UNDERSTANDING PLAYA DEVELOPMENT THROUGH SHALLOW CORING AND SPATIAL ANALYSIS IN BEAVER COUNTY, OKLAHOMA

By

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
December, 1993

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ACKNOWLEDGMENTS

In completing a work such as this, I have received assistance and support from many people, most notably my mother Barbara and my family (Gene, Pat, Trey, Jennifer, Don, Dana, and Chris) and my in-laws (the Bishops and the Grizzles). A well-deserved "Thank You" is given to my advisor, Dr. Brian Carter, and my committee members, Dr. Douglas Kent, Dr. David Waits, and Dr. Darwin Boardman, for their patience with my endless questions, their input when I had no output, and their overall support (including brain-storming sessions at Willie's). Thanks also go to Mark Gregory and Scott Kreiter, who took an interest in my research and became unofficial committee members. In addition, special thanks go to Danny Thomas and the entire staff at the Soil Conservation Service office in Beaver, Oklahoma for their time and assistance during the review and field work phases of this project.

For their interest, support, assistance, and friendship, many people deserve more than a mere thank you. These include: Dick Shields and his family, Jim Puckette, Forrest Hess, Chris Campbell, Rick Hobbs, Scott Holmstrom, Dr. Jack Vitek (who made sure I got to OSU in the first place), and so many others that I cannot begin to name them all, although I will never forget them.

A special thank you goes to my fiancee Cynthia, who has supported and assisted me from the very beginning, and to our dogs Bois d'Arc and Tiny, who have also lent their support (even though they don't know any better).

Perhaps the biggest thanks, however, should go to Mr. Victor Terbush, Mr. Mike Coldwater, and Mr. David Sell, who opened their land to me in order that the coring could take place. Without these gentlemen and their generosity, this project could have never been completed.

TABLE OF CONTENTS

Chapter Page

SUMMARY..1

1. INTRODUCTION...3

2. GEOLOGIC EVIDENCE REGARDING PLAYA FORMATION............8

2.1 The Role of Playas in Ogallala Aquifer Recharge....................................15

3. PURPOSE OF THE STUDY....................................18

4. METHODOLOGY..20

4.1 Coring Procedures...........................20

5. ANALYSIS AND RESULTS....................................24

5.1 The Relationship Between Soil Type and Playa Location.............................25

6. CORING RESULTS..32

6.1 Gate Playa..................................32

6.2 Turpin Playa................................35

6.3 Elmwood Playa...............................36

7. CONCLUSIONS...43

7.1 Recommendations for Future Research........46

REFERENCES...48

APPENDIX A - CORING RECORDS FOR PLAYAS................52

APPENDIX B - PHYSICAL DATA FOR RANDOM PLAYA SAMPLES...78

LIST OF TABLES

Table Page

1. Results of the F-test................................30

LIST OF FIGURES

Figure Page

1. Location Map of Beaver County..........................4
2. Topographic and Geologic Cross-Sections...............7
3. Hypothetical Playa Cross-Sections....................22
4. Geologic Map of Beaver County with Playa Locations...26
5. Soils Map of Beaver County with Playa Locations......27
6. Map of Playa Coring Locations........................33
7. Topographic Map of the Gate Playa....................34
8. Topographic Map of the Turpin Playa..................37
9. Cross-Section of the Turpin Playa 38
10. Topographic Map of the Elmwood Playa.................39
11. Cross-Section of the Elmwood Playa...................41

Dedication

To Cynthia

whose neverending love and unwavering faith in me means more to me than I can ever hope to show.

Summary

During the past one hundred years, researchers have noted the occurrence of closed surface depressions on the otherwise relatively flat surface of the High Plains in the Oklahoma Panhandle. Commonly referred to as "playas" or "playa lakes", the formation of these depressions has been the subject of numerous theories (scientific and otherwise) since the first work in this area was conducted by GILBERT (1895). Recent investigations on playa formation in Beaver County, Oklahoma indicate that there is a possible direct relationship between the occurrence of these features and particular soil mapping units found in three areas of the county. In order to substantiate this relationship, detailed stratigraphic cross-sections of the sediments and materials underlying playas from each area should be constructed and evaluated. The information required to ensure accurate portrayal of these sediments would be obtained through the use of shallow soil coring techniques. The objectives of this research project are as follows:

1. To obtain detailed information concerning the soils and sediments which underlie the playa basins.

2. To propose the mechanism or mechanisms responsible for the formation and development of playa basins in the Oklahoma Panhandle.

The methods which will be employed include shallow soil and sediment coring using a Giddings Probe (to a depth of 20 to 30 feet), field analysis of the core samples obtained, and the construction of detailed stratigraphic cross-sections of each playa basin. These cross-sections will then be compared to hypothetical cross-sections which are believed to reflect the presence of a particular mechanism for the formation and development of playa basins.

1 Introduction

The surface of the High Plains in Beaver County, Oklahoma (Figure 1) is flat and relatively featureless, although the area between the High Plains and the stream valleys (locally called the "breaks") may have considerable relief due to erosion by the tributaries of the Beaver and Cimarron Rivers. During the past one hundred years, investigators performing research on the High Plains have noted the occurrence of closed surface depressions which may retain water after a rain. Commonly referred to as "playa lakes" or "playas", and locally termed "buffalo wallows", the formation of these depressions has been the subject of controversy over the years. The first widely regarded proposed process of playa formation was developed by early settlers to the Panhandle, who termed these features "buffalo wallows". The popular notion was that the basins were formed by the tramping and wallowing of the great herds of buffalo which once roamed the High Plains (ROTHROCK, 1925). Regardless of the doubtfulness of this idea, many local people still refer to these depressions, no matter the size, as "buffalo wallows".

The earliest scientific discussion of the development of these depressions appears to be by GILBERT (1895) who suggested that deflation was the sole process responsible

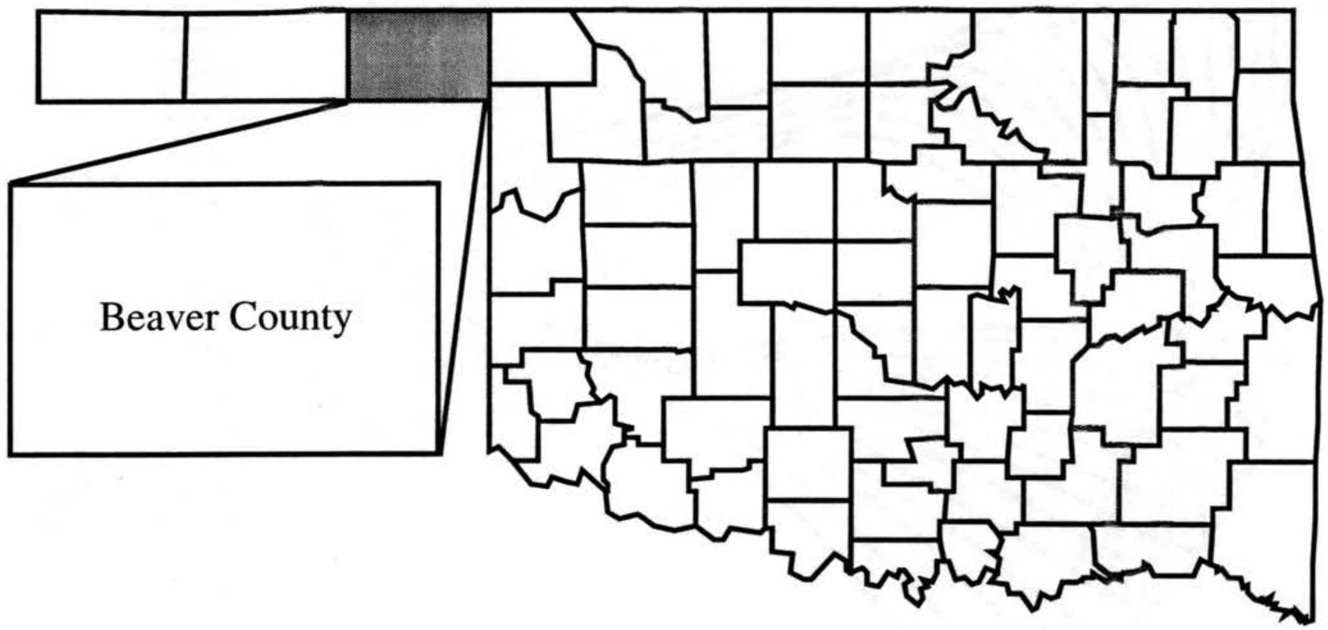


Figure 1. Location Map of Beaver County

for the formation of some of the shallow basins and lakes found on the High Plains. JOHNSON (1901) proposed that there may be more than one possible mechanism for basin development. He believed that shallow depressions were created by the compaction of sediments in the Ogallala Formation (based on the formation of concentric cracks around the rims of some playas since the time that settlers had lived there which suggested a movement of soil and rock material toward the center of the basin) and the dissolution of the caliche caprock. The formation of larger basins, such as Big Basin and St. Jacob's Well, just northeast of Beaver County in Clark County, Kansas, could be attributed to the dissolution of gypsum in the Permian redbeds found near the surface. JOHNSON downplayed the role of deflation in the process of playa development. Later, BAKER (1915) also agreed that the larger basins formed through subsidence over areas of dissolution of Permian evaporites.

EVANS and MEADE (1945) noted the presence of dunes on the leeward side of several playa basins and believed that deflation was a far more effective process than that of dissolution and subsidence and, thus, was the most probable mechanism for playa formation. REEVES (1966) also considered deflation to be the primary formational process involved with most basins, although it was also suggested that some of the larger depressions formed as a result of accelerated erosion at the intersections of fractures and joints related to the Earth's regmatic shear pattern.

LOTSPEICH ET AL (1971) indicated that the formation of certain depressions may be related to the dissolution of the caliche caprock and WOOD ET AL (1992) suggested that playa development is not related to the dissolution of any formations nor solely the work of deflation. They proposed that high watertables found over subsurface topographic highs in certain areas of the High Plains may have prevented the formation of the caliche caprock. After the watertable dropped, the sediments dried and were then eroded by the wind. One final possible source of depressions is the presence of interdunal lakes and basins in areas which are covered by Quaternary eolian materials. Although the sizes of these basins may be small, the interdunal areas which retain water for any length of time may eventually build up layers of organic matter and be able to support vegetation in their floors. These interdunal areas may exhibit the playa-like characteristics of internal drainage, water retention, and growth of hydrophilic plants.

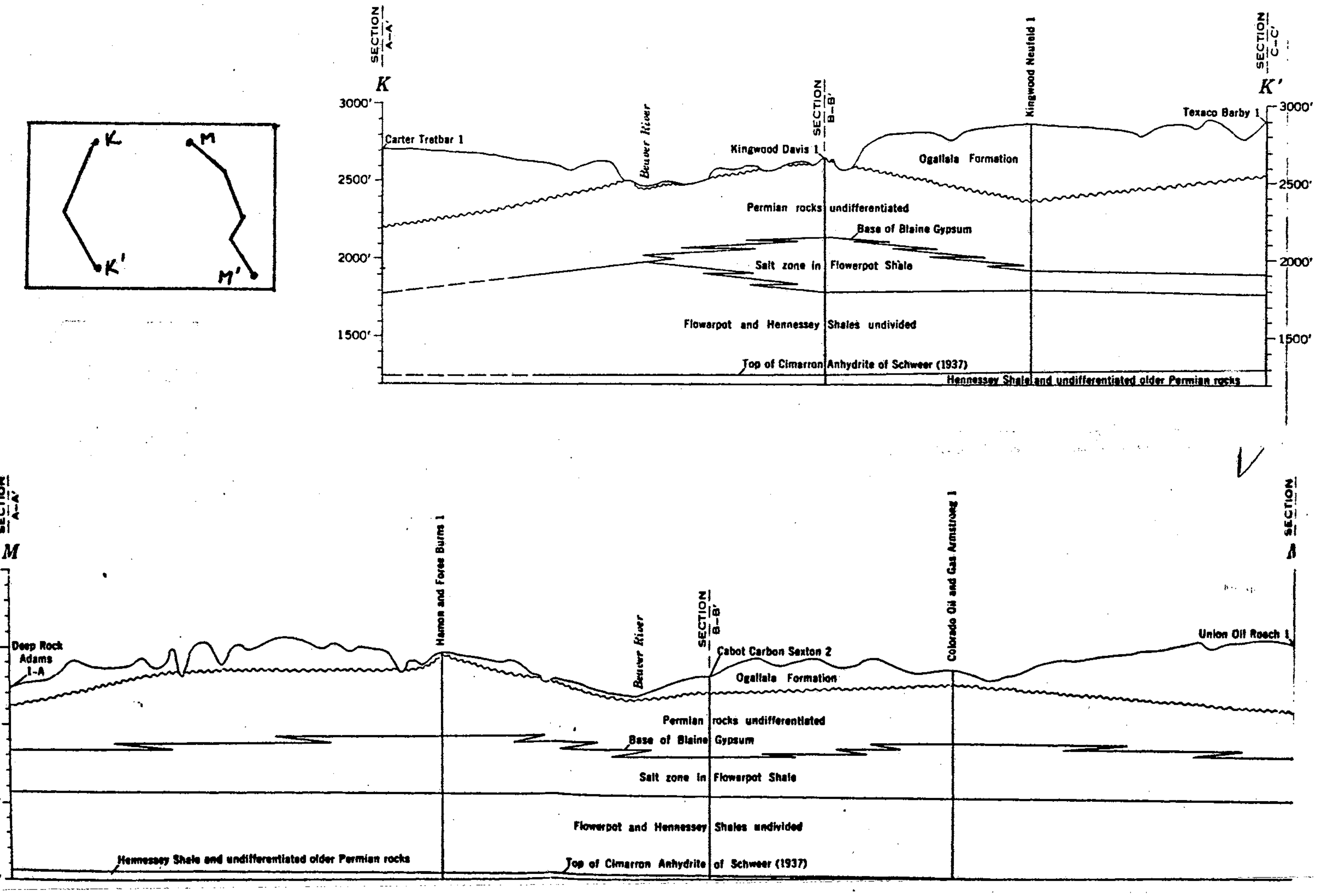


Figure 2. Topographic and Goelogic Cross-Sections of Beaver County (from Morton, 1973)

