones command. The analysis consisted primarily of converting the dBASE IV file into an Excel file and creating graphical chart representations in box plot form of the mean elevation, minimum elevation, maximum elevation, and standard deviation in order to look for patterns or clusters of similarity between collection sites.

After a similarity of clusters was determined for the surface elevation, the similar elevations were analyzed with the hypsography of the area. In ArcView, the contours of the hypsography (400-550 m) that appeared to make up the elevational pattern of collection site locations were queried out of the hypsography coverages by first querying anything greater than 390 m for a set and then selecting from that set anything lower than 560 m (Figures B 30 and B 31). The query was then converted into a shapefile and compared with the Dakota Formation surface outcrop and any similarities determined.

To allow further investigation of the topographic relationships the hypsography coverages were combined into a single coverage using the <Append> command in Arc/INFO. The combined hypsography coverage was clipped by the Dakota Formation using the <CLIP> Command in ARC/INFO (Figure B 32). A surface was then created from these contours by transforming the shapefile into a coverage in ARC/INFO using the commands <SHAPEARC> and <BUILD> lines. A TIN of the Dakota Formation hypsography was then created using ARC/INFO's <CREATETIN> command with the contour lines and altitude/elevation in meters as the inputs. The TIN was converted into a grid via the <LATTICETIN> command in ARC/INFO with the grid or cell size of the lattice was set at a relatively small value—1600 square-meters (40 m x 40 m)—to match with other grid data in case other analyses were required. This allowed for a comparison of the hypsography of the entire Dakota Formation to be investigated in relationship to the elevations of the collection sites.

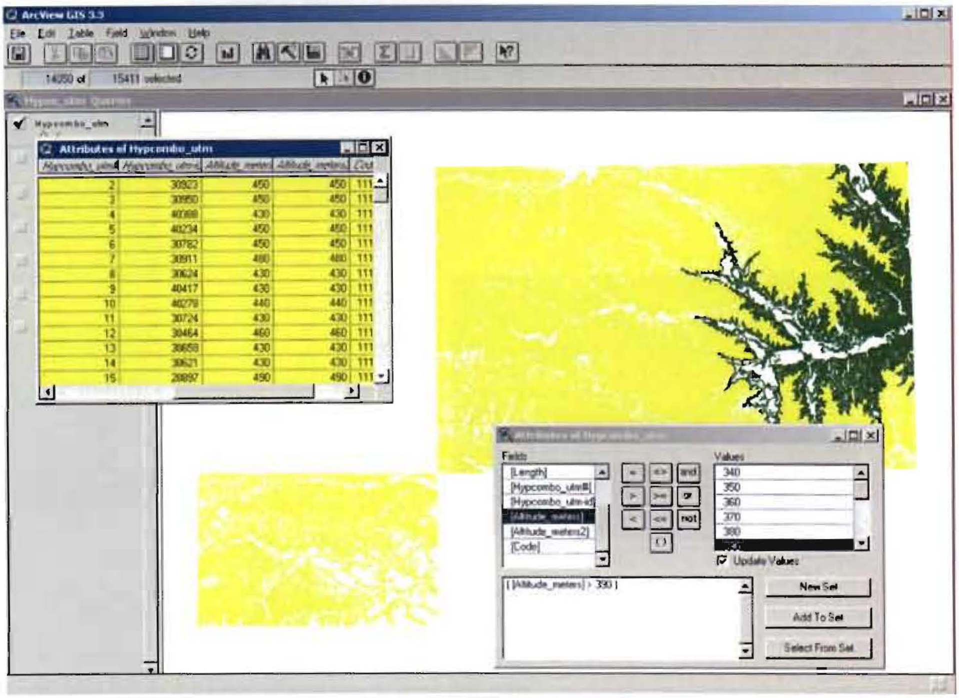


Figure B 30: Initial Hypsography Querying. The initial query for the hypsography of elevations of 400–550 m by selecting values that are greater than 390 m is shown in an ArcView screenshot.

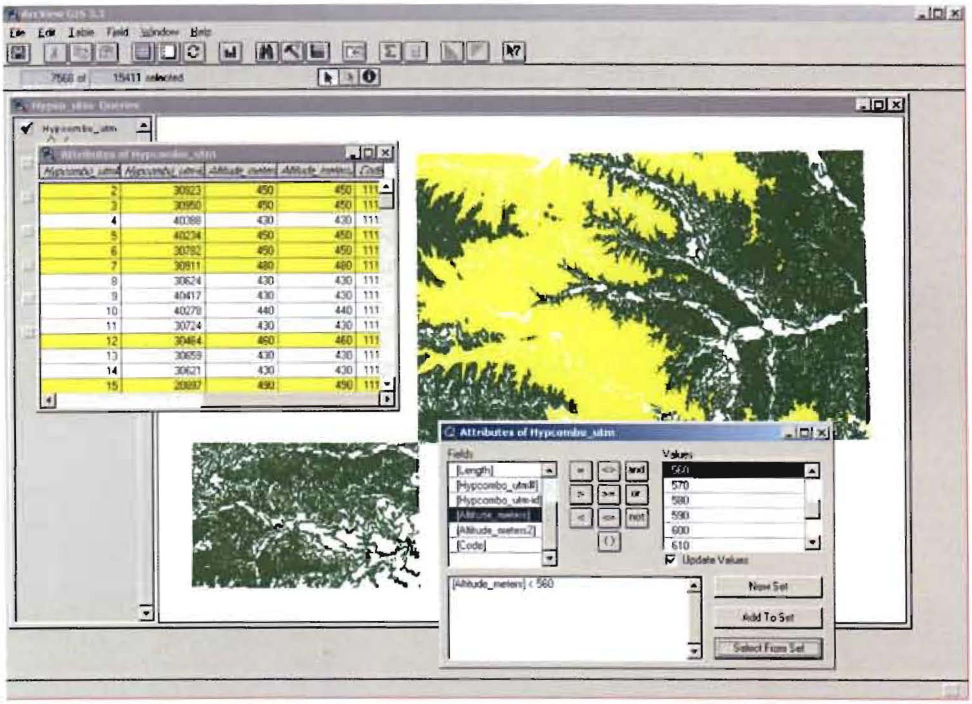


Figure B 31: Final Hypsography Querying. The completion of a query for the hypsography of elevations of 400–550 m by selecting values that are less than 560 m is shown in an ArcView screenshot.

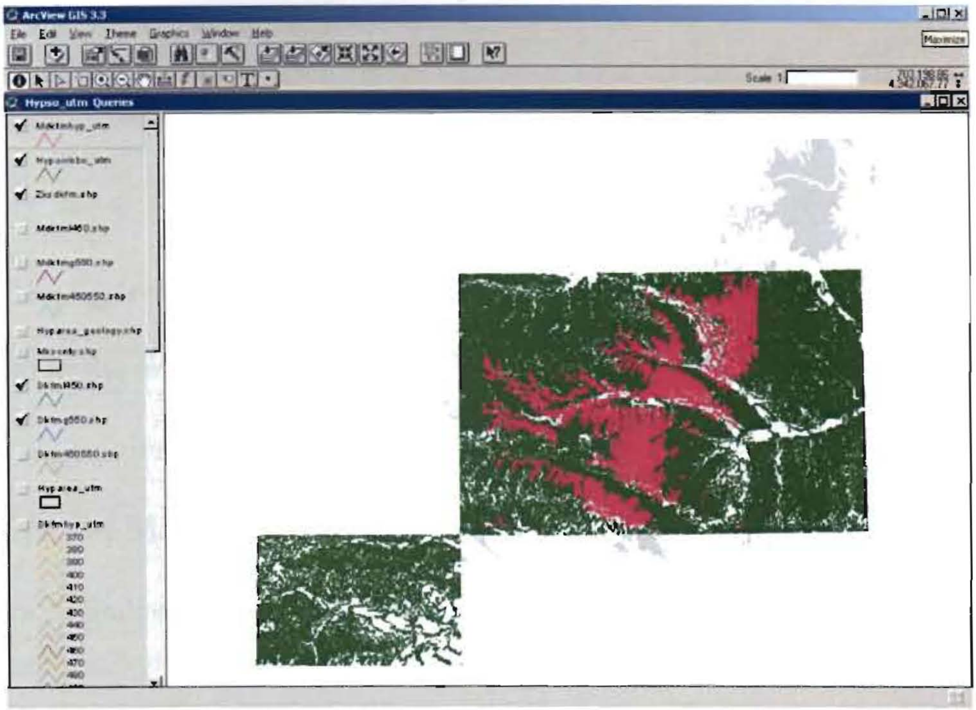


Figure B 32: Dakota Formation Hypsography. The results of the hypsography of elevations clipped by the Dakota Formation are shown in an ArcView screenshot.

Appendix C: Additional Figures

The figures in this appendix contain data and analyses results not included in the text of this thesis in order to make the text more readable. These figures are referenced in the text of the thesis in the tables: "Summary of Collection Site Maps" (Table 8 on page 148) and "Summary of Collection Site Elevational Statistics Graphs" (Table 9 on page 174).

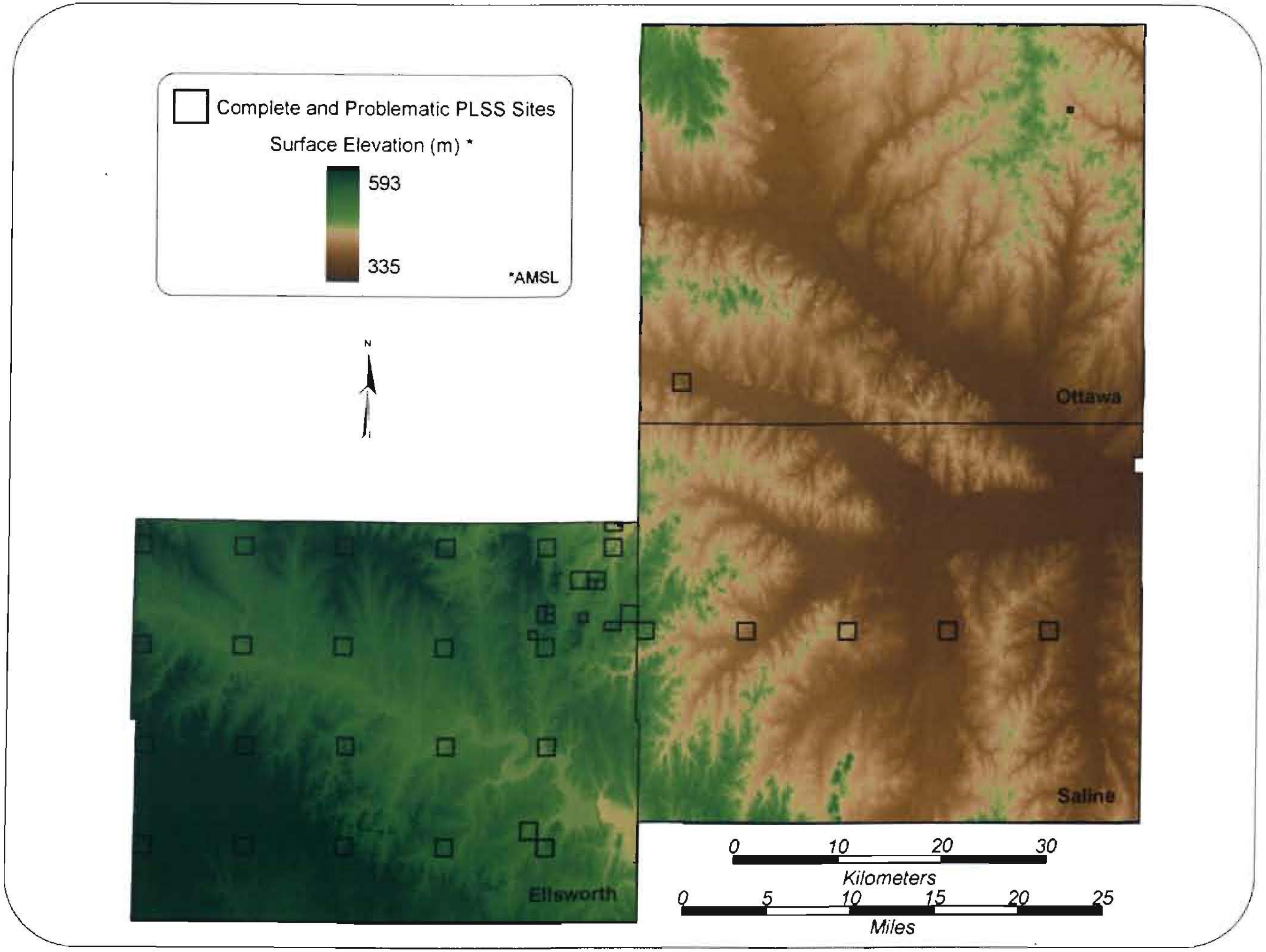


Figure C 1: Surface Elevations of PLSS Collection Site Locations. Mapped locations of the PLSS Collection Sites and the AMSL elevations derived from NED data in Kansas.

