ANALYSIS OF QUATERNARY POLLEN FROM CHEYENNE BOTTOMS, KANSAS: EVIDENCE FOR LATE QUATERNARY VEGETATION AND CLIMATES IN THE CENTRAL GREAT PLAINS

by

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B.A., Louisiana State University, 1977
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ABSTRACT

Cheyenne Bottoms is a large (166 km^2) enclosed basin in central Kansas. The Quaternary pollen record obtained from the upper 20-meter thick zone of marsh sediments provides evidence for local and regional vegetational and climatic change over the last 30,000 years. Two major biostratigraphic units are identified: a Farmdalian zone (30,000 to 24,000 yr. B.P.), and a Holocene zone (11,000 yr. B.P. to present). There appears to be a major hiatus in the sedimentary and pollen record. All of the late-Wisconsinan (Woodfordian) substage is missing from the Cheyenne Bottoms record. Although the causes for this unconformity are not totally understood, the data indicate that the unconformity was preceded by basin drying. This suggests that the unconformity may be the result of wind erosion during a xeric late-Wisconsinan episode. The data indicate that, during the Farmdalian, Cheyenne Bottoms was a persistent shallow water marsh dominated by cat-tail and sedges. The Farmdalian upland vegetation inferred from the pollen data was primarily an open grassland-sage steppe. The pollen data indicate that the Farmdalian landscape was not as treeless as Holocene conditions. The pollen data suggest that localized populations of spruce, juniper, aspen, birch, boxelder, and oak probably persisted in edaphically favorable sites throughout this period. The pollen data from the Holocene portion of the section suggest that the Cheyenne Bottoms wetlands has been rather ephemeral throughout the last 11,000 years. Pollen associated with mudflat-adapted plant communities dominates throughout the Holocene. The Holocene upland plant communities are distinctly different from the open grassland-sage steppe of the Farmdalian. Sage is far less common during the Holocene, while ragweed and forbs become relatively more important. The Cheyenne Bottoms pollen record suggests that the central Great Plains region has been dominated by primarily open, grassland vegetation for at least the last 30,000 years.

Dedicated to my father,

Raymond Fredlund,

who instilled in me a curiosity of

the past and of the natural world.

Thank you.

ACKNOWLEDGEMENTS

I first recognized the potential of Quaternary pollen research at Cheyenne Bottoms many years ago, about 1981. But because of logistical difficulties, early attempts at obtaining a core from Cheyenne Bottoms were unsuccessful. It was not until the Kansas Geological Survey and Kansas Biological Survey began their joint investigation at Cheyenne Bottoms in 1985 that the opportunity for sampling the complete Quaternary sedimentological column presented itself. Thanks to the cooperation and encouragment of many on the KGS staff, but especially to Tom McClain, I was able to obtain the samples which came to form the basis of this dissertation. Tom McClain and the KGS also deserve credit for funding two radiocarbon dates which greatly helped to establish the radiocarbon chronology of the Quaternary sediments.

The staff of the Kansas Biological Survey was also cooperative and helpful. The staff of the Kansas Biological Survey went out of their way to supply me with both modern sediment samples and information on the modern vegetative of Cheyenne Bottoms. Ralph Brooks, a friend and ally, is credited with describing the local plant community ecology which plays a critical role in the interpretations of the pollen record.

Spencer Tomb is responsible for instigating my field work at Cheyenne Bottoms. Although our early efforts at sampling were unsuccessful, he helped establish the contacts which eventually led to the success of this project. I would also like to thank Dr. Tomb for his expert advice and guidance in classification of Asteraceae pollen types.

I also thank Jim Swinehart, of the Nebraska Geoglogical Survey, for allowing me to use some yet unpublished radiocarbon and pollen data from Nebraska.

The individuals of my graduate committee – Wakefield Dort, Curt Sorenson, Phillip Wells, Larry Martin, and William Johnson – deserve recognition for their individual roles in the completion of this dissertation. I am especially grateful to William Johnson who saw this project through from its first feeble field efforts, through several successful field seasons, and eventually through critical periods in the writing and completion of the manuscript.

I also thank the staff and faculty of the University of Wisconsin - Milwaukee, Geography Department, for their support, understanding, and patience in completing this degree.

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CHAPTER 1

STATMENT OF PROBLEMS AND OBJECTIVES

Introduction

In most regions of the world fossil pollen derived from limnic sediments is the principal type of proxy data used to infer change in Quaternary vegetation and climate (Birks and Birks, 1980; Grimm, 1988). Since fossil pollen analysis was first developed by Von Post in 1916 (Faegri and Iversen, 1975), thousands of studies have applied the technique, while hundreds of other studies have explored its limitations. The success of the technique can be credited to two attributes. The first of these is the ability to make regional, rather than local, inferences about plant populations and, therefore, vegetation. In this sense, Quaternary pollen analysis can be considered a method of vegetation sampling and description (Prentice, 1985). The second important characteristic of pollen analysis is its ability to document continuous vegetation and climatic change over many thousands of years at a single location. In this way, pollen records are analogous to measuring vegetation change by repeated visits to the same sampling plot for thousands of years (Jacobson, 1988). Taken together, these attributes have made pollen analysis one of the most widely applied and successful tools used in Quaternary paleoenvironmental reconstruction.

The objective of this dissertation is the application of Quaternary pollen analysis in the central Great Plains for the purpose of reconstructing the late-Quaternary history of vegetation and climatic change in the region. The study focuses on a single site in central Kansas, Cheyenne Bottoms (Figure 1.1). The dissertation comprises four stages: 1) the formulation of hypotheses from other regional data, 2) the documentation of pollen and sedimentary records at Cheyenne Bottoms, 3) the interpretation of the Cheyenne Bottoms data through inferential methods, and 4) discussion of the implication of these interpretations in a regional context. The dissertation concludes with a reconstruction of the nature, extent, and chronology of late-Quaternary vegetation and climatic change in the central Great Plains, to the extent permitted by the data.