2 Geologic Evidence Regarding Playa Formation

The notion of the depressions being "buffalo wallows" was dispelled in early investigations of the High Plains. The proposed process involved buffalo milling about in basins that may have contained water with their movement breaking up the sod which, when dry, could blow away. If the buffalo returned during dry periods, the dried mud could be crushed into a fine dust that could easily be removed by the wind. The major objections to this process, expressed in SCHOFF (1939), are that there are far too many basins across the High Plains to have been created by the number of buffalo believed to have lived in the area, if buffalo were at all like domesticated cattle they would not spend time at a dry water hole, and (according to former Cimarron County Agricultural Agent W.E. Baker) the depressions now visible are actually filling with material due to vegetation reducing the amount of wind erosion. GOULD and LONSDALE (1926) state that ". . . there is no connection between the presence of the animals and the origin of the depressions, though such an origin has sometimes been suggested," (GOULD and LONSDALE, 1926). The idea of playa development through the compaction of the sands and gravels of the Ogallala Formation was described by JOHNSON (1901) but little mention of this is found in any other reports. This proposal was based on the observations of a small number of playas which displayed concentric rings of cracks in the soil around their rims and was generalized to include most small basins across the High Plains. The lack of additional research regarding this theory suggests that it met with limited acceptance and is no longer considered a formational mechanism of depressions.

The proposal by WOOD ET AL (1992), in which deflation is presumed to have occurred in certain areas due to high watertable preventing the formation of the caliche caprock, is so recent that no new studies have addressed it. The authors indicate that in these areas of playa development the caliche caprock was never formed, an idea which is in conflict with another proposed mechanism of basin formation, namely the dissolution of the caliche caprock. It has been suggested that many basins which are now visible were in fact formed after the formation of the caliche caprock (GUSTAVSON and FINLEY, 1985). Several studies which focused on the contribution of these playas to the recharge of the Ogallala Aquifer have identified the underlying caliche caprock as a major influence on the drainage (or lack thereof) of the basins. KNOWLES ET AL (1984) observed that caliche layers under depressions have low permeabilities, while WHITE ET AL (1946) found, after drilling hundreds of test holes in playas across parts of the High Plains, that under almost every basin some caliche was encountered but it usually contained sand and other material and was relatively permeable. LOTSPEICH ET AL (1971) proposed that recharge of the Ogallala Aquifer from playas could take place due to the partial dissolution of the caliche caprock. This dissolution could conceivably be reflected at the surface through the formation of depressions. OSTERKAMP and WOOD (1987) state that playa development and enlargement occurs by the dissolution of carbonate groundwater in the unsaturated zone followed by a movement of water and clastic material toward the center of the basin. They also mention that at times depressions form in linear groups, which is believed to be an unlikely product of deflation or meteorites. Based on the amount of research present in which caliche is found under playas, it appears as if the proposal of depressions forming due to an absence of caliche and subsequent deflation is not valid. They believe the evidence for carbonate dissolution beneath playas is extensive, whereas the well-indurated caprock is generally solid beneath the inter-playa areas (OSTERKAMP and WOOD, 1987), and it seems that the dissolution of the caliche caprock is a legitimate theory of basin development.

The process of deflation, first mentioned by GILBERT (1895) as a playa forming factor was studied by others in later years, most notably EVANS and MEADE (1945). They noted many depressions which contained dunes on their leeward sides and concluded that deflation was far more effective of a playa development agent than dissolution and subsidence. GUSTAVTON and SIMPKINS (1989) agree, believing that the full extent of most basins cannot be attributed solely to dissolution and subsidence. The Blackwater Draw Formation, a Quaternary eolian sand and silt deposit overlying the Ogallala Formation in parts of the Central and Southern High Plains, was formed from material eroded and carried by wind from the Pecos River and Canadian River valleys (GUSTAVSON and FINLEY, 1985). This suggests that deflation is a very powerful geomorphic agent on the High Plains. OSTERKAMP and WOOD (1987) agree that the wind has played a role in the formation of the playas, but believe that the formation of those basins which are not aligned with the regional fracture pattern (which would suggest a dissolution origin) were initiated by water ponding in low areas on the uneven surfaces of eolian deposition. The possible initiation of depressions through the accumulation of lacustrine deposits in these lower areas found on sandy and silty eolian deposits may be occurring at present south of Tahoka, Texas (OSTERKAMP and WOOD, 1987). The importance of the type of surficial material was noted by LOTSPEICH ET AL (1971) when they observed that fewer larger depressions are found in finer-textured deposits while more numerous, smaller basins are found in coarser materials.

Perhaps the most widely studied playa formation process, however, is that of the dissolution of the subsurface Permian evaporite layers. This mechanism is often referred to as "interstratal karst", with a layer of soluble rocks (halite in the salt zone of the Flowerpot

Shale) undergoing dissolution beneath a layer of younger, non-karstic rocks (JOHNSON, 1989). In order for this process to operate, JOHNSON (1981) notes that four requirements must be met. These are: 1) a deposit of halite; 2) a supply of water undersaturated with respect to NaCl; 3) an outlet for the removal of the resultant brine, and; 4) energy to drive the water through the system. Fresh water flows downward from the Ogallala Aquifer through joints and dissolutionally enlarged fractures or cavities in the impermeable Permian redbeds underlying the Ogallala Formation, with the brine produced being discharged downgradient at salt springs or salt pans. SIMPKINS and FOGG (1982) developed a numerical model which confirmed the presence of this cycle under parts of the High Plains. In the Central High Plains the Ogallala Formation rests unconformably upon several thousand feet of Permian evaporites which were deposited on the western flank of the Anadarko Basin. The Ogallala Formation and the Permian strata which overlie the Flowerpot salt zone are structurally disrupted and complex, whereas the units underlying the Flowerpot Shale, such as the Cimarron Anhydrite, are essentially horizontal with none of the chaotic structure found in the formations above (JORDAN and VOSBURG, 1963). It is believed that the Cimarron Anhydrite reflects the original structure of the Permian strata prior to the dissolution of the salt zone in the Flowerpot Shale (JOHNSON, 1989).

In Beaver County and the areas immediately adjacent to it, dissolution is a process which has had an obvious effect on the local geomorphology. In Clark County, Kansas, located just northeast of Beaver County, lies Big Basin and St. Jacobs Well, perhaps the best known and most accessible of Kansas depressions. Big Basin is about one mile in diameter and around 100 feet deep, and is believed to have formed from the coalescence of several smaller depressions (similar to a uvala of a carbonate karst terrain). Although the exact age of this feature has not been determined, it is believed to be only a few thousand years old and is thought to have formed as a result of the dissolution and collapse of near-surface Permian evaporite layers (SHUMARD, 1968). Another well known feature, the Meade Salt Well, is located just west of Big Basin in Meade County, Kansas. Formed in 1879 through a rapid episode of collapse, it quickly filled with a hot brine liquid (159 degrees Fahrenheit) and was used for several years as a local source of salt (SMITH, 1940). In addition, the Cimarron River is believed to have developed its channel through a series of depressions (presumably similar to Big Basin) during the Illinoian or Wisconsin time (MEYERS, 1959). It is also believed that dissolution of the Flowerpot salt zone may have contributed to the formation of the Crooked Creek Fault, which runs from Meade County, Kansas across the northwest corner of Beaver County. Salt dissolution during the deposition of the Ogallala Formation during the Tertiary may have resulted in a structural escarpment on or near the present salt dissolution zone (GUSTAVSON ET AL, 1980). The structurally depressed area to the northwest of this fault in the county has been created from the removal of the Flowerpot salt zone, and contains the thickest (and perhaps oldest) Ogallala Formation sediments. To the southeast, the Flowerpot salt zone is generally present and the Ogallala Formation is considerably thicker. In Meade County, Kansas, only 30 feet of the Rexroad Formation (an eolian deposit overlying the Ogallala Formation) is exposed on the east side of the Crooked Creek Fault while almost 250 feet is exposed on the west (ZAKRZEWSKI, 1988). This fault is not expressed in the Cimarron Anhydrite and thus appears to be directly related to the process of dissolution of the salt zone in the Flowerpot Shale and may serve as a conduit for fresh water from the Ogallala Aquifer to penetrate to the Flowerpot salt zone and continue the process of dissolution.

GUSTAVSON ET AL (1980) suggests that no single explanation is available, nor sufficient, to completely explain the mechanism behind the formation of all depressions on the High Plains. If the observation mentioned earlier of the playas in Texas County are believed to be filling up with material is correct, then there may be other processes at work which have not yet been considered. Indeed, what may actually be the case is a combination of some, or all, of the proposed formation processes acting together to produce a dynamic landscape.

2.1 The Role of Playa Basins in Ogallala Recharge

In a carbonate karst terrain, sinkholes act as natural funnels, collecting water from a catchment area and allowing whatever is put into them to directly enter the subsurface through open conduit flow. In much the same way, runoff on the High Plains is often collected and retained in closed depressions. The role of playas in the recharge of the Ogallala Aquifer is disagreed on by investigators, and so is the role of these features on local water quality.

When water enters and is retained in a playa, there are two possible routes for the water to exit, with the first being evaporation. Many basins have clay soils in their floors (the Randall clay in Beaver County) which will cause them to have low permeabilities. Because the water cannot infiltrate, it evaporates instead and all materials contained in the water are left behind in the basin floor. Evaporation rates in some parts of the High Plains has been estimated to range from 55 to 60 percent of the available water (NATIV, 1988). Other investigators suggest that the playas are a major source of recharge to the Ogallala Aquifer. Direct observation of several large basins in Beaver County showed large desiccation cracks in the clay floors, which could act to direct water into the subsurface. Studies focusing on the caliche layers under depressions have found sand present in some areas, increasing the permeability of the caliche (WHITE ET AL, 1946) and the presence of dissolutionally enlarged joints in other areas (LOTSPEICH ET AL, 1971). There is also a lack of evaporites and hallophytic flora present in the floors of the playas, indicating that there is no salt accumulation through evaporation but instead that the depressions drain rather quickly (NATIV, 1988).

The most extensive study conducted on the effect of playa recharge was by NATIV (1988). In this report, recharge rates were determined by using daily rainfall samples collected over the span of one year at five different locations across the Southern High Plains. In addition, samples of groundwater and of playa lake water were also obtained. The isotropic compositions of precipitation and groundwater were found to be almost identical, indicating that the amount of water which evaporates from basins prior to infiltration is minimal. This observation is based on the assumption that as more water in the basins evaporates than infiltrates, playa lake water and groundwater would become more saline and isotopically enriched, whereas if the recharge from the basins is so rapid that little of the water evaporates then the water in the playas and the groundwater should be isotopically constant and remain similar to the composition of local precipitation. Tritium values of all samples (rainwater, groundwater, and playa lake water) were also obtained and found to be higher in groundwater from areas in which the unsaturated zone of the Ogallala Aquifer was thinner. This suggests that the aquifer may be recharged very rapidly from discrete sources (such as playa lakes). Tritium values in areas where the unsaturated zone is much thicker were essentially zero. Based on the high recharge rates (calculated from the tritium data) and the isotopic values of the groundwater, which is lower than those values found in areas of diffuse recharge, it was concluded that the most likely method of recharge to the Ogallala Aquifer was through the discrete recharge of playa lakes (NATIV, 1988).

Although the role of playas in the recharge of the Ogallala Aquifer is not entirely certain, evidence suggests that the biggest threats to groundwater quality come from dissolved solids from evaporites below and not from contaminants introduced through playas. Due to the volumes of water pumped from the Ogallala Aquifer for irrigation and domestic purposes, the hydraulic gradient in some areas has been reversed. This lowering of the Ogallala Aquifer potentiometric surface below that of the underlying Permian redbeds may cause water high in dissolved solids, including chlorides and sulfates, to be drawn upward into the Ogallala Aquifer. In future years this situation may become a major water quality factor across the entire High Plains region.