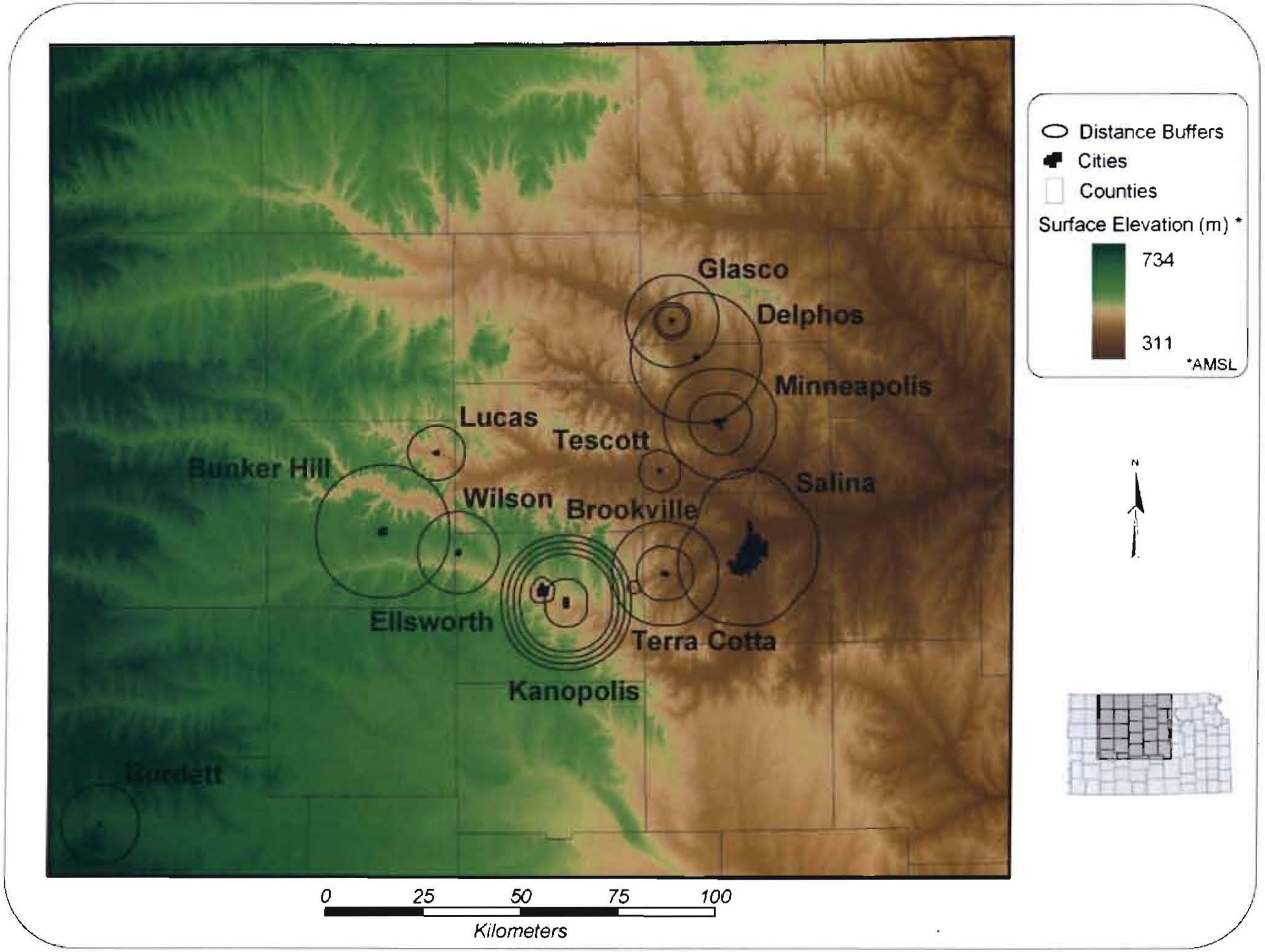


Figure C 2: Surface Elevations of Distance Collection Site Locations. Mapped locations of the Distance Collection Sites and the AMSL elevations derived from NED data in Kansas.

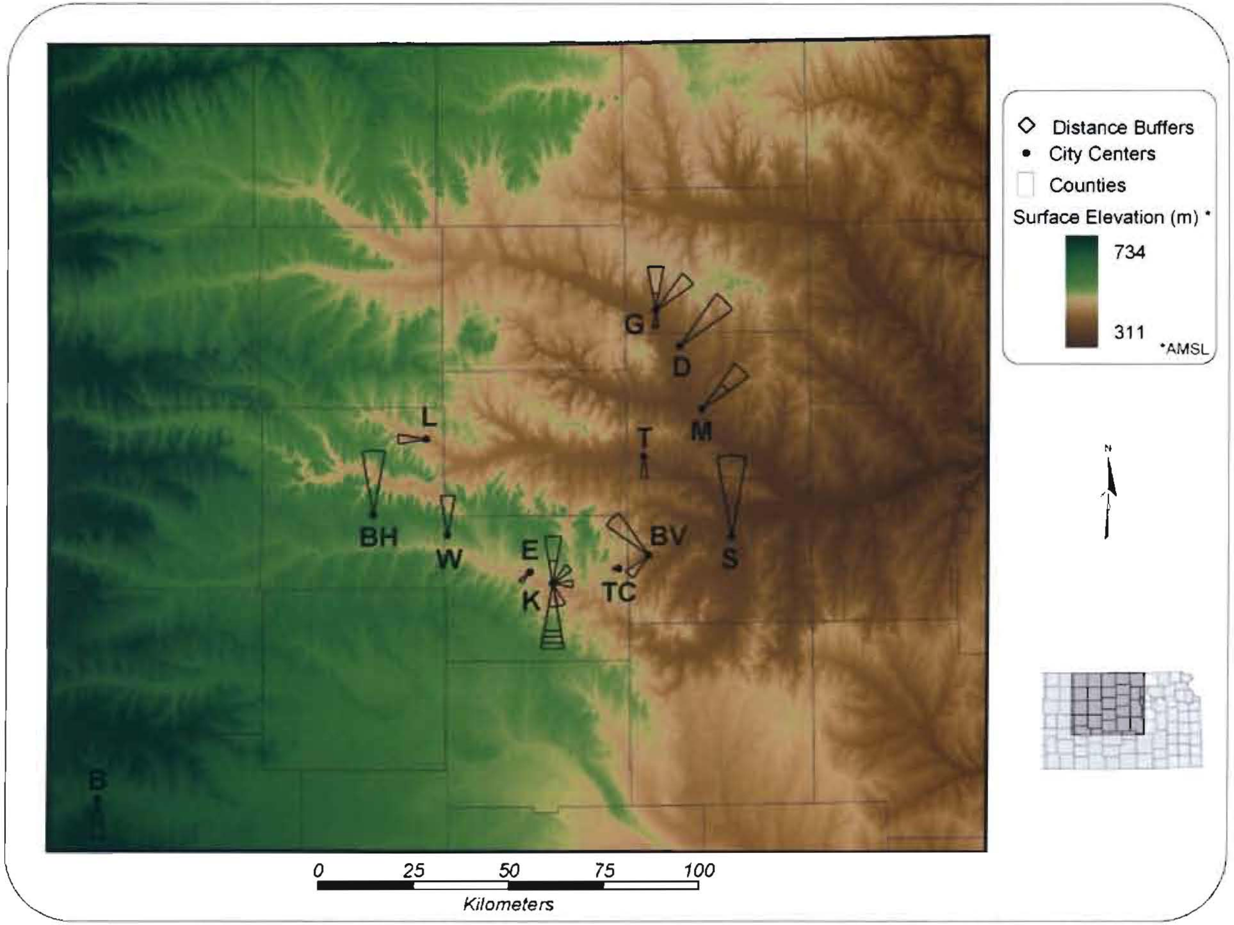


Figure C 3: Surface Elevations of Limited Distance Collection Site Locations. Mapped locations of the Limited Distance Collection Sites to the AMSL elevations derived from NED data in Kansas. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

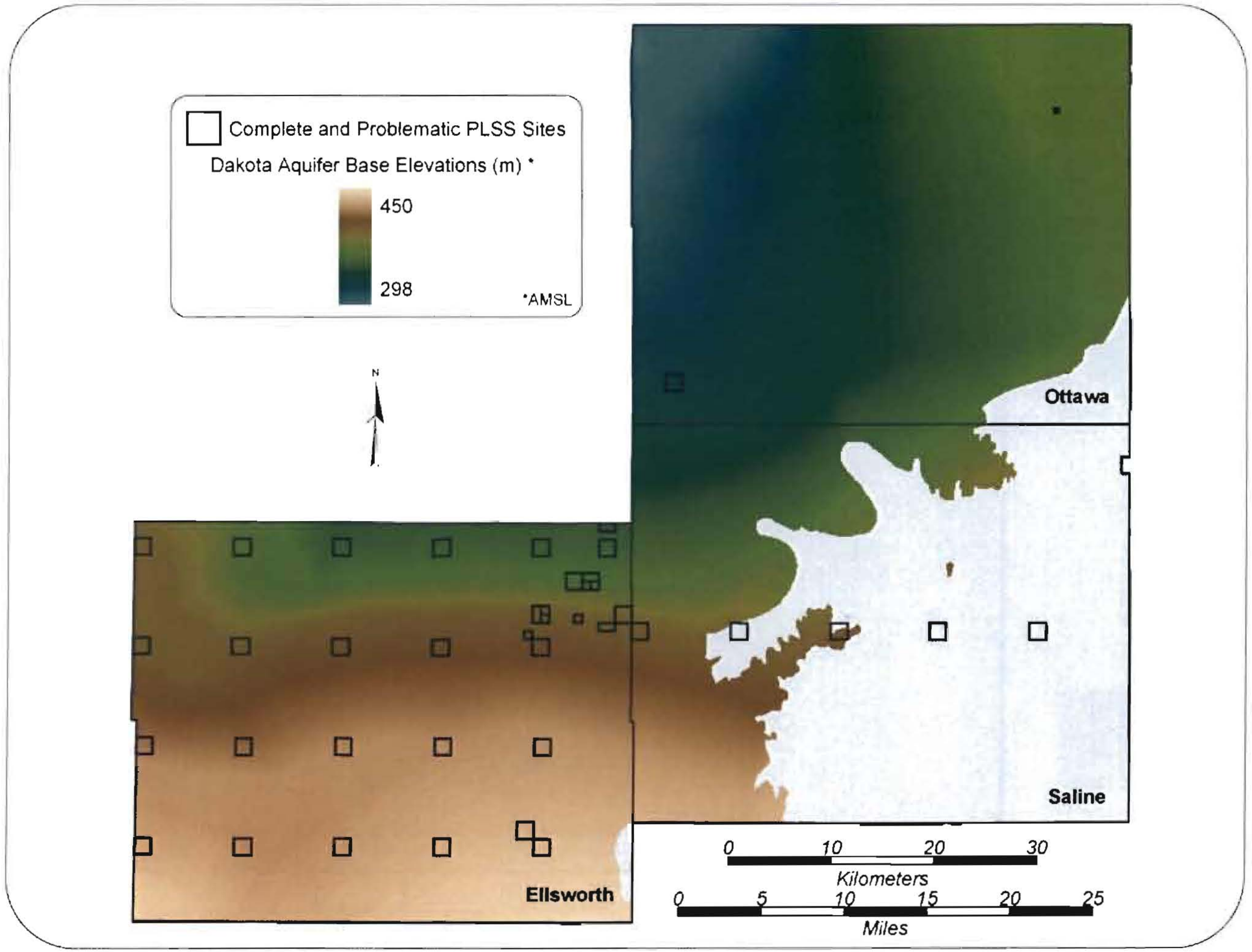


Figure C 4: Dakota Base Elevations of PLSS Collection Site Locations. Mapped locations of the PLSS Collection Sites and the DB elevations above mean sea level in Kansas derived from Dakota Aquifer data downloaded from DASC.

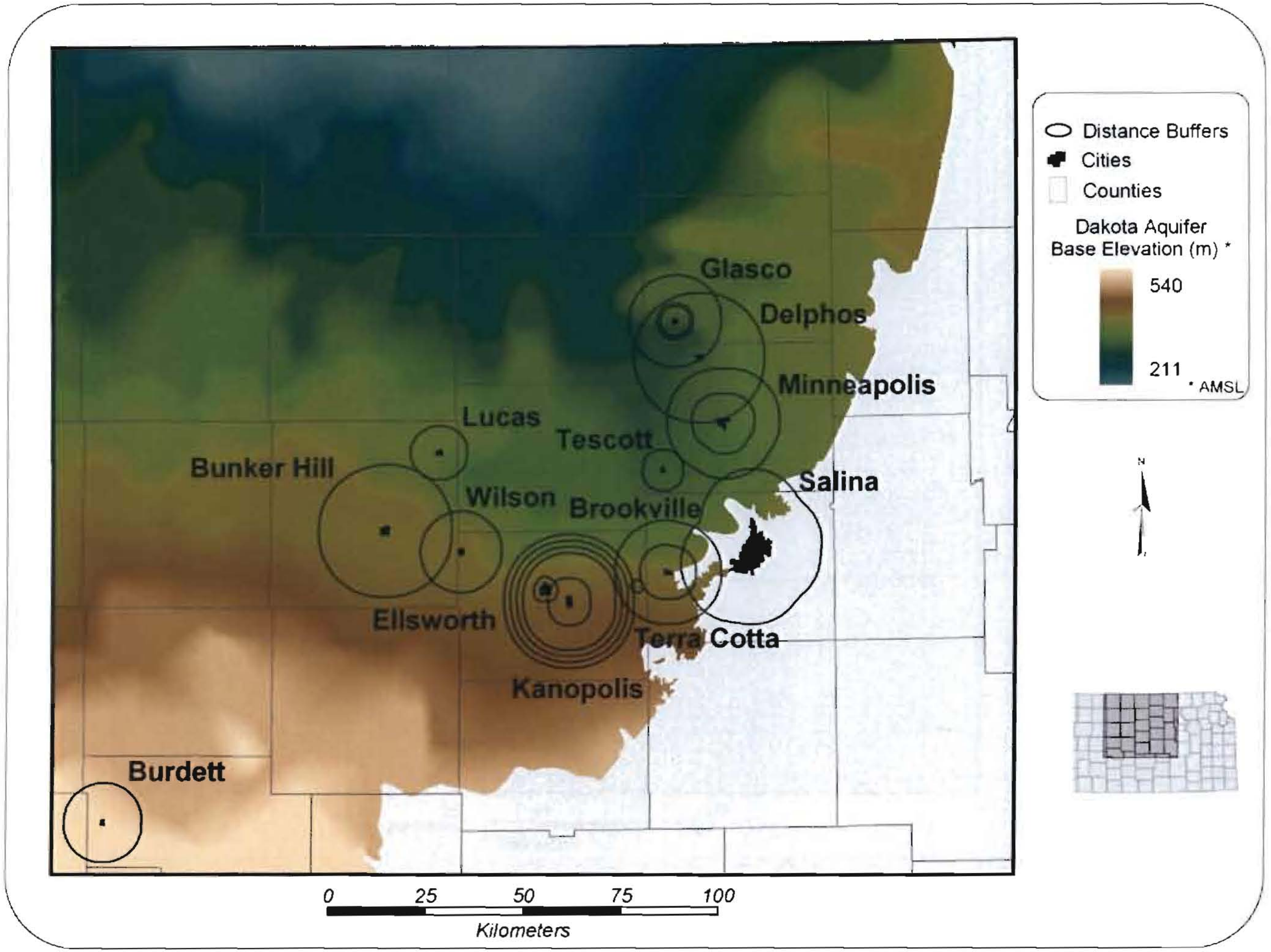


Figure C 5: Dakota Base Elevations of Distance Collection Site Locations. Mapped locations of the Distance Collection Sites and the DB elevations above mean sea level in Kansas derived from Dakota Aquifer data downloaded from DASC.

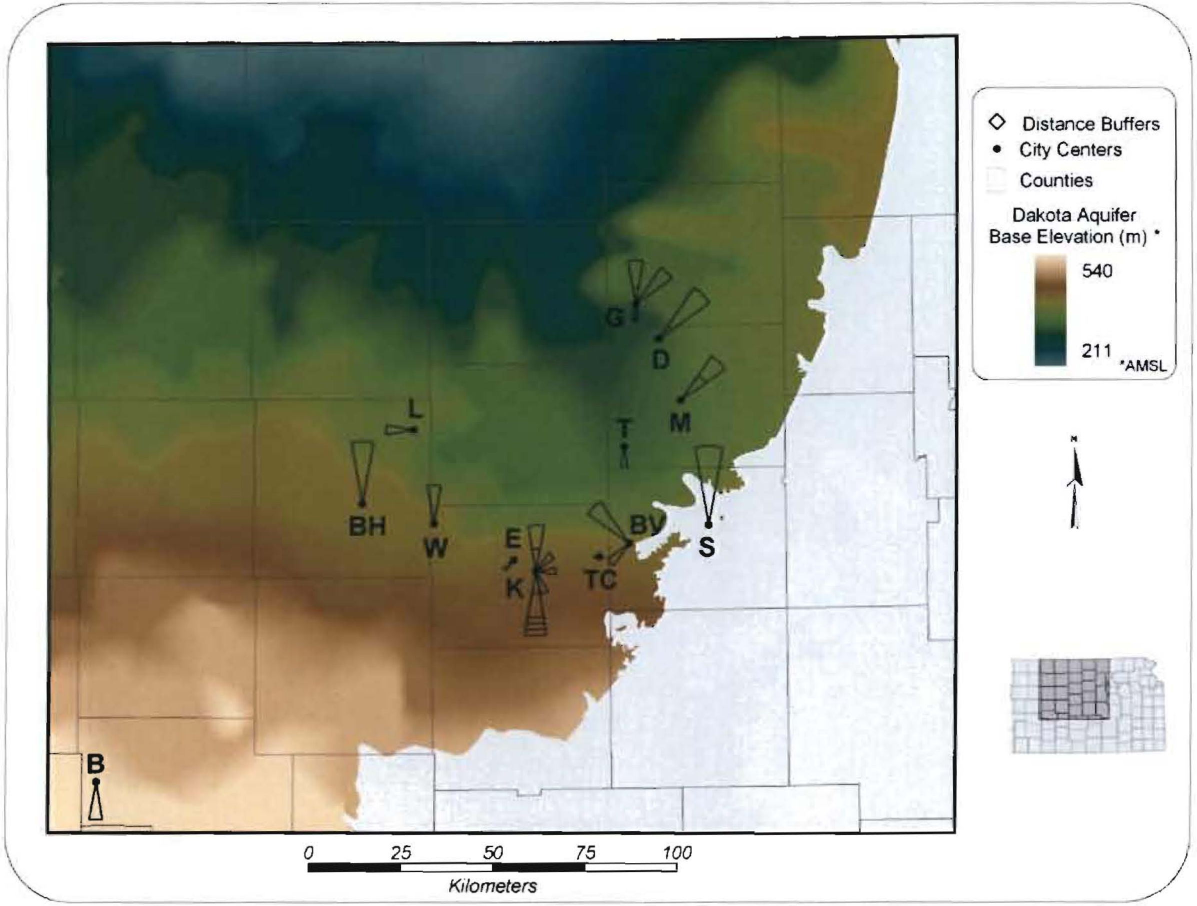


Figure C 6: Dakota Base Elevations of Limited Distance Collection Site Locations. Mapped locations of the Limited Distance Collection Sites and the DB elevations above mean sea level in Kansas derived from Dakota Aquifer data downloaded from DASC. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

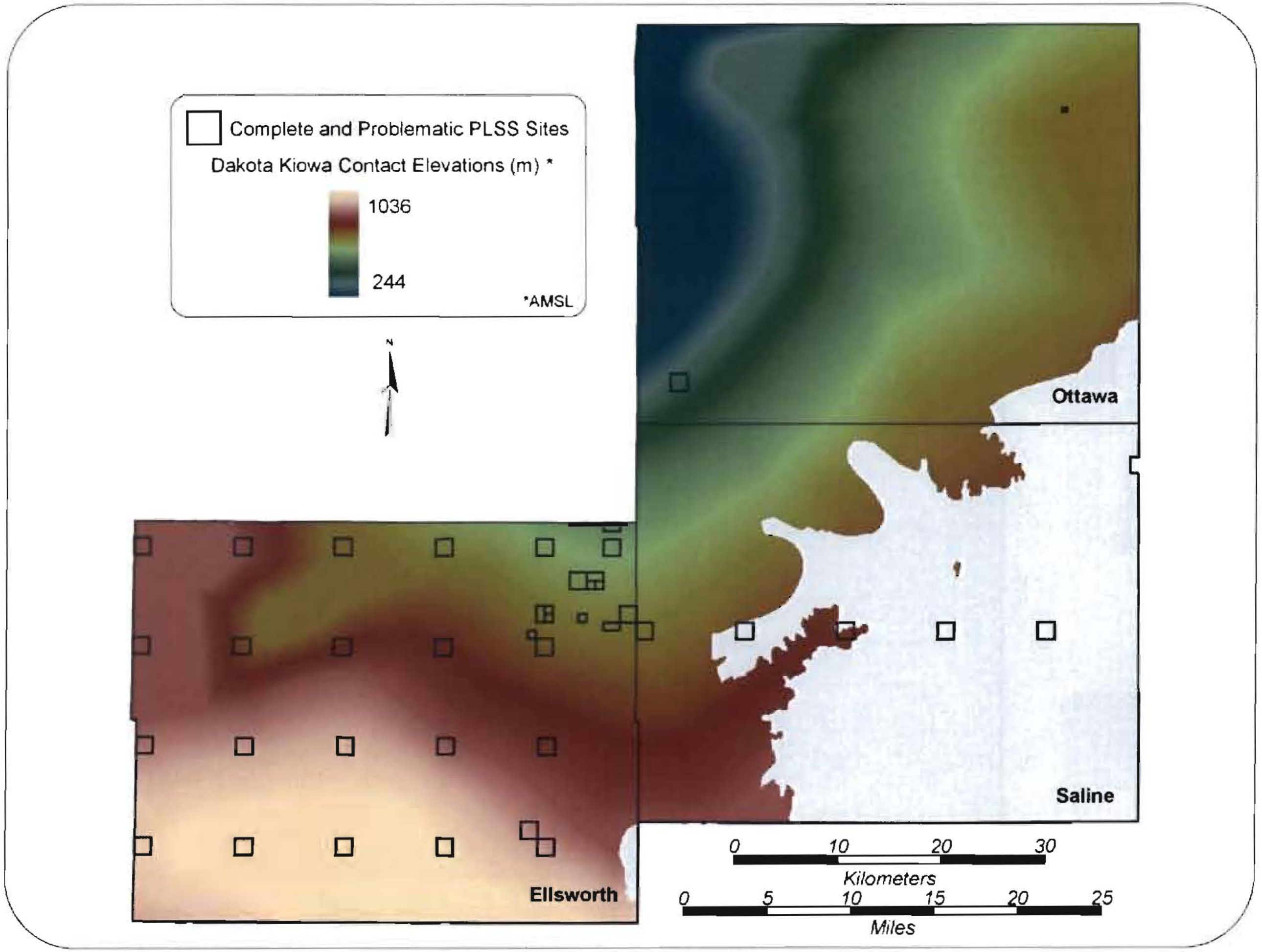


Figure C 7: Dakota-Kiowa Contact Elevations of PLSS Collection Site Locations. Mapped locations of the PLSS Collection Sites and the TKW elevations above mean sea level in Kansas derived from 1989 map contours from *1989 Top Configuration of the Kiowa Formation* map.

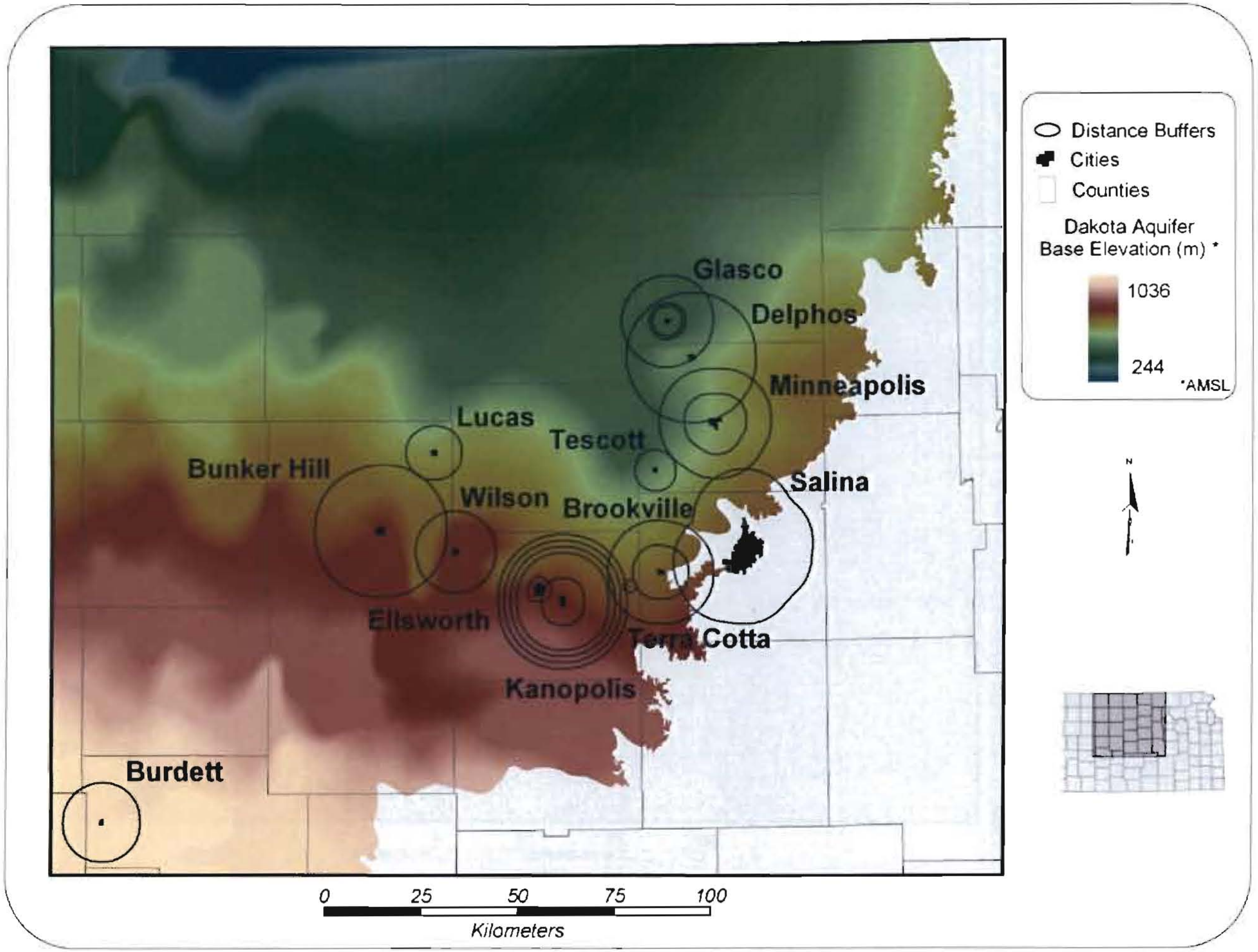


Figure C 8: Dakota-Kiowa Contact Elevations of Distance Collection Site Locations. Mapped locations of the Distance Collection Sites and the TKW elevations above mean sea level in Kansas derived from 1989 map contours from *1989 Top Configuration of the Kiowa Formation* map.