3 Purpose

Playa basins are common surficial features which are found in certain areas of Beaver County. Their presence appears to be concentrated in three regions of the county -- near the towns of Gate (in the northeast portion of the county) and Elmwood (in south-central Beaver County), and in the northwest corner of the county between the towns of Forgan and Turpin. The hydrogeology and groundwater resources of Beaver County have been studied in detail by previous workers, focusing mainly on the Ogallala Formation, an important local and regional aquifer. Additional studies have investigated the surficial and subsurface geology of the county and volcanic ash deposits located in the area. The depressions, however, have been given little attention in any of these reports.

This study will focus on the relationship between the location of the depressions and the physical factors of geologic materials and soil type. By evaluating these relationships through statistical means and through field research, a better understanding of possible mechanisms for the formation of the depressions will be gained.

Specifically, this study will attempt to support the following hypotheses:

1. The depressions are clustered in certain areas of Beaver County and are absent from others.

2. Each cluster will differ from the others according to the mean lengths, mean widths, and mean elongation ratios of the member depressions.

3. The stratigraphic cross-sections of playas from each of the three areas will differ from each other.

4. These differences between the playas in each cluster will reflect the influence of the physical factors in each area.

4 Methodology

Fifteen hundred sixty nine depressions were identified in Beaver County through the analysis of the United States Geological Survey 7.5 minute topographic quadrangle map series for the county and through the utilization of the results of a recent countywide Soil Conservation Service Wetlands Inventory. The locations of these depressions, along with geologic and soil maps, were digitized and entered into the GRASS 4.0 GIS program.

The degree of clustering of the depressions will be determined through the use of a quadrat analysis statistical procedure, and the differences in the means and variances of the lengths, widths, and elongation ratios of a random sample of depressions from each cluster will be determined using the statistical F-test and t-test. Finally, chi-square analyses will be used to determine the significance of the relationships between the depression locations and the physical factors of surficial geologic materials and soil type.

4.1 Coring Procedures

This project will involve the use of shallow coring techniques to better understand the manner in which playa basins form and develop on the High Plains of the Oklahoma

Panhandle. It is believed that, to this time, that no detailed investigations of playa basins in the Oklahoma Panhandle have taken place and also that the proposed uses of the coring and stratigraphic techniques have not been employed in any similar studies in the High Plains. A soil coring device known as a Giddings Probe, which has an average coring range of between 20 and 30 feet will be used to obtain a sample of the sediments and materials underlying selected playas. This procedure would involve the drilling of cores on transects through three playa basins (one randomly chosen from each area) and analyzing the sediments found on their rims, side slopes, and floors. Following the completion of the coring operations, detailed cross-sections of each playa basin will be created using the data obtained from the field procedures and compared with hypothetical cross-sections which reflect the belief that the action of each possible playa forming process will result in a distinct arrangement of sediment layers underneath the playas.

There are at least three different possibilities of coring results, each of which may indicate the influence of a particular formation mechanism on playa development in that area. These possibilities are illustrated in Figures 3a, 3b, and 3c, and briefly described below:

1) Playa basins form <u>before</u> the deposition of the Ogallala Formation and overlying eolian layers.

The layers of material will be thinner on the edges than in

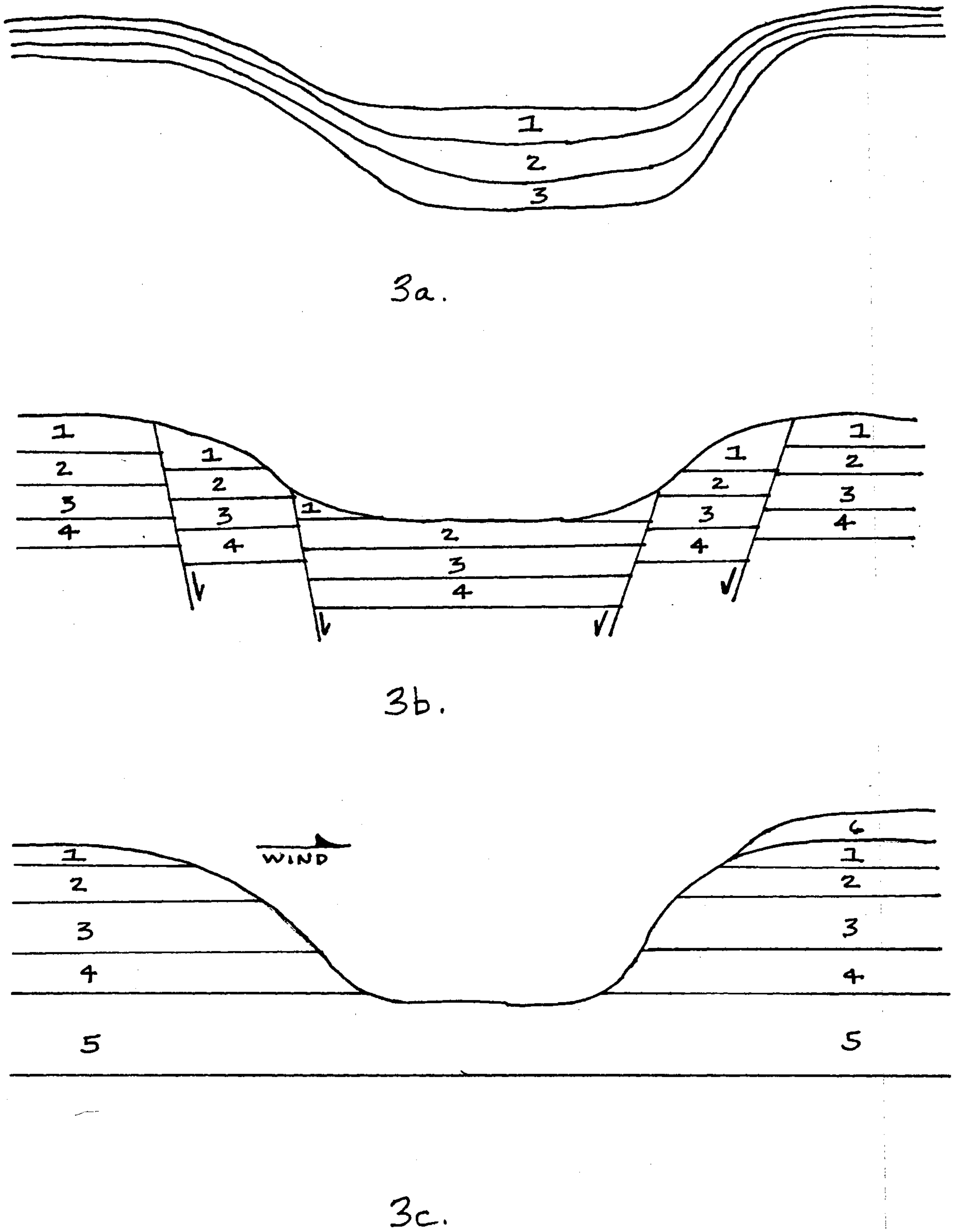


Figure 3. Hypothetical Playa Cross-Sections

the center of the playa, and more layers may be present in the floor than on the rim due to a greater accumulation of sediments in the basin.

2) Playa basins form <u>after</u> the deposition of the Ogallala Formation and overlying eolian layers.

The layers of material will be of equal thicknesses (generally) throughout the playa and onto the rims. Along the side slopes of the basin, truncations may be present where the material has subsided into the basin.

3) Playa basins form or develop as a result of deflation.

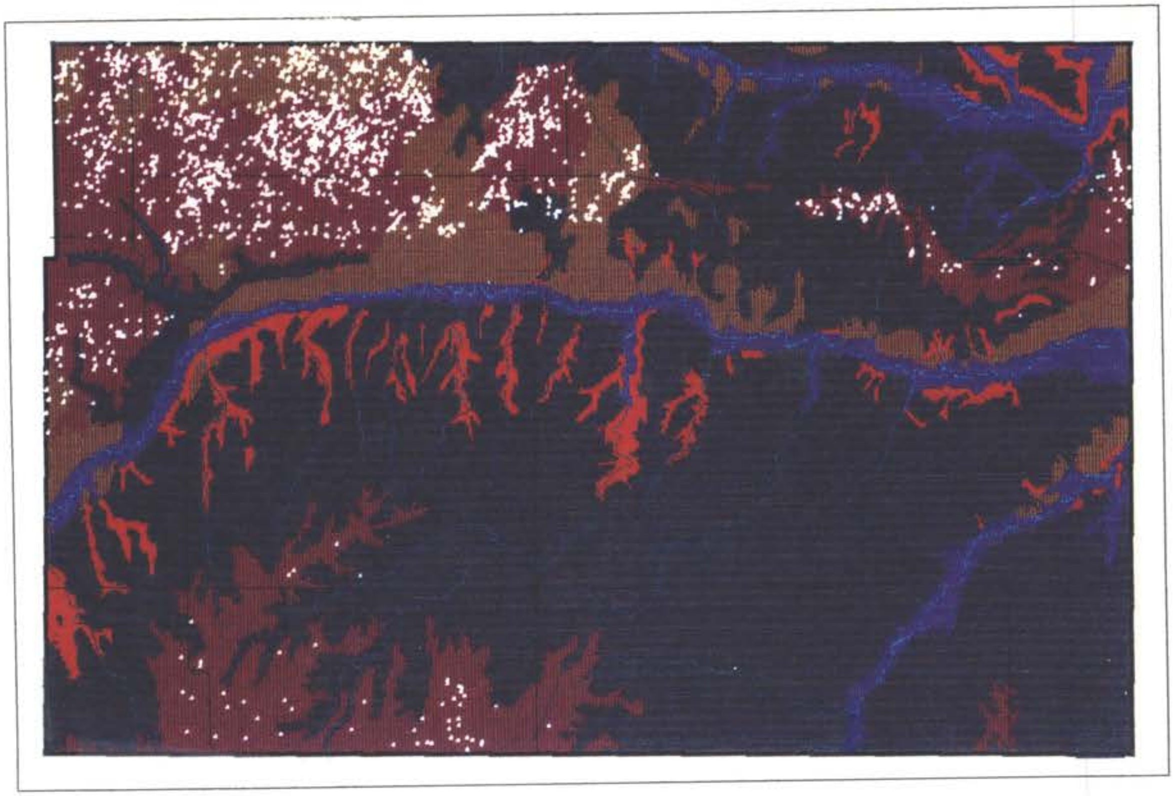
The layers which are found on the sides of the basin may be absent from the floor due to removal and subsequent deposition on the leeward side of the basin by the wind (creating layers on the leeward side which are not present on the windward side).

5 Analysis and Results

During the research phase of this study, 1569 playas were identified in Beaver County through the utilization of US Geological Survey 7.5 Minute Topographic Quadrangle coverage and the recently completed Soil Conservation Service Wetlands Inventory. A statistical method known as a scattered quadrat analysis was used to determine whether the playa basins were arranged randomly or if they are instead found in clusters. This method, discussed in detail in BOOTS and GETIS (1988), involves the counting of points within discrete sampling areas of any consistent shape and size located throughout the region being studied. The results are reported as a chi-square statistic, and whether the pattern under investigation is regular or clustered is determined using a variance to mean ratio (VMR). In Beaver County, the chi-square value of the quadrat analysis was calculated to be $X^2_{calc} = 27.55$. Using a significance level of .05, the critical value for a similar chi-square distribution is $X^2_{crit} = 5.99$, which falls far below the calculated value. This indicates that the pattern of playas in the county is not random. The VMR results gave values of 17.78 for the variance of the number of points per quadrat and 2.22 for the mean number of expected points per quadrat. Because the measured variance is larger than the expected mean suggests that the pattern is clustered. Analysis of the map of playa locations indicates that these clusters are located in the northeast corner (near the town of Gate), the northwest corner (between the towns of Forgan and Turpin), and in the south-central region (near the town of Elmwood) of Beaver County.