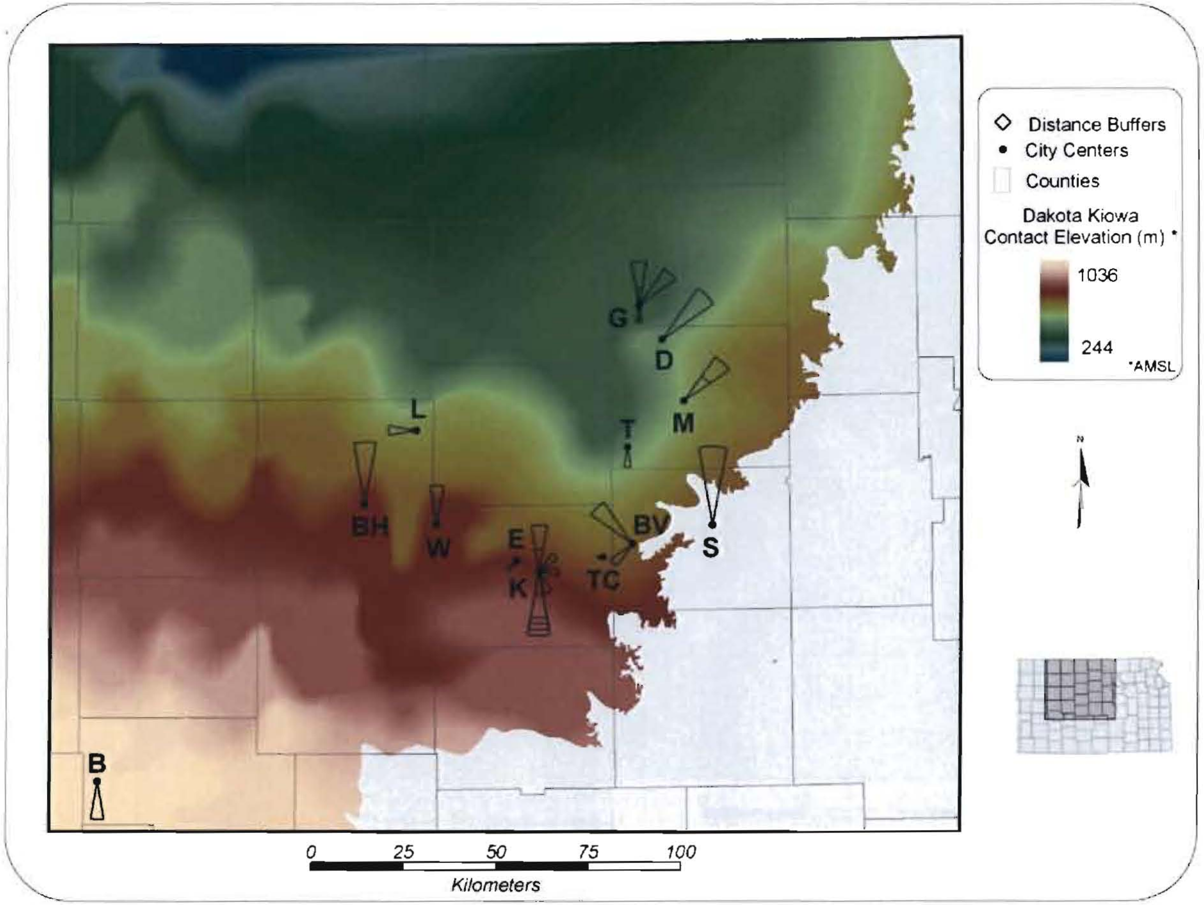


Figure C 9: Dakota-Kiowa Contact Elevations of Limited Distance Collection Site Locations. Mapped locations of the Limited Distance Collection Sites and the TKW elevations above mean sea level in Kansas derived from 1989 Top Configuration of the Kiowa Formation map. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

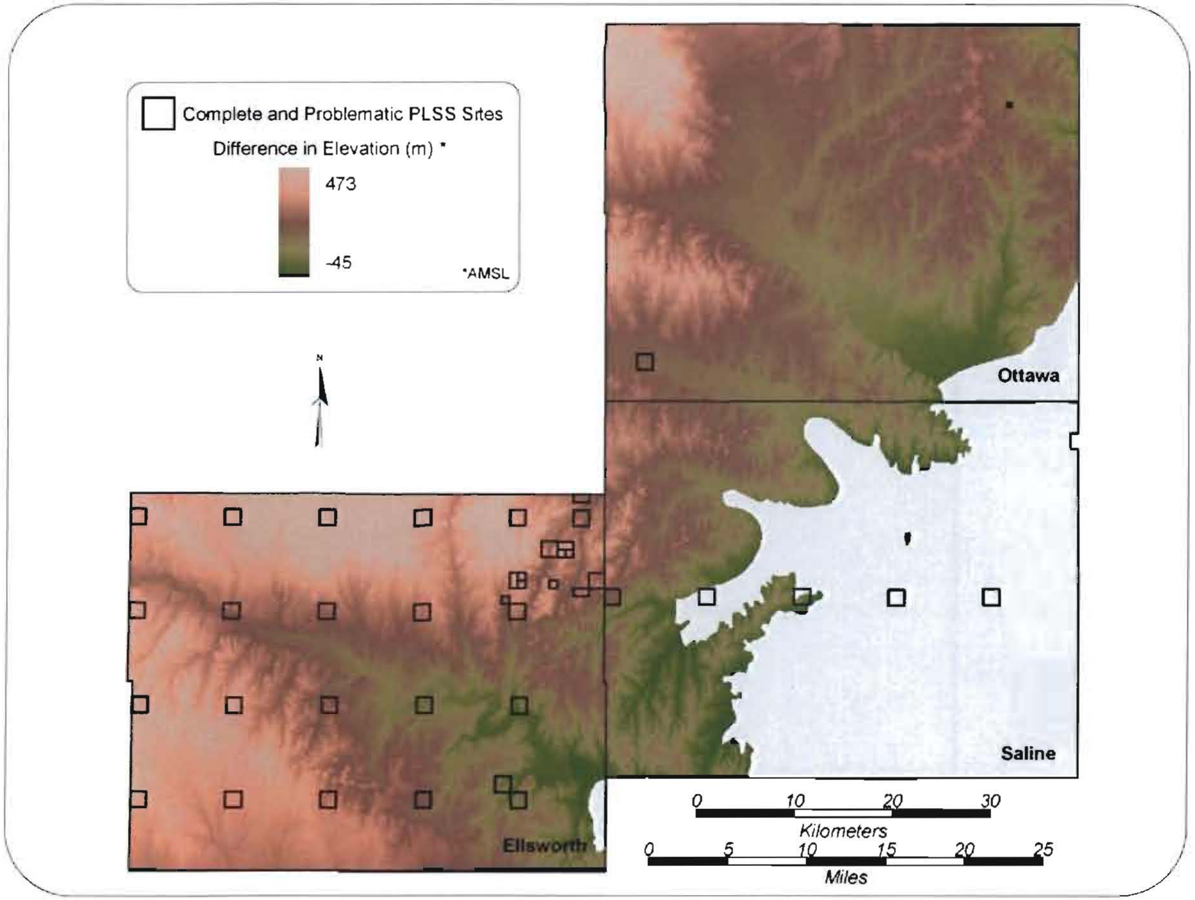


Figure C 10: Dakota Aquifer Derived Dakota Formation Thickness Elevations of PLSS Collection Site Locations. Map created from the locations of the PLSS Collection Sites and the ABD # 1 thickness estimate for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Additional problems exist because in places the Dakota strata is not present and the base used was actually the top of the Permian strata. Negative values are better seen in Figure 51.

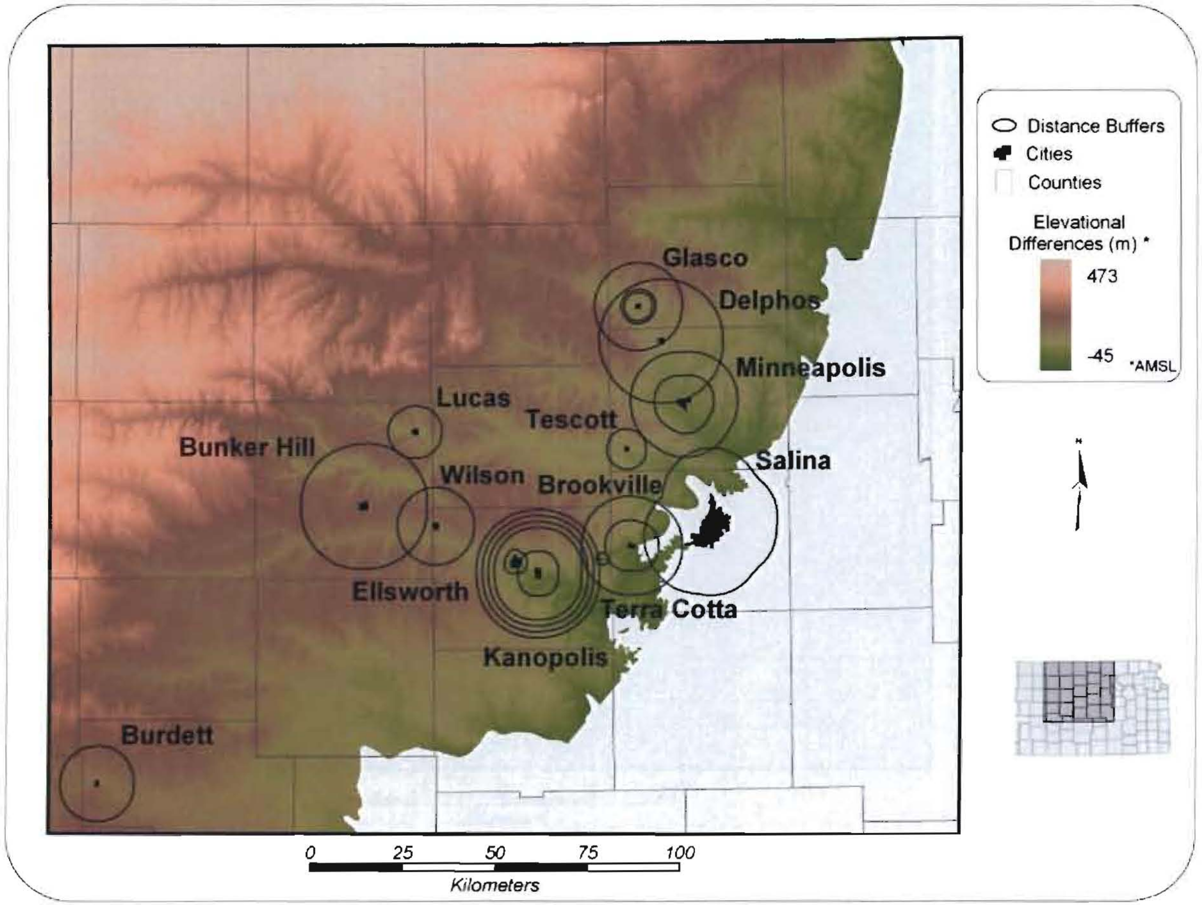


Figure C 11: Dakota Aquifer Derived Dakota Formation Thickness Elevations of Distance Collection Site Locations. Map created from the locations of the Distance Collection Sites and the ABD # 1 thickness estimate for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Additional problems exist because in places the Dakota strata is not present and the base used was actually the top of the Permian strata. Negative values are better seen in Figure 52.

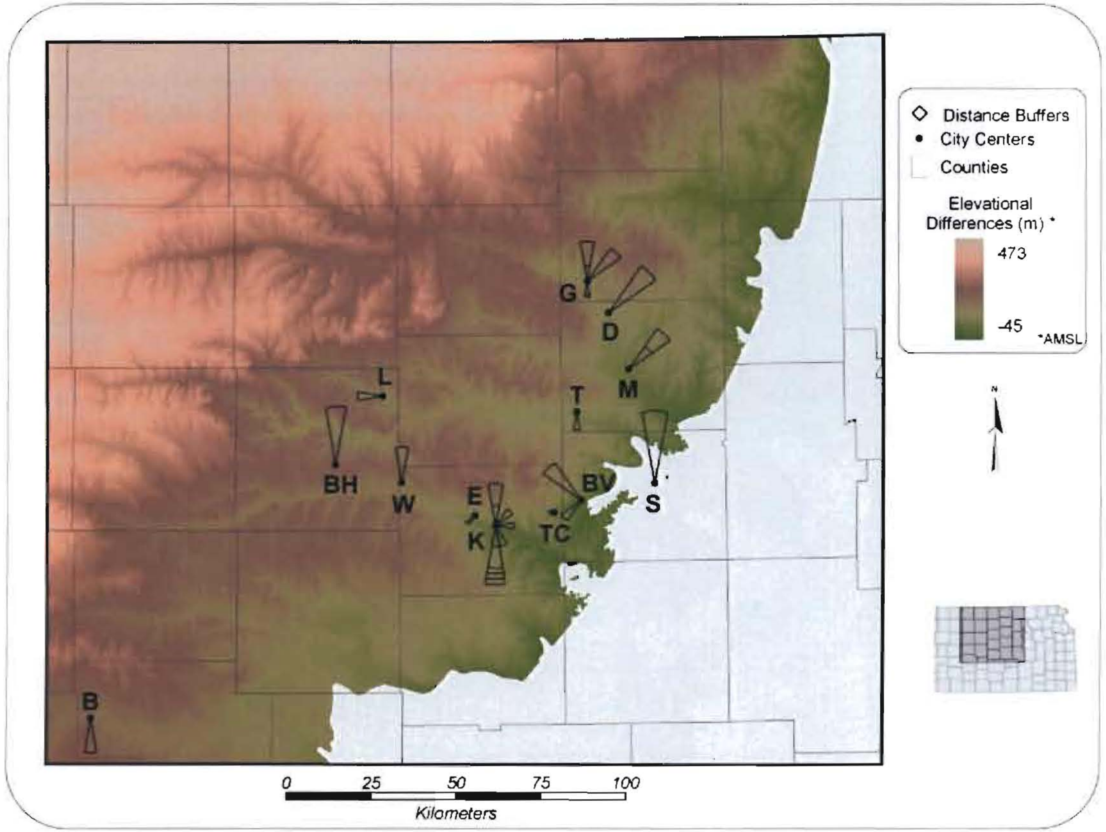


Figure C 12: Dakota Aquifer Derived Dakota Formation Thickness Elevations of Limited Distance Collection Site Locations. Map created from the locations of the Limited Distance Collection Sites and the ABD # 1 thickness estimate for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Additional problems exist because in places the Dakota strata is not present and the base used was actually the top of the Permian strata. Negative values are better seen in Figure 53. The city centers are labeled with an abbreviation (BV=Brookville, BH=Bunker Hill, B=Burdett, C=Carnerio, D=Delphos, EW=Ellsworth, G=Glasco, K=Kanopolis, L= Lucas, M=Minneapolis, TC=Terra Cotta, T=Tescott, S=Salina, and W=Wilson) for the city.

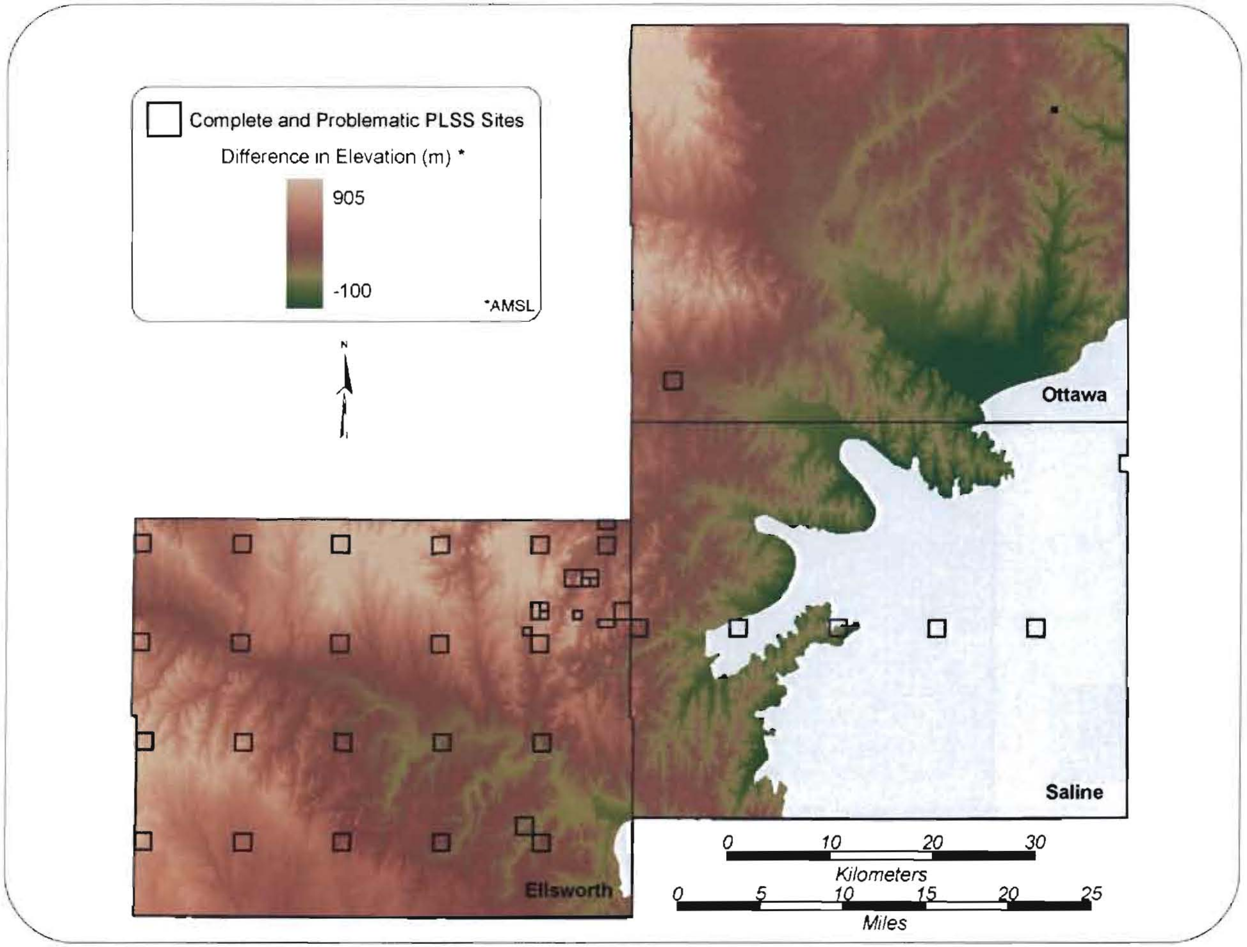


Figure C 13: Kiowa Formation Derived Dakota Formation Thickness Elevations of PLSS Collection Site Locations. Map created from the locations of the PLSS Collection Sites and ABD # 2 thickness estimate for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Negative values are better seen in Figure 54.

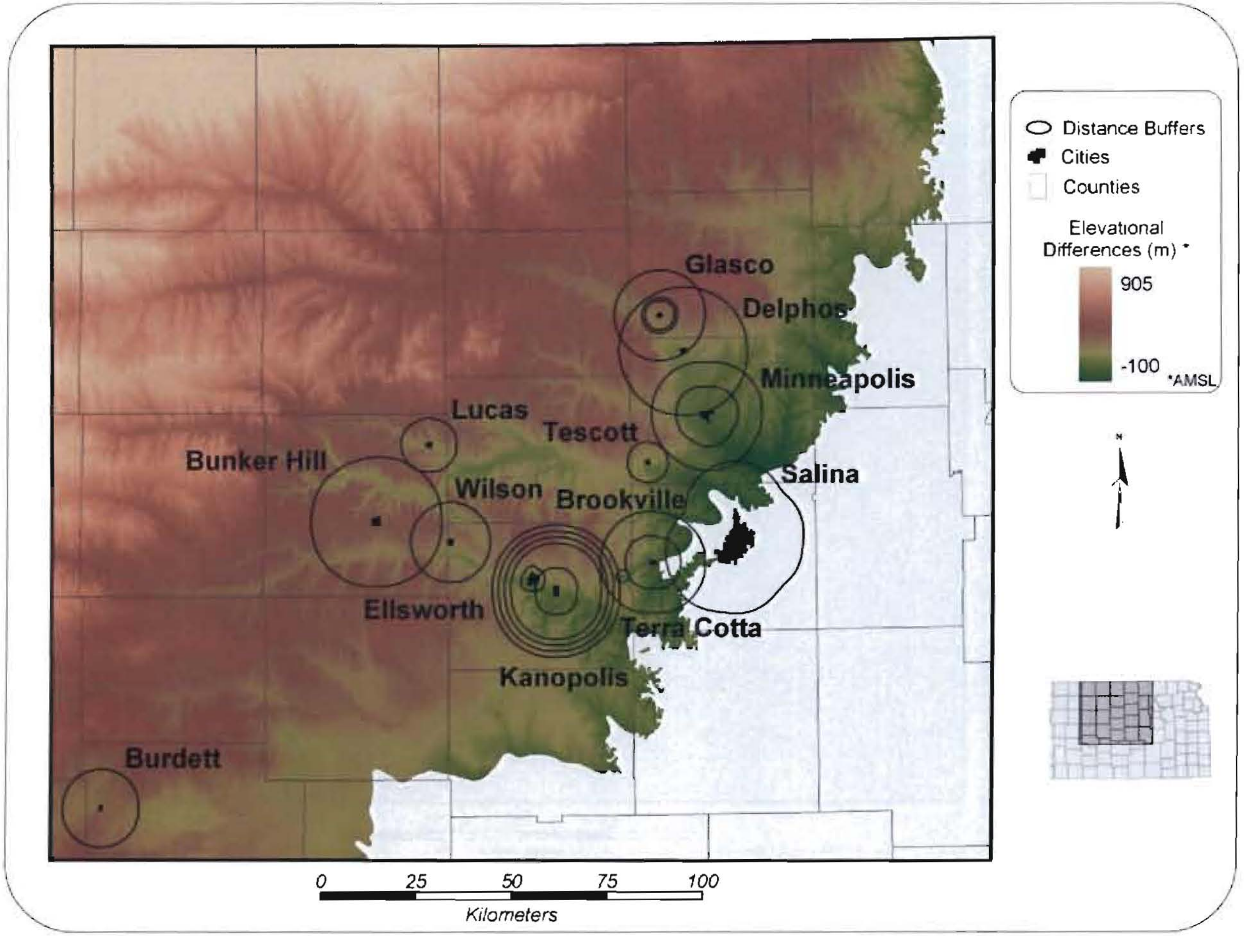


Figure C 14: Kiowa Formation Derived Dakota Formation Thickness Elevations of Distance Collection Site Locations. Map created from the locations of the Distance Collection Sites and ABD # 2 thickness estimate for the Dakota Formation in Kansas. Problems with this estimate exist because in some cases the strata exposed at the surface are not the Dakota but the Greenhorn. Negative values are better seen in Figure 55.

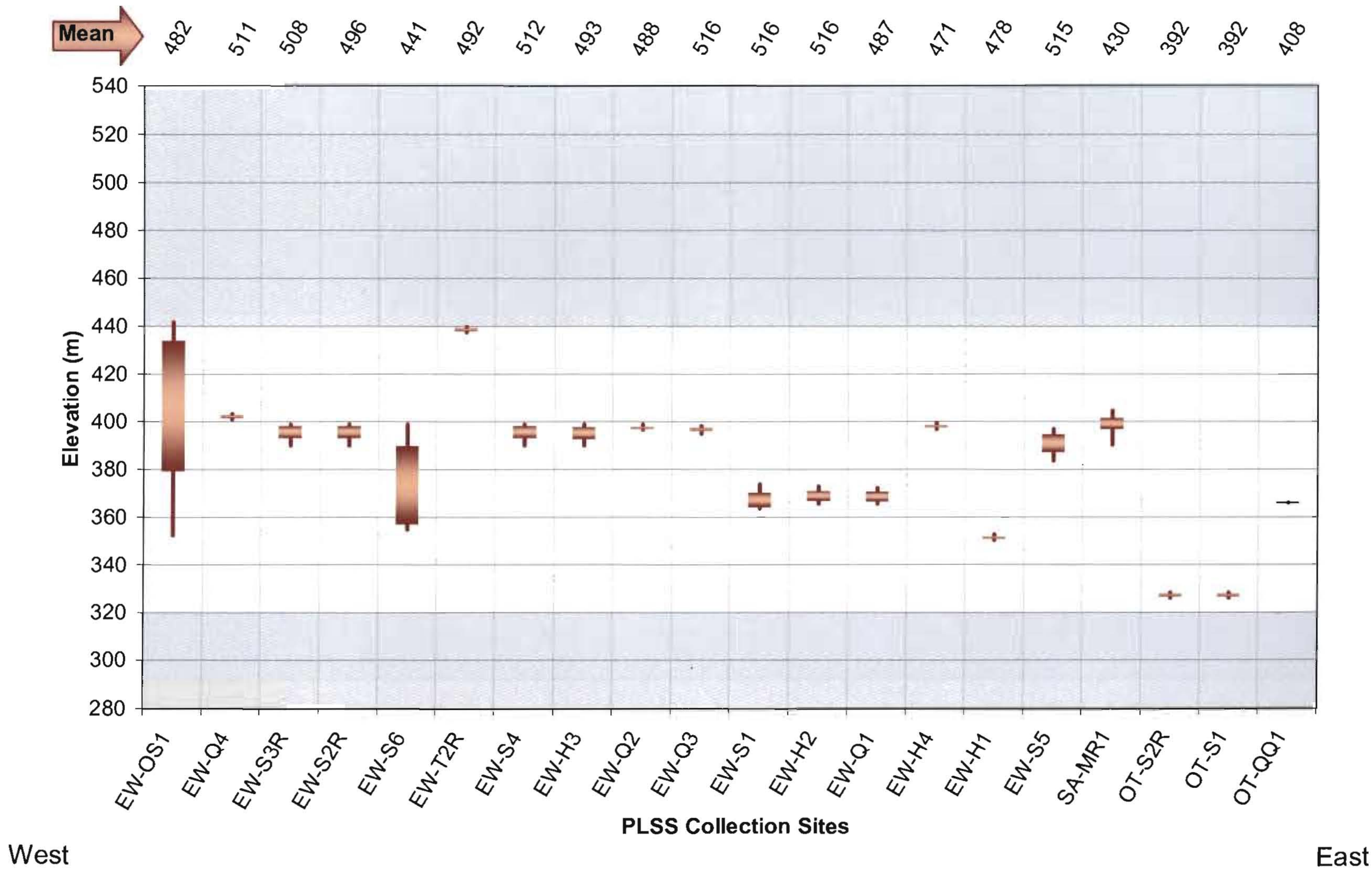


Figure C 16: Dakota Aquifer Base Elevation Statistics for PLSS Collection Sites. Statistics of the Dakota Aquifer base elevations of the PLSS Collection Sites are depicted as a box and whisker plot.

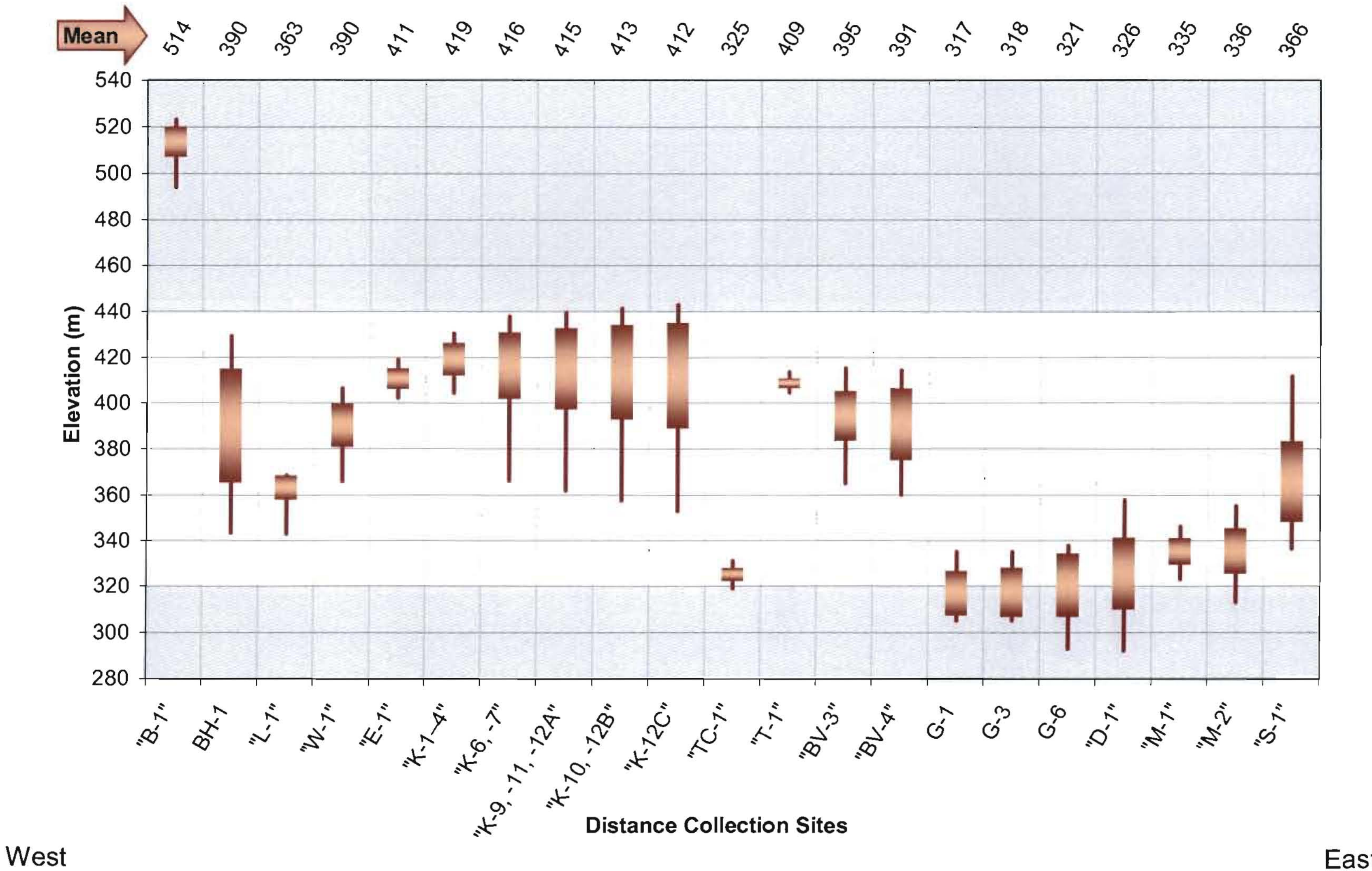


Figure C 17: Dakota Aquifer Base Elevation Statistics for Distance Collection Sites. Statistics of the Dakota Aquifer base elevations of the Distance Collection Sites are depicted as a box and whisker plot.