5.1 The Relationship Between Soil and Geologic Materials and Playa Location

In order to evaluate the possible factors which could lead to the formation and development of the playas, two chi-square statistical analyses were performed which related the playa locations to the physical factors of surficial geological materials (Figure 4) and soil type (Figure 5). The chi-square is a statistical value which measures the difference between the observed frequencies of a set of data and the frequencies that would theoretically be expected to be found (AMBROSE and AMBROSE, 1978). The first test determined whether the distribution of playas was related to the surficial materials present. Of the 1569 playas, 1129 (72%) were found in the Windblown Cover Sand/Silt surficial deposits, 407 (26%) formed in the Windblown Sand/Sand Dune deposits, and 33 (2%) were located in the Ogallala Formation. For this distribution, the X^2_{calc}= 3565.9, with the critical value of rejection being X^2_{crit}= 79.1 at the .05 significance level. The null hypothesis is rejected and the distribution of playas is presumed to be directly



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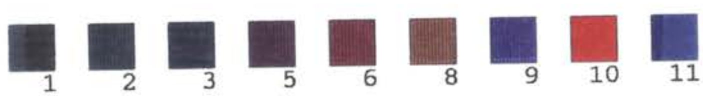

1 Kda (Dakota Group)
2 Tol (Laverne Member)
3 To (Ogallala Formation)
5 Qo (Odee Formation)
6 Qcs (Windblown cover sand)

8 Qs/Qsd (Windblown sand/sand dunes)
9 Qal (Alluvium)
10 Pu (Permian Undifferentiated -- "Blaine Formation")
11 Qt (Fluviatile terrace deposits)

Figure 4. Geologic Map of Beaver County with Playa Locations

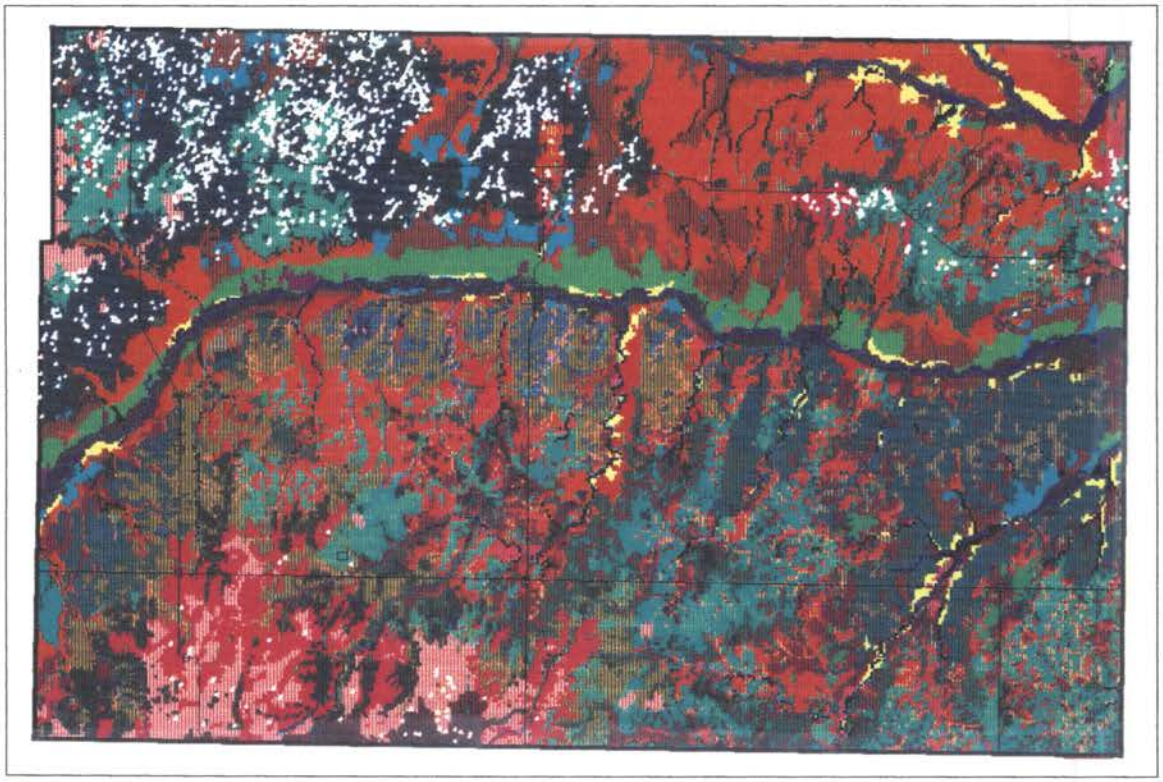

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Figure 5. Soils Map of Beaver County with Playa Locations

related to the type of geologic materials present at the surface.

The second chi-square test was used to determine whether the distribution of playas in the county was related to the soil type present. Eleven hundred seventy three playas (75%) in the county were found in soils which were sandy, most notably the Dalhart and Pratt Series, both of which have predominantly fine sandy loam textures, while 396 (25%) formed in soils which had silt loam or clayey textures such as the Richfield Series and the Ulysses-Richfield Complex. The calculated chi-square value was $X^2_{calc} = 6805.1$, while the rejection value was $X^2_{crit} = 79.1$ with a significance level of .05. Again, the null hypothesis is rejected and there is believed to be a strong relationship between soil type and playa location.

The coarse textured soils (Dalhart and Pratt) are found in the northwest corner of the county between Forgan and Turpin and the soils with fine textures are located in the northeast and south-central areas. These regions correspond with the geologic materials present at the surface. The Windblown Sands/Sand Dunes areas, which are predominantly fine to coarse grained sands that have been moved by southerly winds from the bed of the Beaver River and deposited as dunes north of and adjacent to the stream which evolve into smoother sheets of sandy materials further north toward the Kansas border. In the south-central area of the county, the surficial materials (Windblown Cover Silt) are fine grained sands to mostly silts and clays which are the finer textured components of eolian materials which were eroded from the bed of the Canadian River in the Texas Panhandle to be transported and deposited by the prevailing southerly winds. The area near Gate in the northeastern corner of the county also has finer grained surficial geological materials, but the origin of these sediments is ancient Cimarron River terraces.

Through the analysis of topographic maps and verification by field checking, there is a relationship between the texture of the surface materials in an area and the size and number of playas. The area near Turpin, which is underlain by sand, has the largest number (1422)and greatest density (9.1 per square mile), yet they are relatively small (a few acres) in size. The playas located near Elmwood are underlain by silts, and are less numerous (52) and less dense (2 per square mile) than the Turpin area. The Elmwood playas appear to be larger than those at Turpin. In the northeast corner of the county near Gate, the playas there also seem larger, less numerous (95), and less dense (3.5 per square mile) than those in the Turpin area. To substantiate these differences in size, random samples of 35 playas were taken from each of the three cluster areas and measured for length, width, and elongation ratio (length divided by width).

The relationships between the samples from each cluster were evaluated using the F-test statistical method. This

Table 1

Results of the F-Test

Areas	Factor	F Calc.	F Crit.	Result
Turpin and Elmwood	length	63.92	1.84	Null is Rejected
	width	86.87	1.84	Null is Rejected
	elong.ratio	3.03	1.84	Null is Rejected
	orientation	2.9	1.84	Null is Rejected
Turpin and Gate	length	88.28	1.84	Null is Rejected
	width	62.1	1.84	Null is Rejected
	elong.ratio	2.37	1.84	Null is Rejected
	orientation	1.79	1.84	Null is Rejected
Elmwood and Gate	length	1.38	1.84	Null is not Rejected
	width	1.4	1.84	Null is not Rejected
	elong.ratio	1.28	1.84	Null is not Rejected
	orientation	1.62	1.84	Null is not Rejected

test measures the difference between the variances of the samples being compared, with the null hypothesis stating that the variances are not significantly different between the two groups (AMBROSE and AMBROSE, 1978). The variances of the sample of playas at Turpin differ significantly in length, width, and elongation ratio from those at both Gate and Elmwood (Table 1). This difference supports the observation that smaller playas develop in areas which have coarse grained material at the surface while larger playas are found in regions which are underlain by fine materials. This observation can also be directly related to soil types, with smaller and more abundant playas located in areas with sandy soils (such as the Dalhart Series) and locations with soils having a texture of silt or clay (similar to the Richfield Series or the Ulysses-Richfield Complex) having larger, fewer playas developing.

6 Coring Results

During the spring of 1993, three playa basins were selected as coring sites in Beaver County. Because the playas are clustered in three areas in the county, one playa from each area was randomly chosen, then evaluated by landowner cooperation, drainage ability, and accessibility (Figure 6). By taking cores from the uplands, side slopes, and floors of the playas, possible changes from one side of the playa to the other could be illustrated in cross-sections.

6.1 Gate Playa

The first playa to be cored was near the town of Gate in the northeast corner of the county (Figure 7). The hypothesis is that the cross-section of the sediments would resemble that of Figure 3b (the playa formed after the deposition of all materials). The cross-section of the core samples shows a complex sequence of materials which, with the exception of the uppermost layers, do not correlate from one location to the next. In the floor of the playa, the soils were clayey and the soil profiles lacked a B horizon. On the sides, however, clays are uncommon and the soils have a weakly developed B (Bw) horizon. The soil horizons below the B are untraceable from one core to another, and discontinuities appear to be present between the core locations. These discontinuities are indicators of the downward movement of

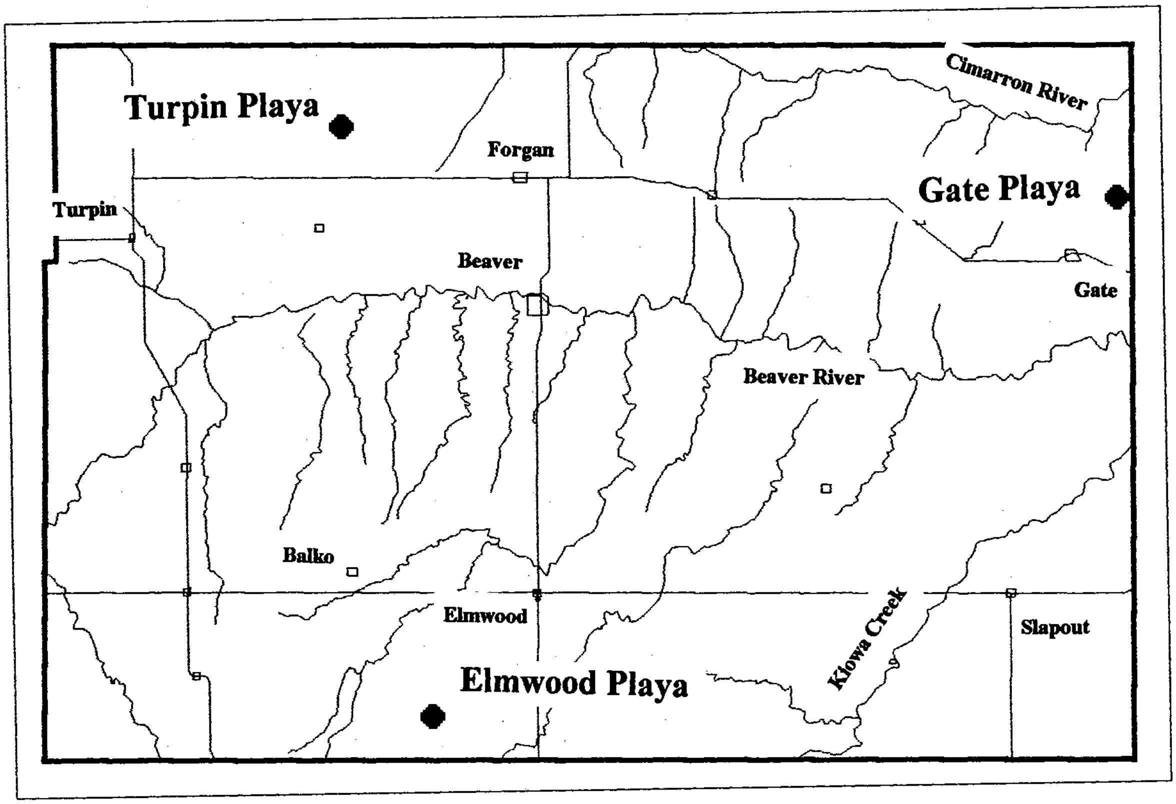

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Figure 6. Map of Cored Playa Locations

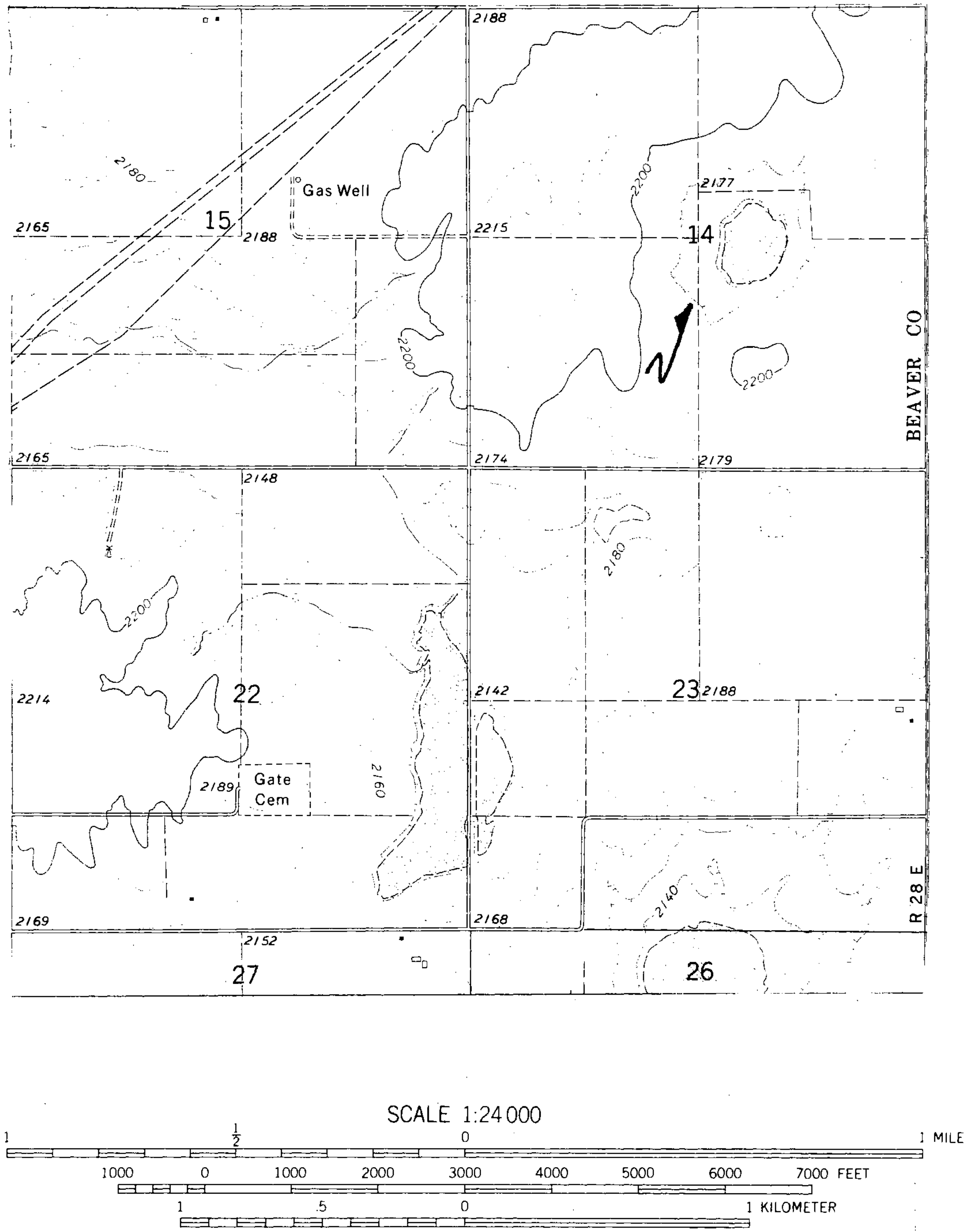

Figure 7. Topographic Map of the Gate Playa

soils and surficial materials. The playa formed rapidly enough (geologically speaking) so that soil development could not keep pace. The apparant lack of discontinuities in the upper A and B horizons indicates that the growth of the playa slowed dramatically or ceased altogether, allowing soil development to take place under similar conditions across the entire basin.