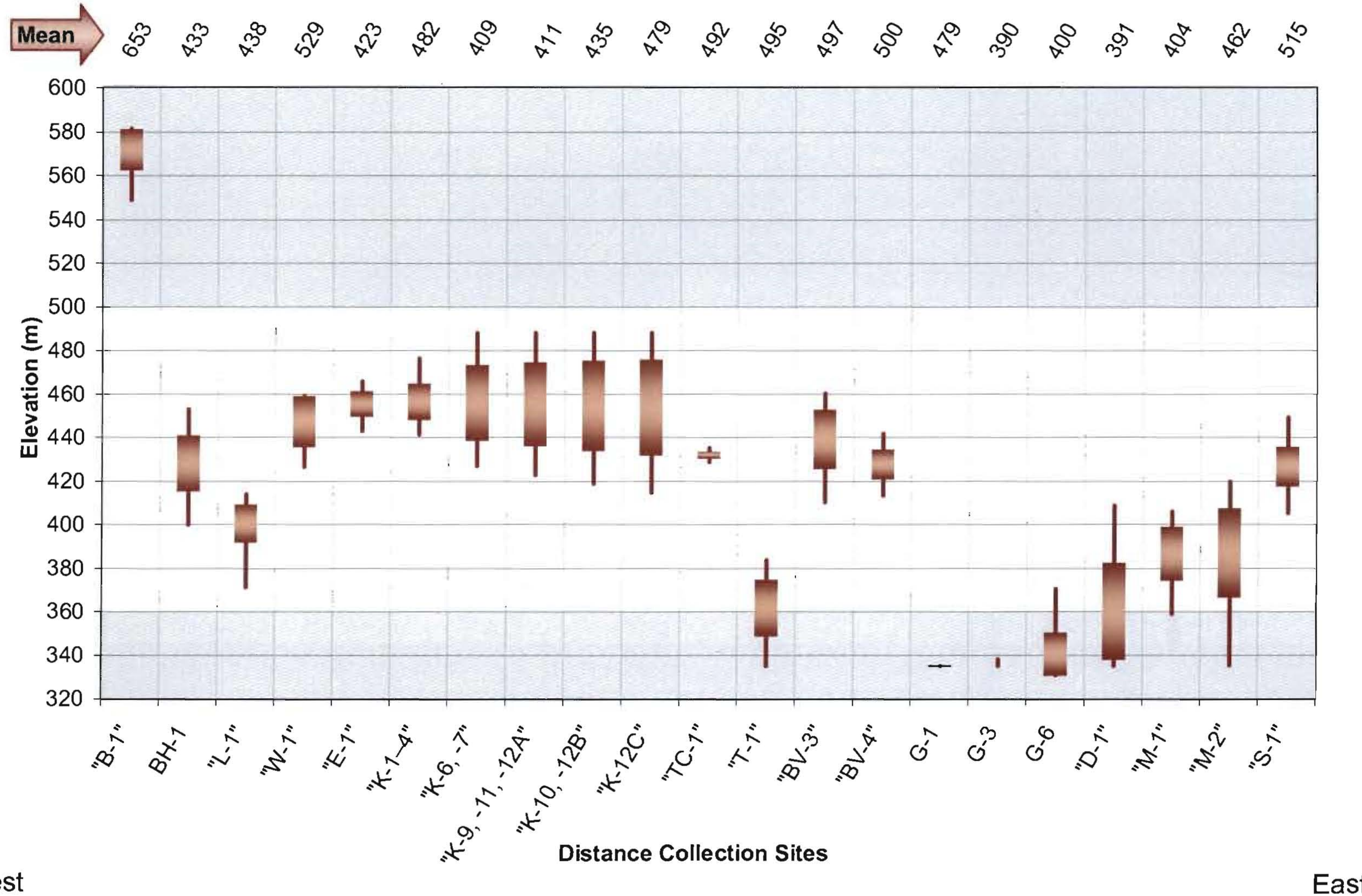


Figure C 18: Dakota-Kiowa Contact Elevation Statistics for Distance Collection Sites. Statistics of the Dakota-Kiowa contact elevations of the Distance Collection Sites are depicted as a box and whisker plot.

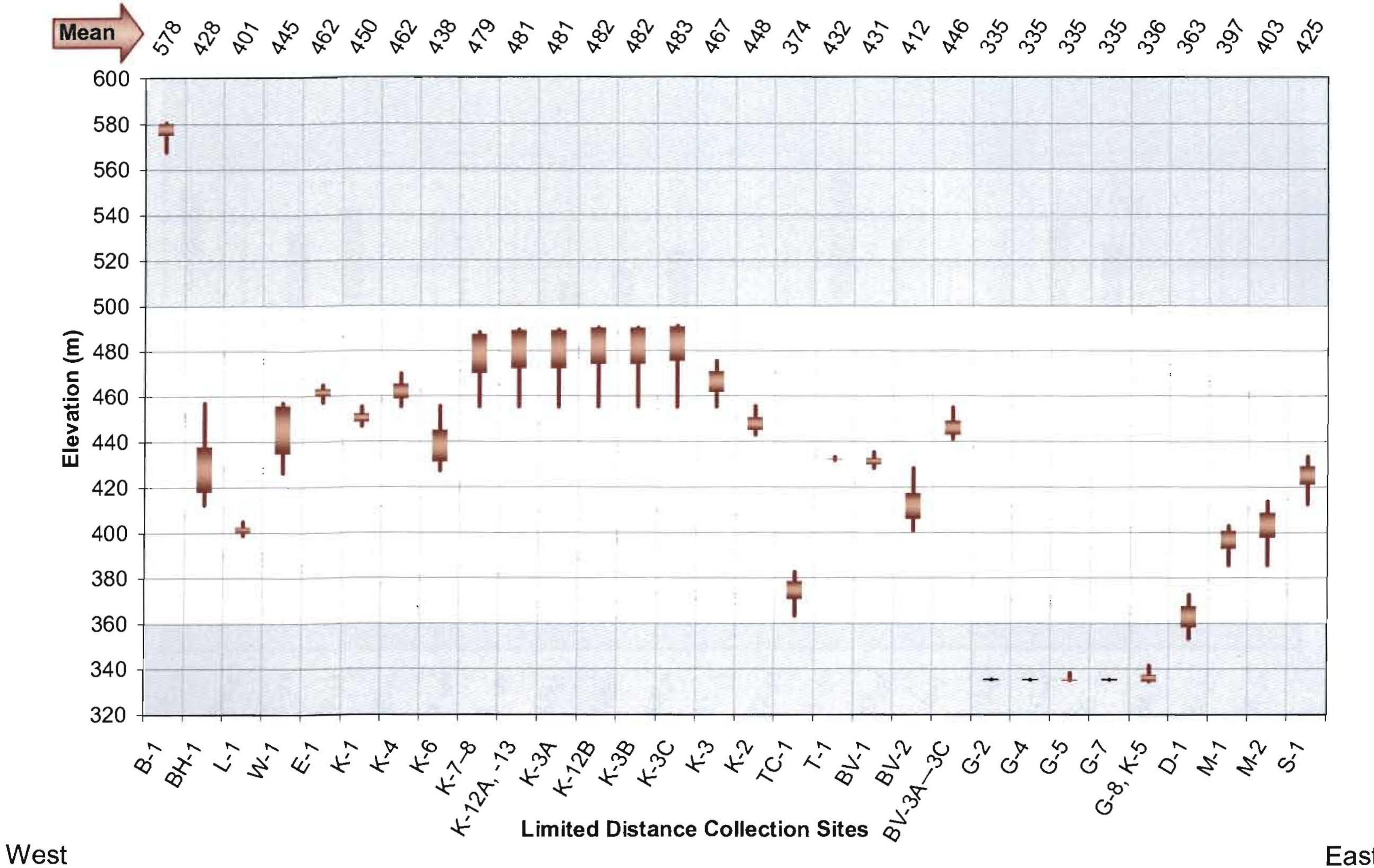


Figure C 19: Dakota-Kiowa Contact Elevation Statistics for Limited Distance Collection Sites. Statistics of the Dakota-Kiowa contact elevations of the Limited Distance Collection Sites are depicted as a box and whisker plot.

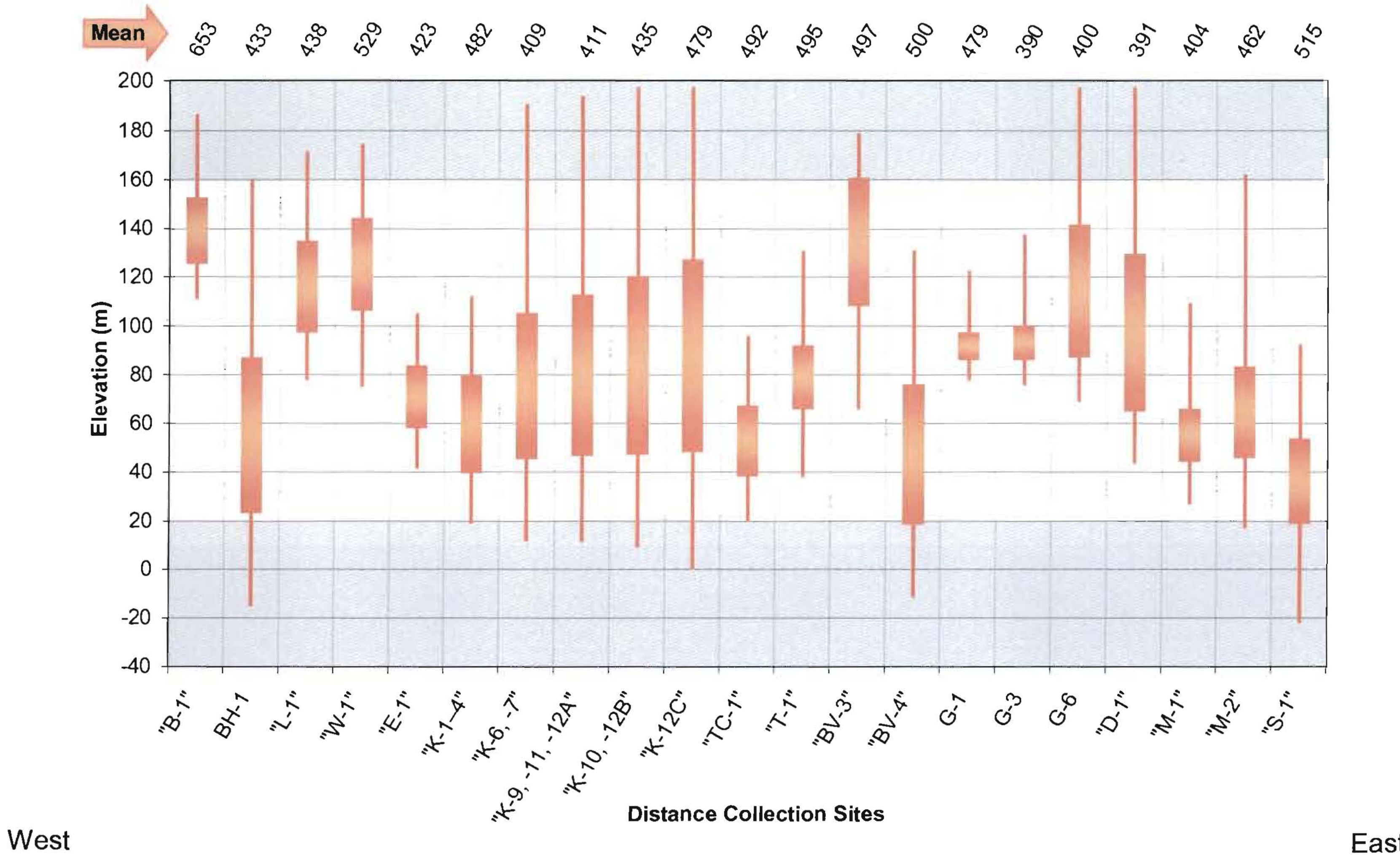


Figure C 20: Dakota Aquifer derived Dakota Formation Thickness Estimate for Distance Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas for the Distance Collection Sites are depicted as a box and whisker plot.

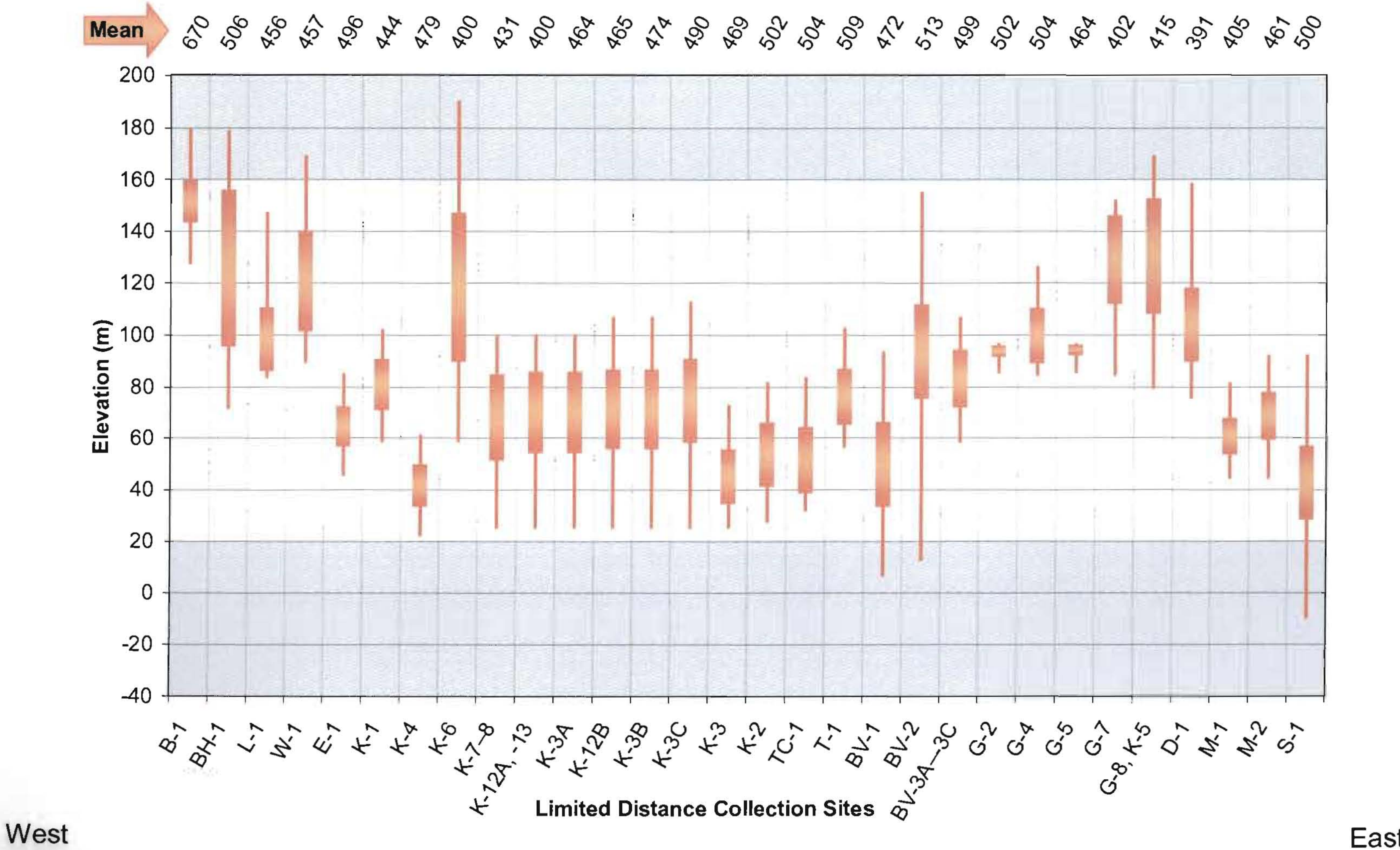


Figure C 21: Dakota Aquifer derived Dakota Formation Thickness Estimate for Limited Distance Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Dakota Aquifer in Kansas for the Limited Distance Collection Sites are depicted as a box and whisker plot.

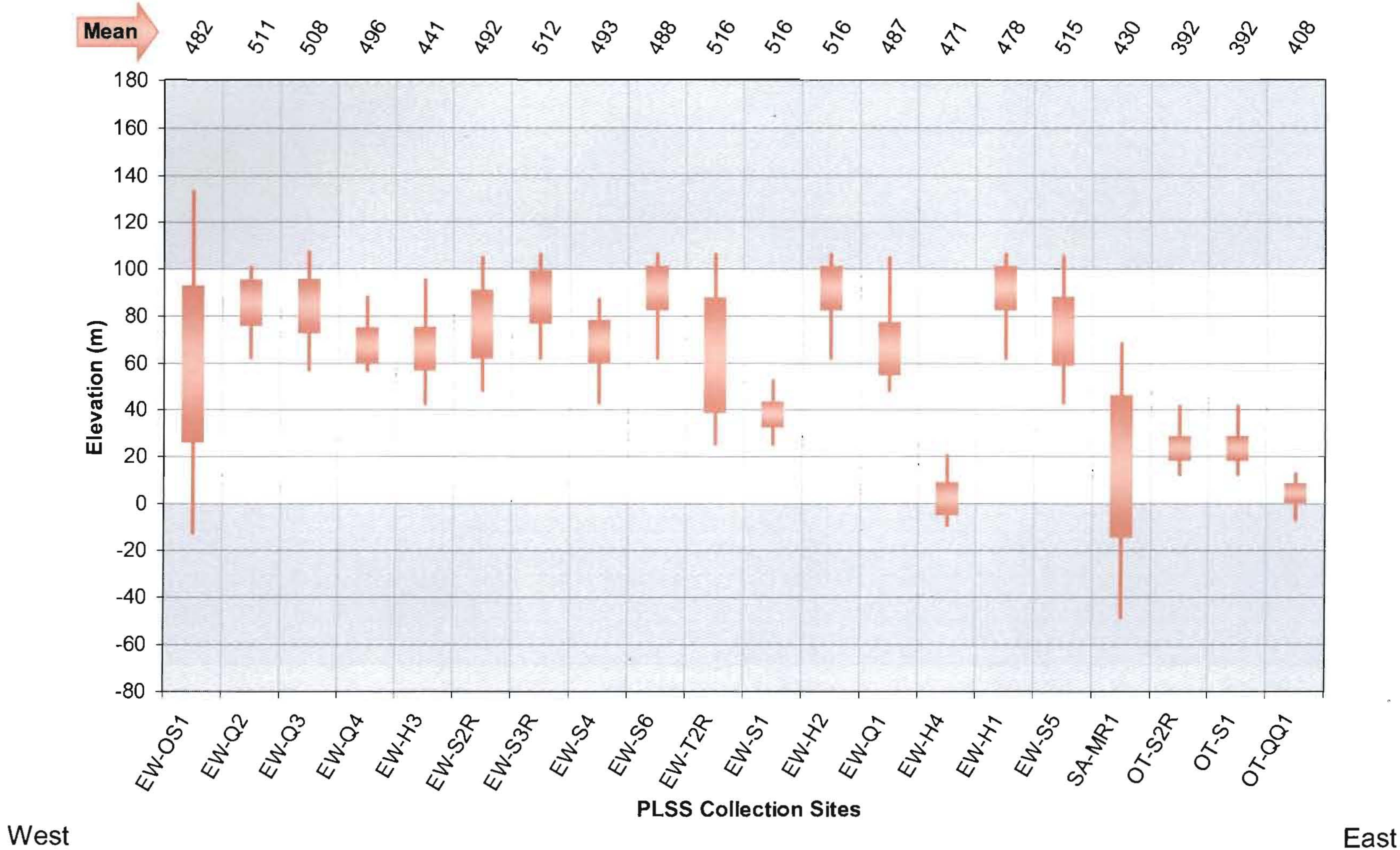


Figure C 22: Kiowa Formation derived Dakota Formation Thickness Estimate for PLSS Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas for the PLSS Collection Sites are depicted as a box and whisker plot.

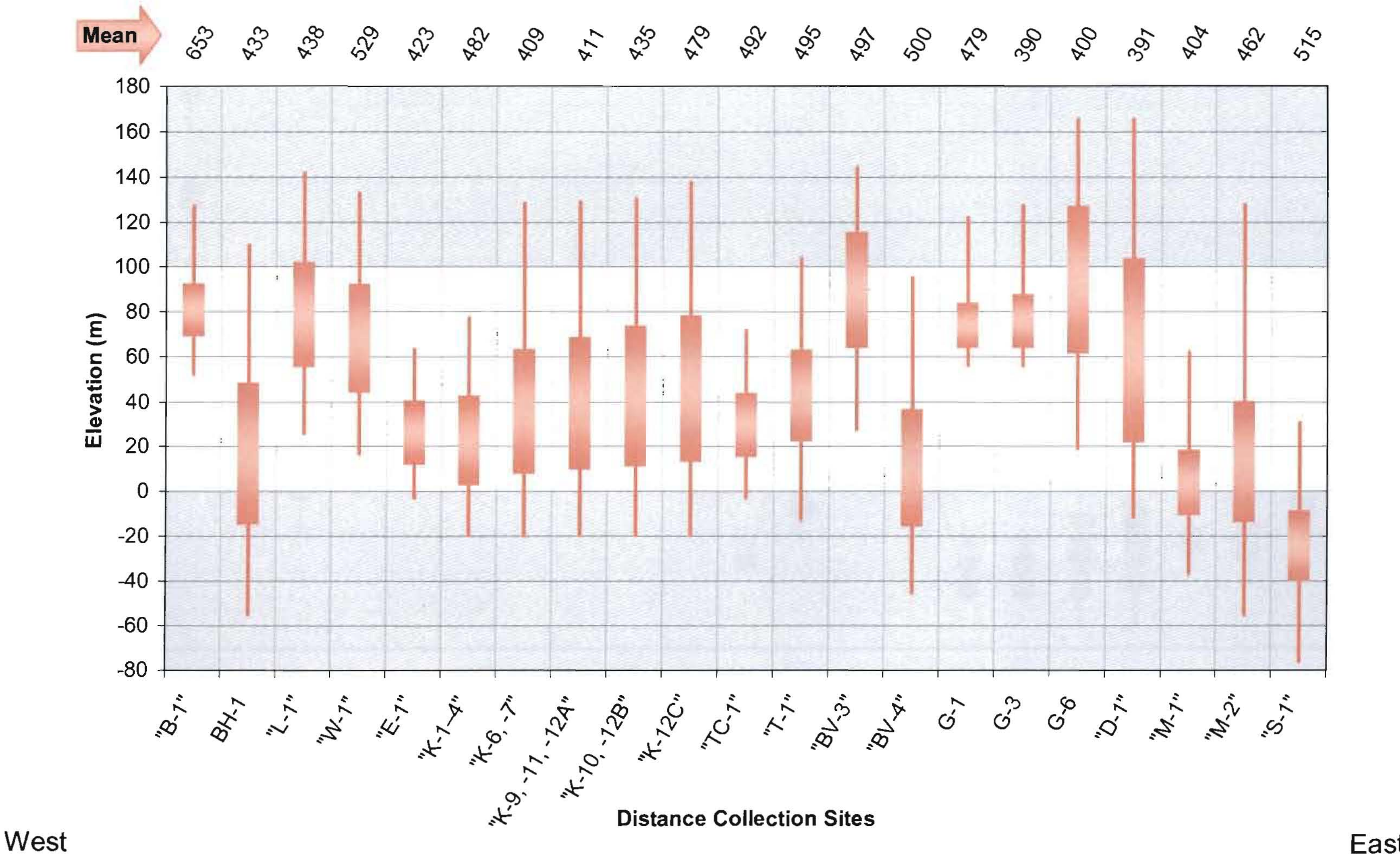


Figure C 23: Kiowa Formation derived Dakota Formation Thickness Estimate for Distance Collection Sites. Statistics of the Dakota Formation thickness estimate derived from the Kiowa Formation in Kansas for the Distance Collection Sites are depicted as a box and whisker plot.