The rapid downward movement of materials which is reflected in the cross-section is believed to be caused by the dissolution and collapse of Permian evaporites which underlie the playa very close to the surface. This formation mechanism is believed to be responsible for the formation of Big Basin and St. Jacob's Well, two large collapse sinkhole features located several miles northeast of this playa in Clark County, Kansas (SHUMARD, 1968). The process of dissolution and collapse is also believed to have occurred just north of the Gate Playa on a wide-spread basis during the Illinoian and Wisconsin epochs. This episode of basin formation led to the development of the present channel of the Cimarron River (MEYERS,1959).

6.2 Turpin Playa

The Turpin Playa is located approximately two miles north of the town of Floris (between Forgan and Turpin) in the northwestern part of Beaver County. The hypothesis is that the cross-section of the sediments would resemble Figure 3c, which suggested that the playa basin formed as the result of wind deflation removing materials from the basin. The cross-section constructed as a result of the coring procedures (Figure 9) indicates that the wind has played an important role in the development of this playa. This playa appears to have formed and developed through a series of erosional truncations and subsequent depositions of younger materials. Cycles of erosion and deposition within the Turpin Playa are a direct effect of the action of the prevailing winds.

The oldest horizons obtained in the core samples in the Turpin Playa were buried soils which contained large amounts of carbonates. These horizons were identified in all cores and extend continuously beneath the entire length of the playa. The top of this layer is characterized by an abrupt change of material which contains no carbonates. Thus, the upper layers of the original soil profile, of which the buried carbonate layer was a part, was eroded and removed by deflation. Erosion continued to remove the A and B horizons, producing a flat, truncated surface. After the completion of this erosional stage, new material was brought into the area by the wind, as evidenced by these layers having dune-shaped bedding.

6.3 Elmwood Playa

The Elmwood Playa is located southwest of the town of Elmwood in the south-central Beaver County (Figure 10).

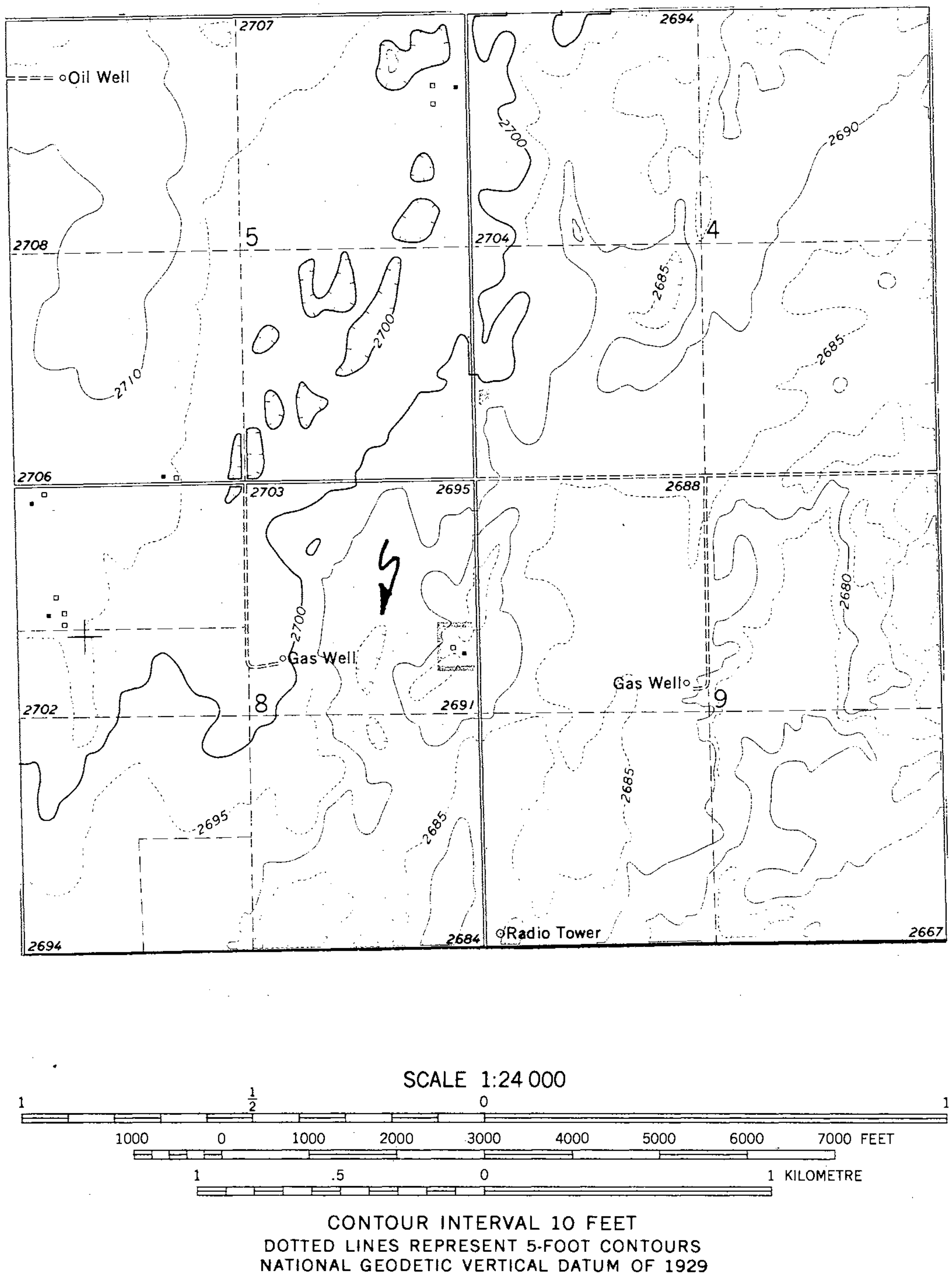

Figure 8. Topographic Map of the Turpin Playa

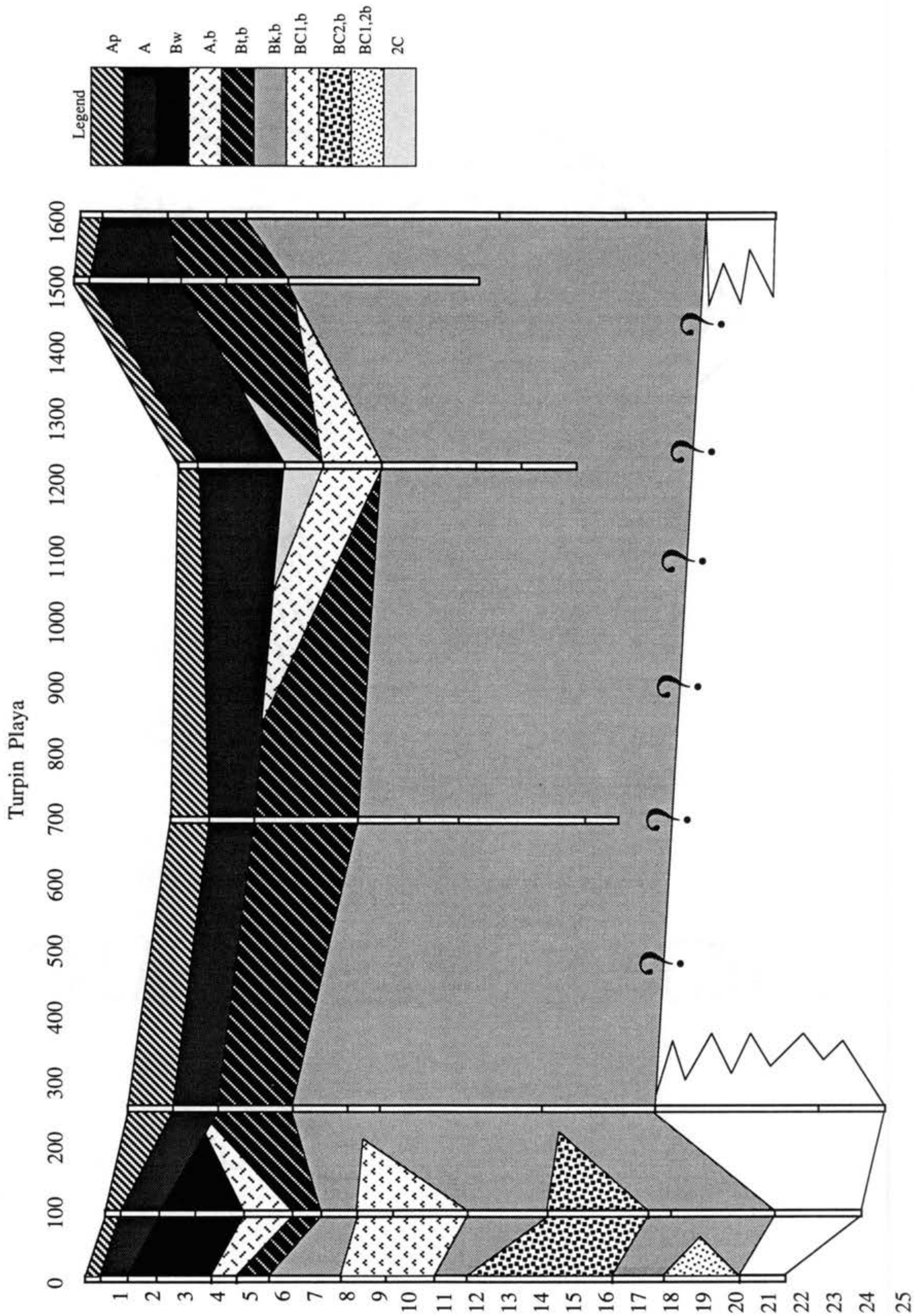

Figure 9. Cross-Section of the Turpin Playa

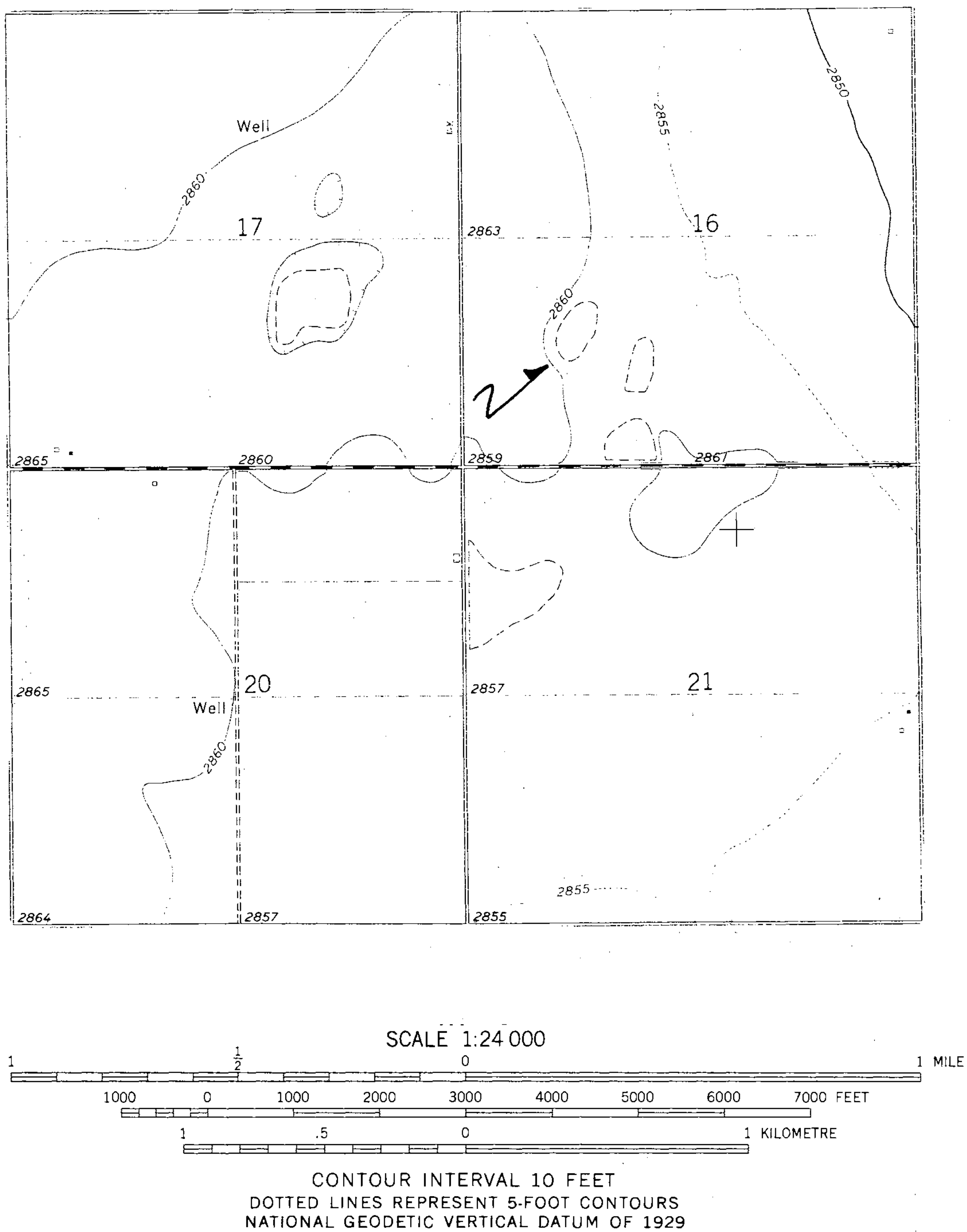

Figure 10. Topographic Map of the Elmwood Playa

This playa was believed to have formed after the deposition of the Ogallala Formation but before any overlying eolian layers (similar to Figure 3a), which would result in a thickening of materials in the floor of the basin as compared to the outer edges (Figure 11).

The oldest (deepest) soil materials present in the cores are a series of red, calcareous buried B horizons. The amount of soil carbonates (as caliche) in this layer was enough to stop the penetration of the coring rig at some points. The calcareous layers are not horizontal. The surface of these calcareous soil horizons forms a bowl-shaped depression when portrayed on the cross-sections. In the deepest area of this buried basin, which is located between Sites Three and Six, is a buried clay layer. This clay layer is similar in texture and other characteristics to the Randall Clay soil mapping unit which is found in the floor of many present-day playas across the High Plains. A major boundary occurs at the top of the buried layers, with the color of the sediments changing abruptly from red to black. Overlying these black calcareous B layers is the A horizon, which exhibits a greater thickness in the center of the playa than is found toward the edges.

The presence of the buried clay layer, along with the depressed cross-section of the deepest buried calcareous sediments, indicates the presence of a buried playa at this location. Because the coring rig could not core below the buried clay layers, the process which formed the paleoplaya

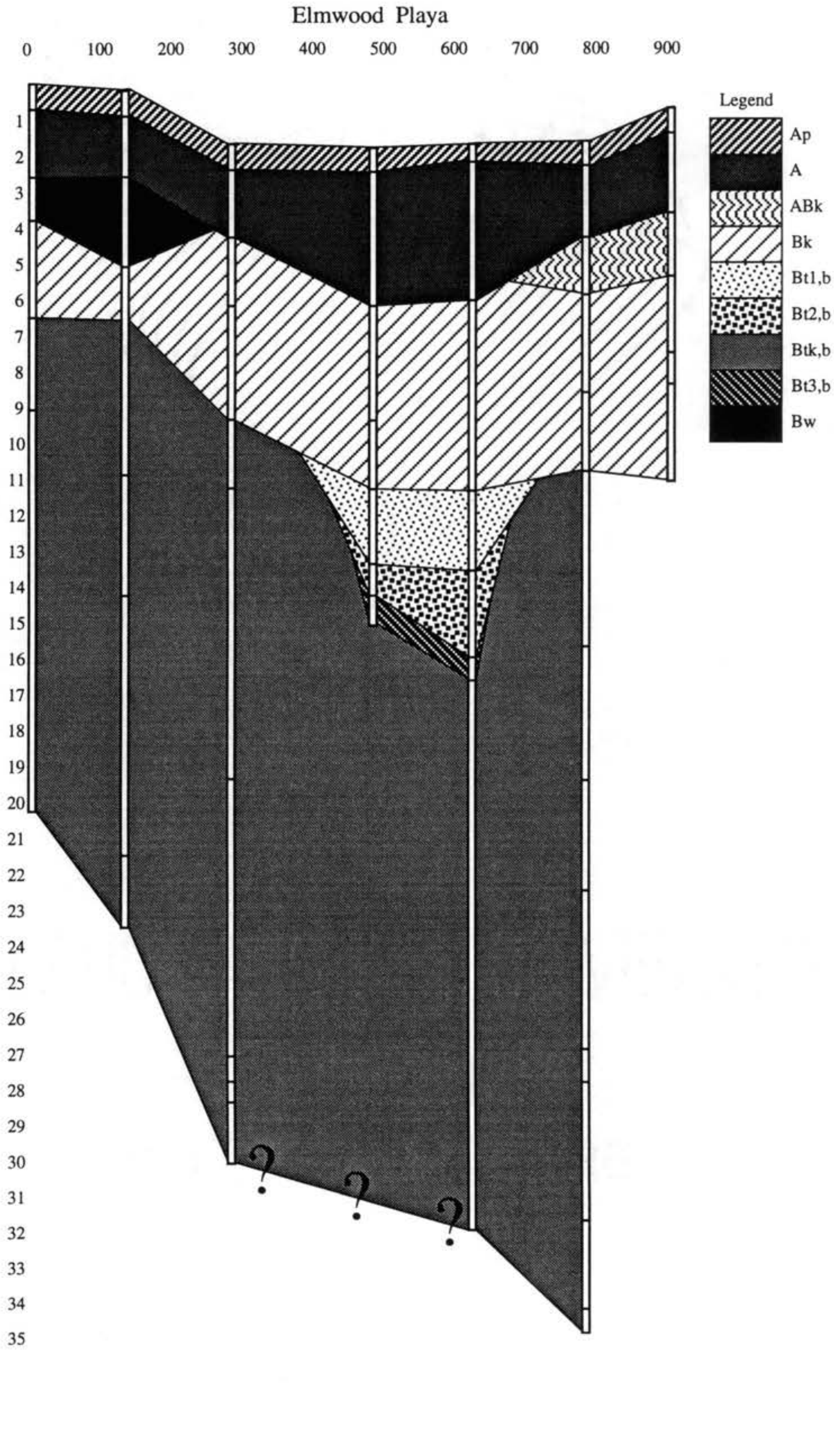

Figure 11. Cross-section of the Elmwood Playa

7 Conclusions

Although previous studies have investigated the presence and formation of playas in other regions of the High Plains, no detailed studies have been undertaken in the Oklahoma Panhandle. Four hypotheses to explain playa development in the Oklahoma Panhandle were presented, each being investigated through the use of statistical techniques and field research. The final conclusions follow:

1. The playas are clustered in certain areas of Beaver County and not in others.

One thousand five hundred sixty nine playa basins were identified in the county through the analysis of the topographic quadrangle coverage of the area and through the use of the recent Soil Conservation Service Wetlands Inventory. When mapped, these playas appeared to be distributed in clusters rather than evenly across the county. By using the statistical method of scattered quadrat analysis the distribution of playas is not random, but instead the basins are clustered in three areas -- near Gate in the northeast corner, near Elmwood in the south-central area, and between the towns of Turpin and Forgan in the northwestern region of Beaver County. Chi-square statistical tests also indicated that playa location and both geologic surficial materials and soil mapping units are significantly related.

2. Each cluster differs from the others according to the mean lengths, mean widths, and mean elongation ratios of the member playas.

Through the use of the F-test statistical method, there was a significant difference in these measured parameters between the playas near Turpin and the ones near Gate and Elmwood.

3. The soil stratigraphic cross-sections of playas from each of the three areas are different from each other.

The Turpin Playa and Elmwood Playa generally resemble each other because soil horizons are generally traceable from one core site to the next adjacent one, yet differ greatly in their arrangement. The Gate Playa, however, has layers which, for the exception of the uppermost A and B horizons, are untraceable from site to site. Instead, the horizons were discontinuous, with most layers only being found in one or two cores.

4. Differences between the playas in each cluster reflects the influence of the physical factors of surficial geologic and soil material present in each area.

By combining the results of the first two hypotheses, there is a relationship between playa location and size and the type of surficial materials present in an area. In regions where coarser grained materials are found at the surface, playas are generally smaller and more numerous. In contrast, there are fewer, larger, playas in areas which are underlain by materials with finer textures. This is a very important relationship, and should influence future playa studies in the Oklahoma Panhandle.

The interpretations of the three cross-sections represent the first study in the Oklahoma Panhandle in which such information has been obtained and analyzed. Playa cross-sections have been used to provide a possible explanation for the general development of playas in each area. The Gate Playa began with materials being deposited on the Permian bedrock. These Permian evaporite layers then underwent rapid dissolution and collapse -- so rapid that soil development could not keep pace. Movement along developing vertical cracks in the soil occurred, which displaced soil horizons (creating discontinuities) and caused changes in soil development and morphology. Discontinuities are especially evident toward the center of the playa. Eventually growth ceased, allowing younger and undisturbed soil horizons to form.

The Turpin Playa and the Elmwood Playa were not formed through the process of dissolution and collapse. Instead, the Turpin Playa began forming through the erosion of the original materials, creating a flat surface. On this, new material was deposited by the wind in dune-shaped layers. Eventually deposition stopped, and the wind then eroded these sediments into another flattened surface. Finally, younger materials were deposited to form the present surface. These sandy materials are believed to have been deposited by eolian processes based on the particle size and texture of the material and the topography (recent dunes) surrounding the playa.

The Elmwood Playa has also been influenced by eolian processes, although the exact mechanism of formation is still uncertain. Beneath the present landscape lies a buried playa, evidenced by an abrupt boundary at the top of these older, bowl-shaped materials and the presence of well-developed clay layers in the center of the basin. These buried clay layers strongly resemble the Randall Clay soil, which is found in the floors of present-day playa basins across the High Plains. A mantle of younger eolian materials (silt) was deposited on top of this paleoplaya, covering it entirely yet retaining the playa's shape. Cycles of burying older playas with younger eolian silt has taken place in the past, the result of episodic eolian deposition. The original playa may have formed in a natural low formed on the irregular surface of these windblown layers.

7.1 Recommendations for Future Research

This project was a pilot study for the feasibility of conducting playa research in the Oklahoma Panhandle. The success of the outcomes obtained in this study should lead to further playa research in the Oklahoma Panhandle using the following methods:

1. Continued playa observation. Through the coring of more playas, and the use of larger coring mechanisms to penetrate deeper into each playa, more information about the developement of these features can be gained.

2. Geophysical research. Through the use of geophysical techniques, especially DC Resistivity and Seismic Refraction, a better understanding of the subsurface materials, including caliche caprock and Permian evaporite units, can be obtained.

3. Geographic Information Systems analysis. These systems are powerful tools for the analysis of large quantities of data. By studying other factors which may be indirectly related to playa development (watertable elevation, geologic structure, etc.), the role of these subsurface processes can be evaluated using more powerful spatial analysis techniques.