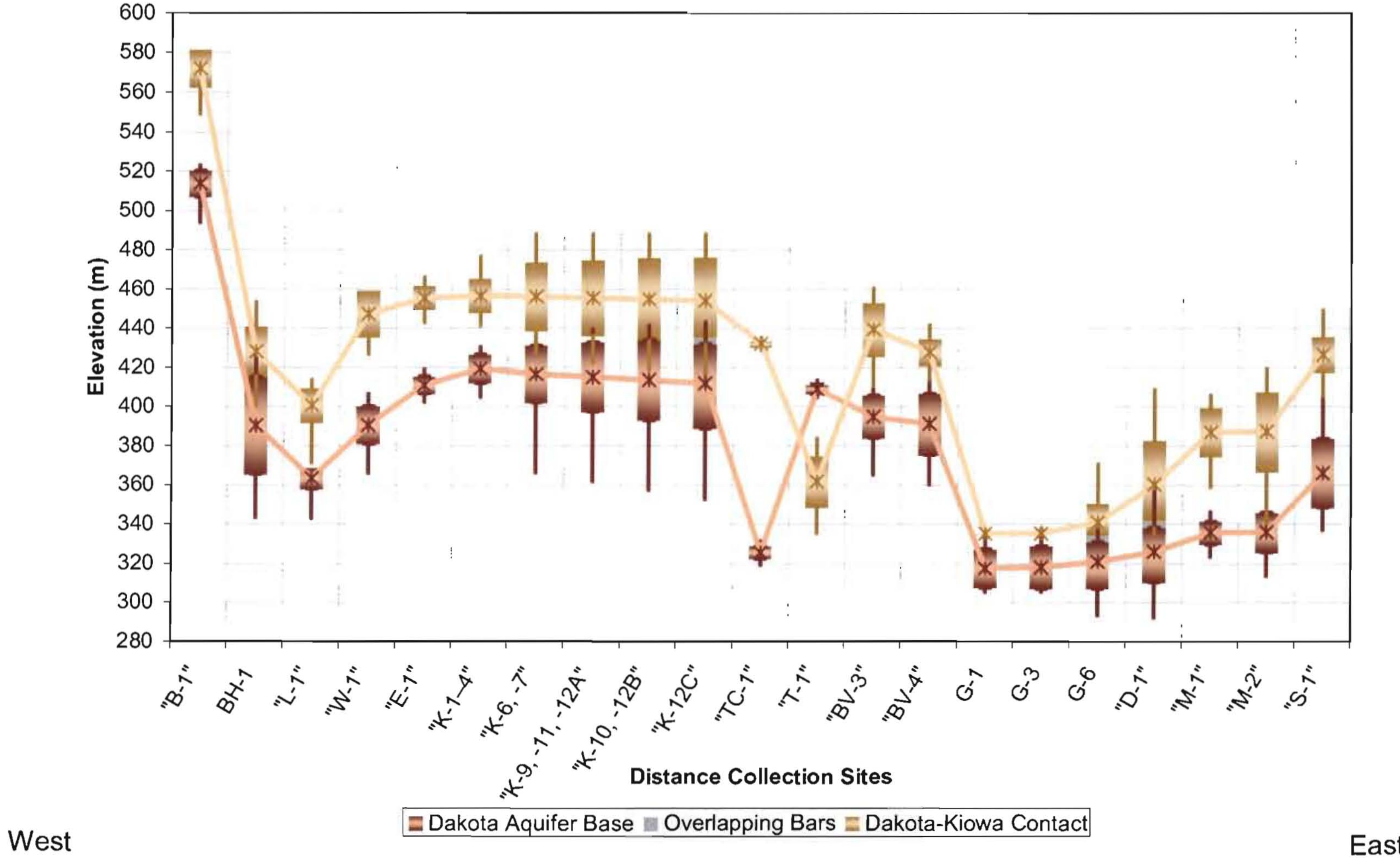
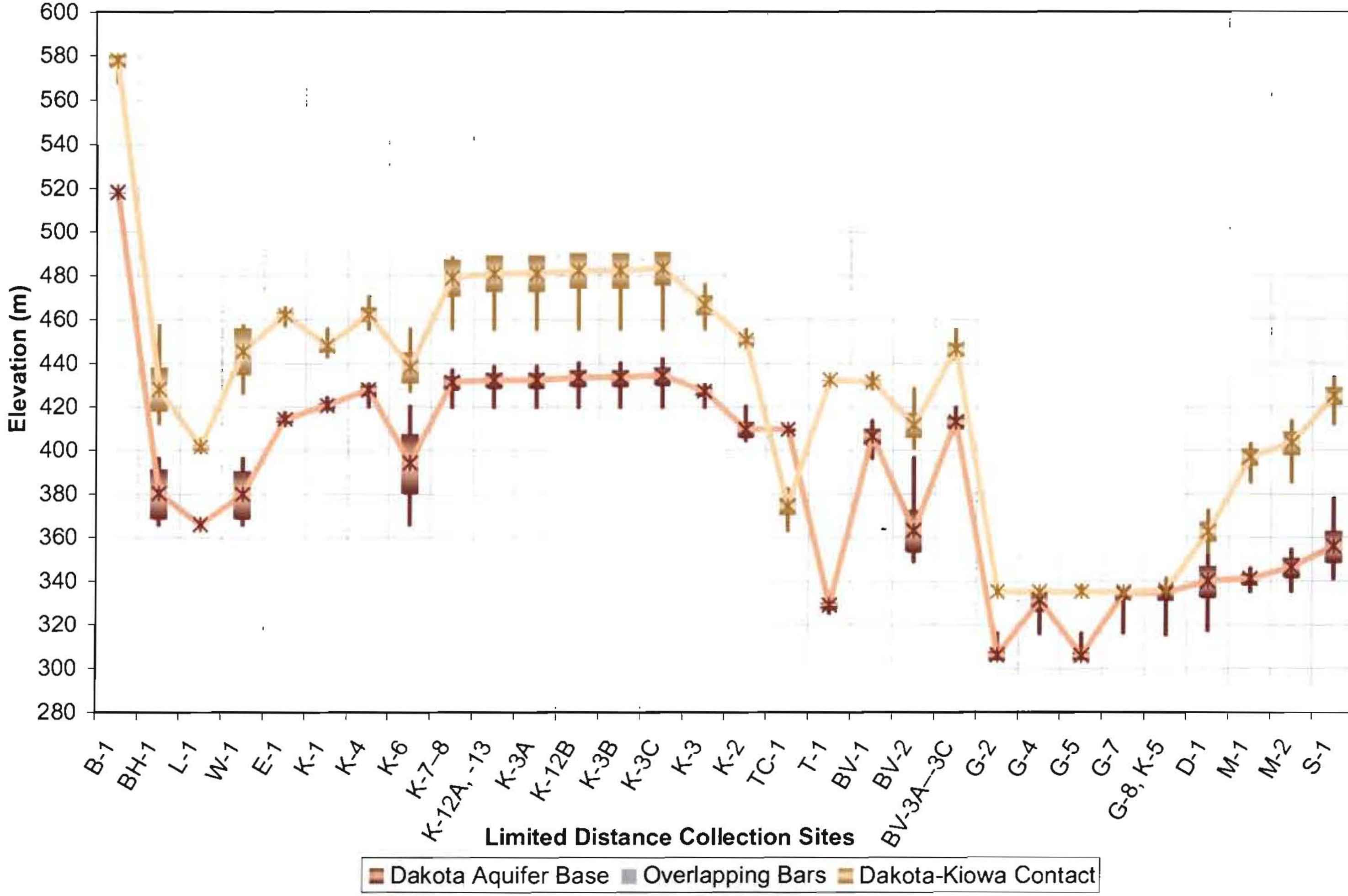


Figure C 24: Comparison of Dakota Aquifer Base and Dakota-Kiowa Contact for Distance Collection Sites. Statistics of the Dakota Aquifer base elevations and the Dakota-Kiowa contact elevations for the Distance Collection Sites are depicted as a box and whisker plot for comparison.



West

East

Figure C 25: Comparison of Dakota Aquifer Base and Dakota-Kiowa Contact Elevations for Limited Distance Collection Sites. Statistics of the Dakota Aquifer base elevations and the Dakota-Kiowa contact elevations for the Limited Distance Collection Sites are depicted as a box and whisker plot for comparison.

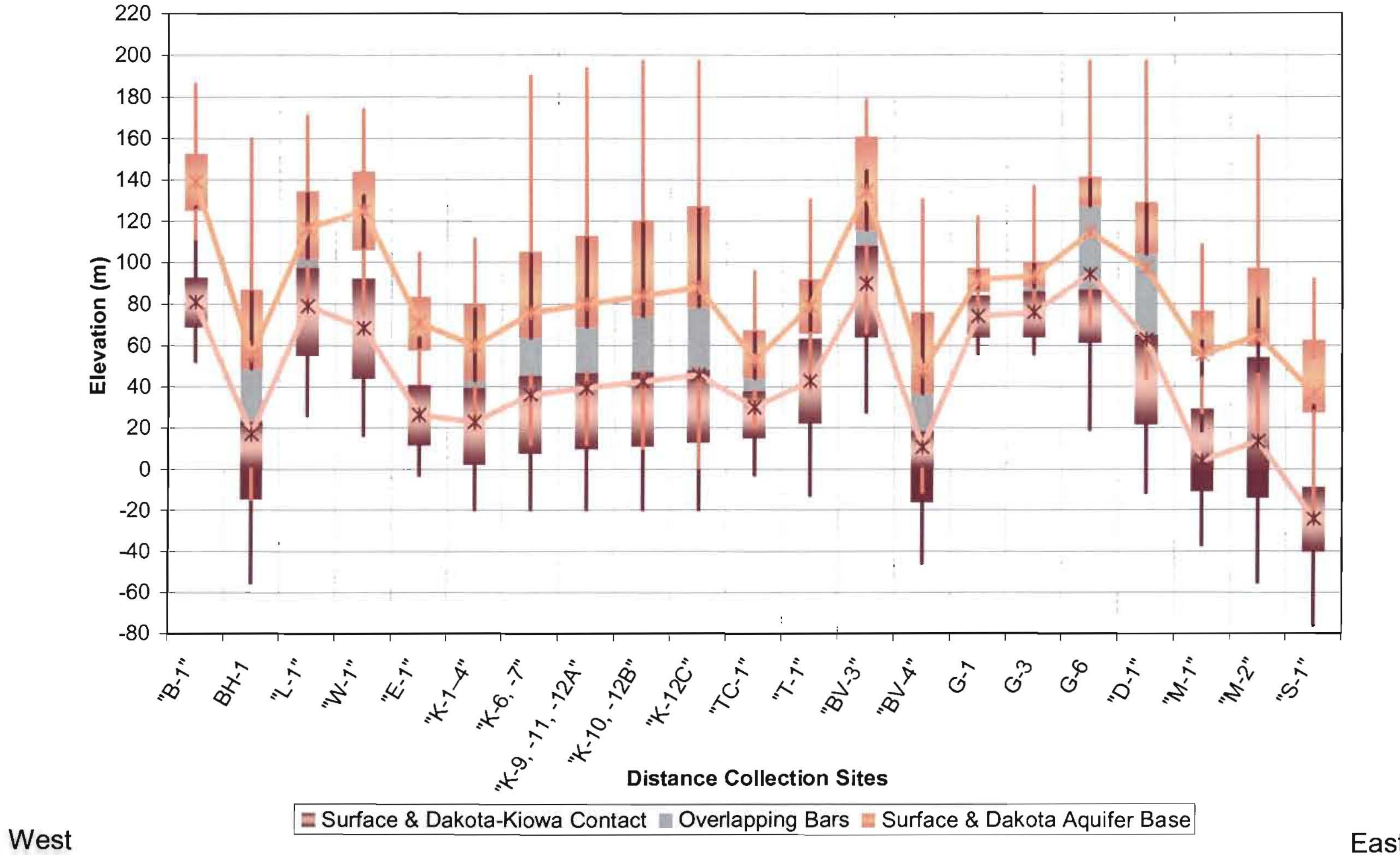


Figure C 26: Comparison of the Estimated Formational Thickness for Distance Collection Sites. Statistics of the Dakota Aquifer derived Dakota Formation thickness estimate and the Kiowa Formation derived Dakota Formation thickness estimate for the Distance Collection Sites are depicted as a box and whisker plot for comparison.

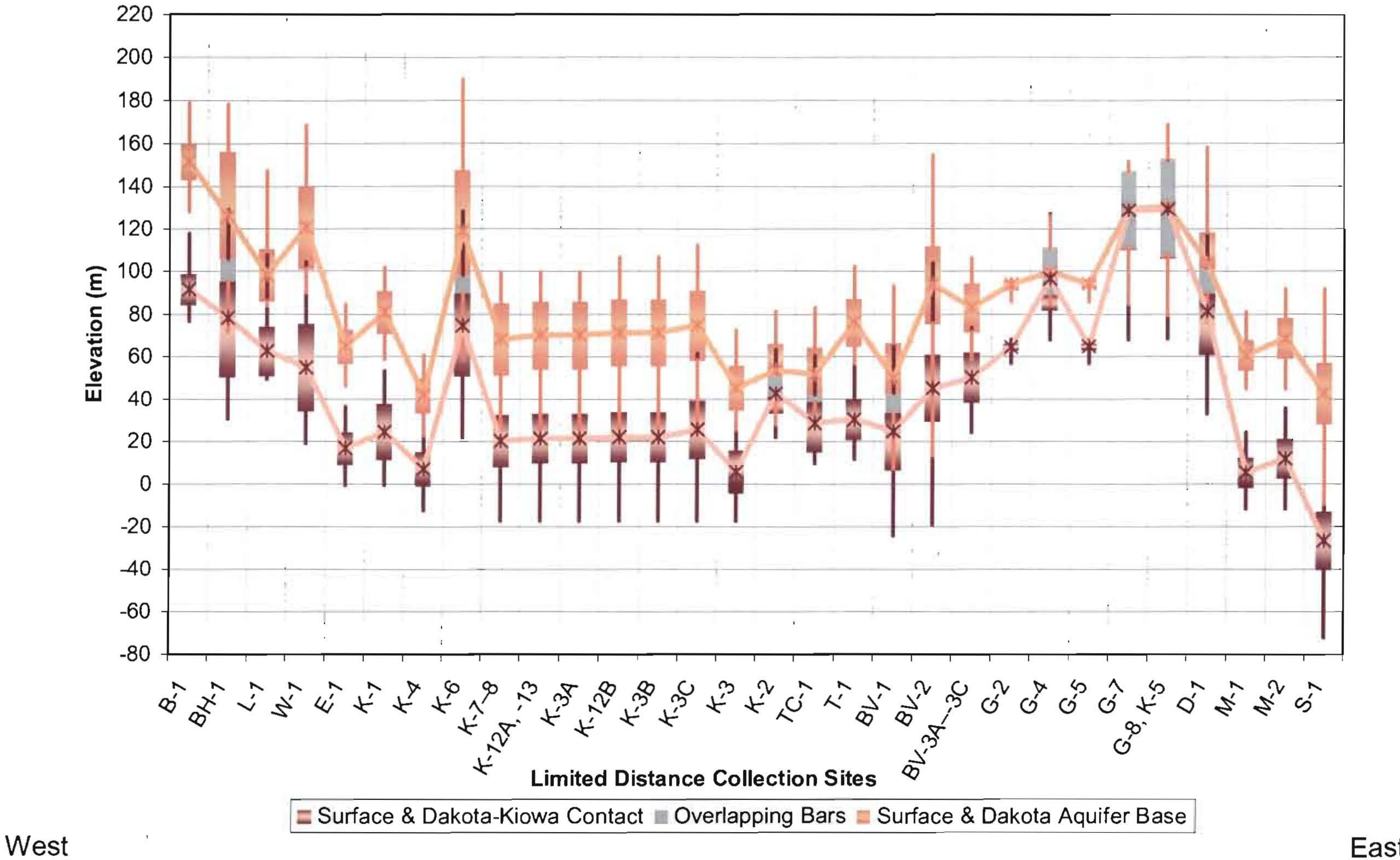


Figure C 27: Comparison of the Estimated Formational Thickness Statistics for Limited Distance Collection Sites. Statistics of the Dakota Aquifer derived Dakota Formation thickness estimate and the Kiowa Formation derived Dakota Formation thickness estimate for the Limited Distance Collection Sites are depicted as a box and whisker plot for comparison.

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Margaret Landis

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