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APPENDIX A

CORING RECORDS FOR PLAYAS

BEAVER COUNTY, OKLAHOMA

Coring Record for the Gate Playa, Site One

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silty Clay	10YR3/2	1fSBK	abrupt	none
A	8-31	Silty Clay	10YR3/2	2mSBK	gradual	slightly effervesent
AB	31-46	Silty Clay Loam	10YR4/4	2mSBK	abrupt	strongly effervesent
Btk	46-80	Silt Loam	71/2YR3/2	1mPR	clear	effervesent; some CaCO3 root fillings
Btk2	80-109	Silt Loam	71/2YR6/4	1mPR	abrupt	violently effervesent
Btk3	109-244	Silty Clay Loam	71/2YR4/4	2mPR		violently effervesent; coarse common CaCO3 nodules; fine Mn nodules common

Coring Record for the Gate Playa, Site Two

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silt Loam	10YR3/2	1fSBK	abrupt	none
A	8-29	Silty Clay Loam	10YR3/2	2mSBK	clear	effervesent
Bw	29-59	Silt Loam	101/2YR4/4	2mPR	gradual	violently effervesent
Btkss1	59-82	Silty Clay Loam	71/2YR4/4	2mPR	abrupt	effervesent; some CaCO3 root fillings
Bwkss,b	82-128	Silt Loam	71/2YR6/4	2mPR	clear	violently effervesent common coarse CaCO3 nodules
Btkss1,b	128-169	Silt Loam	71/2YR4/4	1fPR	clear	effervesent; fine Mn nodules common
Btkss2,b	169-202	Silty Clay Loam	71/2YR5/4	3mPR	clear	violently effervesent; coarse common CaCO3 nodules
Btk,2b	202-255	Silt Loam	71/2YR6/4	1mPR	clear	strongly effervesent; medium moderate CaCO3 nodules
Bk,2b	255-279	Silt Loam	71/2YR6/4	1mPR		violently effervesent; few coarse CaCO3 nodules

Coring Record for the Gate Playa, Site Three

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silty Clay	10YR3/2	1fSBK	abrupt	none
A	8-31	Silty Clay	10YR3/2	2fSBK	gradual	none
Btk1	31-54	Silty Clay Loam	71/2YR4/4	2mSBK	gradual	strongly effervesent; some CaCO3 root fillings; medium few CaCO3 nodules
Btk2	54-92	Silt Loam	71/2YR4/6	1mPR	clear	violently effervesent; coarse common CaCO3 nodules
Bw,b	92-115	Silt Loam	71/2YR5/6	1mPR	abrupt	none
Btk,b	115-212	Silt Loam	71/2YR5/4	3mPR	clear	violently effervesent; many coarse CaCO3 nodules; fine Mn nodules common
Bk,2b	212-305	Silt Loam	71/2YR4/6	1mPR	abrupt	strongly effervesent; few medium CaCO3 nodules; few fine Mn nodules
Bk,3b	305-320	Silty Clay Loam	71/2YR4/4	2mPR	clear	strongly effervesent; medium common CaCO3 nodules
Btk,3b	320-334	Silty Clay Loam	5YR4/6	3mPR	gradual	strongly effervesent; few medium CaCO3 nodules
Ck,3b	334-341	Silt Loam	71/2YR6/4	M		violently effervesent; more CaCO3 than anything; probe unable to penetrate layer

Coring Record for the Gate Playa, Site Three (continued)

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silty Clay	10YR3/1	1mSBK	abrupt	none
A	8-51	Silty Clay	10YR3/1	2mSBK	abrupt	none
Bw	53-91	Silt Loam	10YR3/2	3fSBK	clear	slightly effervesent; few CaCO3 root fillings
Bk	91-114	Silt Loam	10YR3/3	2mSBK	gradual	violently effervesent; many meduim CaCO3 nodules
Bt,b	114-139	Silty Clay Loam	10YR3/2	2mSBK	clear	none
Bt2,b	139-150	Silty Clay	10YR5/3	2fSBK	gradual	none
Bt3,b	150-159	Silty Clay Loam	21/2Y6/2	1fSBK		no effervesence; redox reactions taking place which indicates water retention

Coring Record for the Gate Playa, Site Four

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-6	Silty Clay Loam	10YR3/2	1mSBK	abrupt	none
A	6-23	Silty Clay Loam	10YR3/1	2mSBK	gradual	none
Bt	23-53	Silty Clay	10YR3/1	2mSBK	gradual	none
A,b	53-118	Silt Loam	10YR3/2	2mSBK	clear	effervesent; few CaCO3 filled root tracings
Bt,b	118-143	Silt Loam	101/2YR4/3	1mPR	gradual	none
Bt2,b	143-172	Clay	10YR54/3	2fPR	gradual	none very few,small Mn nodules
Bt3,b	172-178	Clay	5YR4/6	1mPR	abrupt	none
Btk1,b	178-197	Clay	5YR4/6	2mPR	clear	violently effervesent;;fine numerous CaCO3 nodules
Btk2,b	197-247	Silty Clay	71/2YR5/4	3mPR	gradual	violently effervesent; coarse numerous CaCO3 nodules
Bk,2b	247-364	Silt Loam	71/2YR4/6	2mPR		strongly effervesent; few meduim CaCO3 nodules found in zones

Coring Record for the Gate Playa, Site Five

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silt Loam	10YR3/1	1mSBK	abrupt	none
A	8-32	Silty Clay Loam	10YR3/1	1mSBK	gradual	none
ABk	32-52	Silty Clay Loam	71/2YR3/2	2mSBK	gradual	strongly effervesent
Bt1	52-84	Silty Clay Loam	71/2YR4/4	2mSBK	clear	effervesent; few CaCO3 filled root tracings
Btk2	84-110	Silt Loam	71/2YR5/4	1mPR	gradual	violently effervesent; medium common CaCO3 nodules
Btk1,b	110-169	Silt Loam	71/2YR4/4	2mPR	clear	strongly effervesent; few medium CaCO3 nodules
Btk2,b	169-213	Silty Clay Loam	71/2YR4/6	2mPR	clear	violently effervesent; few medium CaCO3 nodules
Btk3,b	213-251	Silt Loam	71/2YR4/5	2mPR	clear	violently effervesent;; large common CaCO3 nodules
Btk1,2b	251-303	Silt Loam	71/2YR4/6	2mPR	abrupt	strongly effervesent; few medium CaCO3 nodules
Btk2,2b	303-314	Silt Loam	71/2YR6/4	3mPR	clear	violently effervesent; many large CaCO3 nodules

Coring Record for the Gate Playa, Site Six

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Btk,3b	314-366	Silt Loam	71/2YR4/6	2mPR	abrupt	violently effervesent
Btk2,3b	366-391	Silt Loam	71/2YR5/4	2mPR	gradual	violently effervesent; large common CaCO3 nodules
Btk3,3b	391-400	Silt Loam	71/2YR7/4	3fPR		violently effervesent; mostly CaCO3

Coring Record for the Gate Playa, Site Seven

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silt Loam	10YR3/2	1mSBK	abrupt	none
A	8-35	Silty Clay Loam	10YR3/2	2mSBK	gradual	none
ABk	35-56	Silt Loam	10YR3/3	2mSBK	gradual	strongly effervesent; few medium CaCO3 nodules
Bt	56-82	Silt Loam	71/2YR4/2	2mPR	clear	effervesent; few CaCO3 filled root tracings
Btk1	82-92	Silty Clay Loam	71/2YR4/4	2mPR	clear	violently effervesent; large common CaCO3 nodules
Btk2	92-125	Silt Loam	71/2YR5/4	3fPR		violently effervesent; very common large CaCO3 nodules -- can't penetrate

Coring Record for the Turpin Playa, Site One

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-4	Silt Loam	10YR4/2	1mSBK	abrupt	effervesent
A	4-20	Silt Loam	71/2YR3/2	2mSBK	gradual	slightly effervesent
AB	20-24	Loam	10YR4/4	2mSBK	clear	violently effervesent
Btk	24-47	Clay Loam	10YR5/4	3mPR	clear	violently effervesent; coarse CaCO3 filled root tracings; 71/2YR6/2 mottles
Bk	47-94	Loamy Sand	71/2YR5/4	M	clear	effervesent;coarse CaCO3 root tracings; concretions
C1	94-136	Loamy Coarse Sand	71/2YR7/6	M	clear	slightly effervesent
C2	136-159	Loamy Coarse Sand	71/2YR7/6	M		slightly effervesent

Coring Record for the Turpin Playa, Site One (continued)

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Silt Loam	10YR3/3	2mSBK	abrupt	none
A	8-13	Silt Loam	10YR3/2	2mSBK	clear	none
A,b	13-32	Silt Loam	10YR3/1	1mSBK	gradual	strongly effervesent
AC,b	32-39	Loam	10YR4/3	1mSBK	gradual	strongly effervesent
Ck,b	39-87	Sandy Loam	10YR4/4	M	abrupt	strongly effervesent; stratified with Silt Loam layers
A,2b	87-124	Silt Loam	10YR3/3	2mSBK	clear	none
Bk1,2b	124-170	Loam	10YR4/3	1mSBK	gradual	strongly effervesent
Bk2,2b	170-196	Sandy Loam	10YR4/4	2mPR	clear	violently effervesent; CaCO3 on prism faces
Ak,3b	196-208	Sandy Loam	10YR4/3	2mSBK	gradual	strongly effervesent
Bk,3b	208-243	Sandy Loam	71/2YR5/4	2mPR		violently effervesent; CaCO3 on prism faces

Coring Record for the Turpin Playa, Site Two

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-11	Silt Loam	71/2YR4/2	1mSBK	abrupt	none
A,b	11-34	Silty Clay Loam	71/2YR3/1	1mSBK	gradual	none
AC,b	34-48	Clay Loam	10YR3/3	1mSBK	gradual	none
Ck,b	48-103	Sandy Clay Loam	10YR4/3	M	abrupt	effervesent; finely stratified; CaCO3 filled root tracings common
Ak1,2b	103-144	Silty Clay	10YR4/2	2mSBK	diffuse	effervesent; common CaCO3 filled root tracings
Akss2,2b	144-163	Silty Clay	10YR4/2	2mSBK	diffuse	slightly effervesent
Ak3,2b	163-208	Silt Loam	10YR4/2	2mSBK	gradual	effervesent; common CaCO3 filled root tracings
ACK,2b	208-221	Loam	10YR4/3	M	gradual	slightly effervesent; some CaCO3 filled root tracings
Ck,2b	221-257	Sandy Loam	10YR5/4	M	clear	slightly effervesent; some CaCO3 filled root tracings
A,3b	257-285	Sandy Clay Loam	10YR3/3	3mSBK	clear	slightly effervesent; some CaCO3 filled root tracings

Coring Record for the Turpin Playa, Site Two (continued)

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
C,3b	285-293	Sandy Loam	10YR4/3	M	abrupt	slightly effervesent; some stratification
A,4b	293-309	Clay Loam	10YR3/2	3fAB	clear	slightly effervesent
Bt,4b	309-317	Silt Loam	10YR4/1	2mSBK		violently effervesent; 10YR7/2 mottle color

Coring Record for the Turpin Playa, Site Three

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-13	Silt Loam	71/2YR3/2	1mSBK	abrupt	none
Bw	13-27	Silt Loam	71/2YR5/4	1mSBK	gradual	violently effervesent
2BC	27-68	Loam	71/2YR4/2	1cSBK	gradual	strongly effervesent
2C	68-83	Sandy Loam	71/2YR5/4	M	clear	strongly effervesent
2Ck	83-130	Sandy Clay	71/2YR5/6	M	clear	strongly effervesent; few coarse CaCO3 nodules
2Ck2	130-158	Loamy Sand	71/2YR6/6	SG		effervesent; few coarse CaCO3 nodules

Coring Record for the Turpin Playa, Site Four

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-7	Clay	71/2YR3/2	1mSBK	abrupt	none
A	7-65	Clay	71/2YR2/1	2mSBK	gradual	none
AB	65-86	Clay	10YR3/2	1mSBK	diffuse	none
Bt	86-105	Silty Clay Loam	10YR4/3	1mSBK	gradual	none
C1	105-136	Silt Loam	10YR4/4	M	clear	slightly effervesent; stratified sands and clays
C2	136-190	Sandy Loam	71/2YR5/4	M	gradual	effervesent
Bk1,b	190-204	Loam	10YR5/3	1mSBK	diffuse	effervesent
Bk2,b	204-234	Clay Loam	10YR5/3	1mSBK	gradual	effervesent
C,b	234-270	Sandy Clay Loam	10YR4/6	M	gradual	slightly effervesent
C2	270-283	Sandy Loam	10YR5/4	M		slightly effervesent

Coring Record for the Turpin Playa, Site Five

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-15	Silty Loam	10YR3/2	2fSBK	abrupt	none
2Btk1	15-34	Silty Clay Loam	10YR3/3	2mSBK	gradual	violently effervesent
2Btk2	34-48	Silty Clay Loam	10YR4/3	2mSBK	abrupt	violently effervesent
2C	48-86	Loamy Sand	71/2YR5/4	M	clear	violently effervesent
A,b	86-106	Clay Loam	10YR4/3	1mSBK	gradual	strongly effervesent
Bk,b	106-148	Sandy Loam	71/2YR4/4	1cSBK	clear	slightly effervesent
A,2b	148-185	Loam	10YR3/2	2mSBK	clear	none
C,2b	185-235	Sand	71/2YR6/2	SG	clear	none
Bt,3b	235-266	Clay Loam	71/2YR5/6	2fSBK	clear	few black Mg/Fe nodules
C,3b	266-273	Loamy Sand	71/2YR8/2	M		none

Coring Record for the Turpin Playa, Site Six

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Sandy Loam	71/2YR3/2	1fSBK	abrupt	none
A	8-16	Sandy Loam	10YR4/3	1mSBK	gradual	none
AB	16-30	Sandy Loam	10YR4/4	1mSBK	clear	effervesent
Btk	30-69	Loam	10YR5/4	2mPR	gradual	effervesent; some CaCO3 filled root channels
Bt	69-94	Sandy Clay Loam	71/2YR5/6	1mSBK	clear	slightly effervesent
C1	94-121	Sandy Loam	71/2YR5/6	M	clear	slightly effervesent
C2	121-147	Loamy Sand	10YR6/6	M	clear	none
C3	147-190	Loamy Sand	71/2YR6/6	M	abrupt	strongly effervesent
Bt,b	190-217	Clay Loam	71/2YR5/4	2fSBK	clear	strongly effervesent; some 5YR8 mottles
Btk,b	217-229	Clay Loam	71/2YR6/4	2mPR		strongly effervesent; some CaCO3 filled root fillings

Coring Record for the Turpin Playa, Site Seven

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-6	Silty Clay Loam	71/2YR3/2	1fGR	abrupt	none
A	6-16	Silt Loam	10YR3/1	2mSBK	gradual	none
Bw	16-27	Silt Loam	10YR3/3	2cSBK	gradual	none
Bw2	27-47	Silt Loam	10YR4/4	2mSBK	clear	effervesent
A,b	47-56	Silt Loam	10YR3/3	2fSBK	clear	effervesent
Bt,b	56-68	Silt Loam	10YR4/4	2cPR	abrupt	violently effervesent
Bk,b	68-95	Silt Loam	10YR5/4	1cSBK	gradual	violently effervesent
BC1,b	95-112	Loamy Sand	71/2YR5/6	1cSBK	clear	slightly effervesent
BC2,b	112-130	Loamy Sand	71/2YR6/6	1cSBK	clear	slightly effervesent
Bk,2b	130-142	Sandy Loam	71/2YR4/6	2mSBK	clear	strongly effervesent

Coring Record for the Elmwood Playa, Site One

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Bc,2b	142-196	Loamy Sand	71/2YR6/4	1cSBK	gradual	strongly effervesent
Bck,2b	196-215	Sandy Loam	71/2YR5/4	2cPR	gradual	strongly effervesent; few medium CaCO3 nodules
Bc1,2b	215-242	Sandy Clay Loam	71/2YR4/6	2cPR	gradual	strongly effervesent; few medium CaCO3 nodules
Bc2,2b	242-259	Loamy Sand	71/2YR6/4	1cSBK		common 71/2YR8/2 mottles

Coring Record for the Elmwood Playa, Site Two

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-6	Silt Loam	10YR3/2	1fGR	abrupt	none
A	6-20	Silt Loam	10YR3/2	2mSBK	gradual	none
Bw	20-33	Silt Loam	10YR3/4	2cSBK	diffuse	violently effervesent
Bc	33-51	Silt Loam	10YR4/4	1cPR	clear	violently effervesent
A,b	51-69	Silt Loam	10YR3/3	2fSBK	clear	effervesent
Bt,b	69-80	Silty Clay Loam	71/2YR5/4	2cSBK	clear	slightly effervesent
Bk,b	80-93	Silty Clay Loam	71/2YR5/6	1cSBK	clear	violently effervesent; many medium CaCO3 nodules
C1,b	93-107	Loamy Sand	71/2YR6/6	M	gradual	effervesent
C2,b	107-134	Loamy Sand	71/2YR7/6	M	abrupt	slightly effervesent
Bk,2b	134-164	Sandy Loam	71/2YR5/4	1mSBK	diffuse	strongly effervesent; fine common CaCO3 nodules

Coring Record for the Elmwood Playa, Site Three

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Bc,2b	164-201	Loamy Sand	71/2YR5/6	1cSBK	clear	effervesent; few medium CaCO3 nodules
Bck1,2b	201-210	Sandy Loam	71/2YR5/4	1cPR	clear	effervesent; few CaCO3 coatings on peds
Bck2,2b	210-248	Loamy Sand	71/2YR6/6	1cPR	abrupt	effervesent; few fine CaCO3 nodules
C,2b	248-279	Loamy Sand	21/2Y7/4	M		none

Coring Record for the Elmwood Playa, Site Four

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-17	Sandy Clay Loam	10YR3/4	1mSBK	abrupt	none
A	17-33	Clay Loam	10YR3/2	2mSBK	clear	none
Bt	33-61	Silty Clay Loam	10YR4/3	3cPR	gradual	none
Bk	61-82	Silt Loam	10YR4/4	3mSBK	clear	violently effervesent; many fine CaCO3 nodules
Btk	82-94	Sandy Loam	71/2YR5/6	1cSBK	clear	slightly effervesent; few coarse CaCO3 nodules
Bk2	94-154	Sandy Loam	71/2YR5/4	1cSBK	gradual	violently effervesent; many fine CaCO3 nodules
Bk3	154-195	Sandy Loam	71/2YR5/6	1cPR	clear	slightly effervesent; few coarse CaCO3 nodules
C1	195-243	Loamy Sand	71/2YR7/4	M	abrupt	slightly effervesent; few medium CaCO3 nodules
C2	243-280	Loamy Sand	2.5Y7/4	M		few coarse cylindrical CaCO3 nodules (coyote turds)

Coring Record for the Elmwood Playa, Site Five

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-14	Clay Loam	71/2YR3/2	1mSBK	abrupt	none
A	14-31	Clay Loam	10YR3/2	1mSBK	gradual	none
Bt	31-69	Clay	10YR3/3	2mSBK	clear	none
Bk	69-92	Silt Loam	10YR5/6	1cPR	clear	violently effervesent; many medium CaCO3 nodules
2Bk1	92-107	Sandy Loam	10YR5/6	1cPR	clear	violently effervesent
2Bk2	107-154	Sandy Clay	10YR6/6	2fSBK		violently effervesent; many medium CaCO3 nodules; 10YR7/2 mottles (faint)

Coring Record for the Elmwood Playa, Site Six

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-7	Silty Clay Loam	71/2YR3/2	1fGR	abrupt	none
A	7-40	Silty Clay	10YR3/1	1mSBK	clear	none
2C	40-54	Sandy Loam	10YR5/4	M	abrupt	none
A,b	54-75	Silt Loam	10YR3/3	3mSBK	clear	none
Bk1,b	75-110	Loam	71/2YR5/4	2mSBK	gradual	violently effervesent; coarse common CaCO3 nodules
Bk2,b	110-127	Silt Loam	71/2YR7/4	1cSBK	abrupt	violently effervesent; many fine CaCO3 nodules
Ck,b	127-147	Silt Loam	71/2YR6/6	M		violently effervesent; coarse common CaCO3 nodules; common med. Mn nodules

Coring Record for the Elmwood Playa, Site Six (continued)

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-7	Sandy Loam	10YR4/2	M	abrupt	none
A1	7-28	Silt Loam	10YR3/2	2mSBK	gradual	none
A2	28-40	Silt Loam	10YR3/2	2mSBK	gradual	none
AB	40-56	Silt Loam	10YR3/3	2mSBK	gradual	none
Bw	56-79	Sandy Loam	10YR5/4	2mPR	clear	none
Bk	79-150	Sandy Loam	71/2YR5/4	1cSBK		strongly effervesent; many coarse CaCO3 nodules

Coring Record for the Elmwood Playa, Site Seven

Horizon Name	Depth Below Surface (in.)	Field Texture	Munsell Color	Soil Structure	Boundary	Special Features
Ap	0-8	Loam	10YR3/2	1mGR	abrupt	none
A	8-32	Loam	71/2YR3/2	2mSBK	gradual	none
Bw1	32-47	Silt Loam	71/2YR4/2	2mSBK	gradual	none
Bw2	47-61	Sandy Loam	71/2YR3/4	1mSBK	clear	none
Btk	61-87	Silt Loam	71/2YR3/4	2mSBK	abrupt	effervesent
BC	87-97	Sandy Loam	71/2YR4/6	2fSBK	abrupt	slightly effervesent
Ck	97-155	Loamy Sand	71/2YR4/6	M	abrupt	violently effervesent; coarse common CaCO3 nodules; few fine Mn nodules
Btk,b	155-201	Silty Clay Loam	71/2YR8/4	2mSBK	clear	violently effervesent; few coarse CaCO3 nodules
Ck,b	201-232	Sandy Loam	71/2YR5/6	1mPR	clear	violently effervesent; coarse common CaCO3 nodules
C2,b	232-257	Loamy Sand	10YR6/6	M		none

APPENDIX B

PHYSICAL DATA FOR RANDOM SAMPLE OF PLAYAS

BEAVER COUNTY, OKLAHOMA

Number	Length	Width	E. Ratio	Orientation	Quadrangle Name
201	350	190	0.54	34	Mocane NW
202	560	290	0.52	35	Mocane NW
203	1100	450	0.41	14	Mocane NW
204	620	300	0.48	-20	Mocane NW
205	600	380	0.63	41	Mocane NW
206	2000	850	0.43	8	Mocane NW
207	720	490	0.68	23	Mocane NW
208	1040	380	0.37	36	Mocane NW
209	790	350	0.44	12	Mocane NW
210	570	240	0.42	-2	Mocane NW
211	1240	510	0.41	44	Mocane NW
212	990	400	0.4	5	Mocane NW
213	3270	1220	0.37	5	Gate NE
214	3800	3750	0.99	30	Gate NE
215	300	200	0.67	-52	Gate NE
216	590	380	0.64	12	Gate NE
217	650	400	0.62	81	Gate NE
218	2320	1640	0.71	31	Gate NE
219	820	170	0.21	20	Gate NE
220	920	550	0.6	-10	Gate NE
221	600	440	0.73	41	Gate NE
222	280	150	0.54	10	Gate NE
223	260	90	0.35	-11	Gate NE
224	1980	800	0.4	-2	Gate NW
225	760	320	0.42	25	Knowles
226	1500	360	0.24	40	Knowles
227	320	110	0.34	-25	Knowles
228	2450	1220	0.5	63	Knowles
229	940	630	0.67	-86	Knowles
230	9500	3560	0.37	-50	Gate
231	490	380	0.78	-74	Gate
232	550	250	0.45	15	Gate
233	1010	620	0.61	10	Gate
234	1240	1150	0.93	83	Gate
235	400	290	0.73	-50	Gate

Data for Selected Playayas, Gate Area

Number	Length	Width	E. Ratio	Orientation	Quadrangle Name
101	410	180	0.44	17	Little Ponderosa
102	240	150	0.63	-29	Little Ponderosa
103	720	500	0.69	42	Little Ponderosa
104	190	130	0.68	-3	Little Ponderosa
105	750	500	0.67	-58	Little Ponderosa
106	180	110	0.61	-6	Little Ponderosa
107	310	200	0.65	39	Little Ponderosa
108	420	160	0.38	60	Little Ponderosa
109	490	270	0.55	8	Little Ponderosa
110	300	220	0.73	-52	Turpin W
111	210	100	0.48	16	Turpin W
112	500	210	0.42	43	Turpin W
113	280	200	0.71	38	Turpin W
114	230	110	0.48	32	Turpin W
115	480	240	0.5	42	Turpin W
116	520	200	0.38	-16	Forgan
117	610	300	0.49	37	Forgan
118	590	220	0.37	8	Forgan
119	330	210	0.64	38	Red Horse Creek
120	500	290	0.58	21	Beaver NW
121	530	310	0.58	22	Beaver NW
122	990	500	0.51	48	Beaver NW
123	510	390	0.76	30	Beaver NW
124	340	200	0.59	47	Beaver NW
125	640	390	0.61	22	Floris
126	360	210	0.58	26	Floris
127	490	200	0.41	23	Turpin E
128	510	280	0.55	-5	Turpin E
129	600	290	0.48	35	Turpin NE
130	580	210	0.36	25	Turpin NE
131	410	200	0.49	29	Turpin NE
132	300	220	0.73	-47	Turpin NE
133	380	210	0.55	32	Turpin NE
134	570	200	0.35	44	Turpin NE
135	560	300	0.54	38	Turpin NE

Data for Selected Playas, Turpin Area

Number	Length	Width	E. Ratio	Orientation	Quadrangle Name
301	1800	1710	0.95	-25	Balko
302	1290	1000	0.76	-50	Balko
303	1280	1200	0.94	-21	Balko
304	1600	1070	0.67	82	Balko SW
305	4820	4320	0.89	-82	Balko SW
306	2350	1670	0.71	-38	Balko SW
307	410	190	0.46	-45	Balko SW
308	1340	1200	0.89	57	Balko SW
309	620	370	0.6	30	Balko SW
310	4350	1000	0.23	14	Bryans Corner
311	1640	1130	0.69	-78	Bryans Corner
312	550	450	0.82	26	Bryans Corner
313	6910	4400	0.64	-14	Bryans Corner
314	900	780	0.87	-42	Bryans Corner
315	1550	1040	0.67	45	Bryans Corner
316	750	340	0.45	-47	Bryans Corner
317	3200	2200	0.69	49	Bryans Corner
318	500	80	0.16	-77	Bryans Corner
319	500	300	0.6	17	Elmwood
320	1640	1080	0.66	46	Elmwood
321	2950	1320	0.45	56	Elmwood
322	700	390	0.56	24	Elmwood
323	600	270	0.45	10	Elmwood
324	780	600	0.77	6	Elmwood
325	2800	1110	0.39	89	Elmwood
326	1420	1260	0.89	21	Elmwood
327	1900	1820	0.96	81	Elmwood
328	410	300	0.73	70	Elmwood
329	740	620	0.84	21	Elmwood
330	500	290	0.58	90	Elmwood
331	1300	1190	0.92	55	Elmwood
332	1210	890	0.74	83	Elmwood
333	340	300	0.88	4	Elmwood
334	760	450	0.59	20	Elmwood
335	810	390	0.48	9	Elmwood

Data for Selected Playas, Elmwood Area

VITA

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Doctor of Philosophy

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