Rationale for Study Site Selection

Cheyenne Bottoms was selected for three reasons: its potential for pollen preservation, its potentially continuous sedimentary record spanning the Holocene and late Pleistocene, and its geographical location. These are considered in order. The primary consideration of this and all pollen studies is that pollen be well preserved (Delcourt and Delcourt, 1980). Although valuable

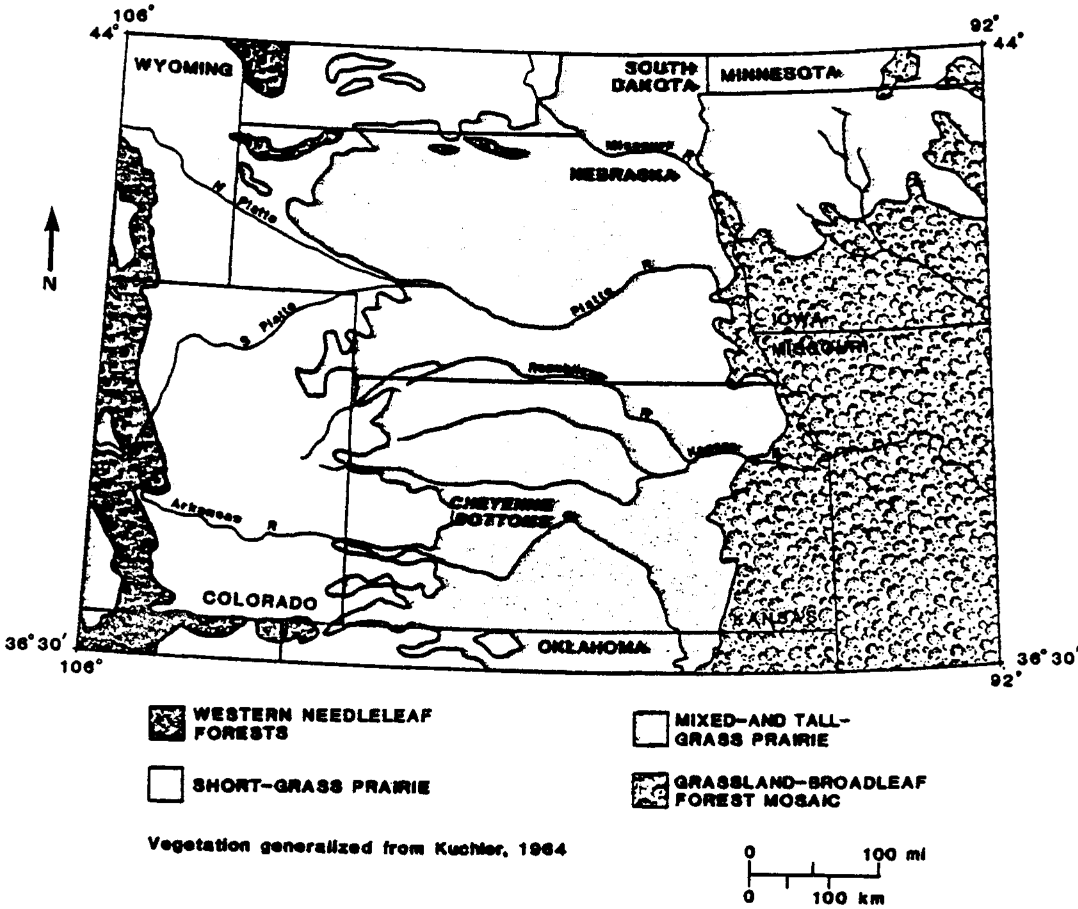


Figure 1.1: Modern vegetation of the central Great Plains and the location of Cheyenne Bottoms.

fossil pollen data have been obtained in the Great Plains from localities with poor pollen preservation, there are substantial problems inherent in inferring vegetation from such records (see Fredlund and Jaumann, 1987). A primary consideration in study site selection was reducing the degree of uncertainty added by poor pollen preservation. Because the destruction of fossil pollen most often results from oxidation, the saturated, anaerobic, and often acidic nature of lacustrine deposits make them ideal for pollen preservation.

In this regard even Cheyenne Bottoms is less than ideal. The flat, shallow water basin today is often dry in the summer. While recent human alteration of the landscape is a factor in the current basin drying (Sadeghipour and McClain, 1987), it is reasonable to assume that periods of drought had similar consequences prior to Euro-American settlement. Such periods of drying can result in oxidation of pollen in the surface sediment of the basin. This potential problem is further compounded by the water chemistry of the wetland. Evaporation from this closed basin results in concentration of soluble elements and compounds and a basic (high pH) water chemistry (Whittemore and Huggins, 1987). Although reason for concern, the water and lacustrine sediment chemistry at Cheyenne Bottoms doese not necessarily result in poor pollen preservation. Means of evaluating this potential problem throughout the sedimentary record are discussed later.

As noted above, one major strength of pollen analysis as applied to lacustrine deposits is its ability to record change in vegetation and climate continuously over thousands of years. Because the central Great Plains contains few natural wetlands, few long-term pollen records are available from which to infer regional vegetation and climatic change (see Baker and Walen, 1985; Fredlund and Jaumann, 1987). Of the wetlands investigated to date in the central Great Plains, few have pollen records extending back into the Pleistocene epoch. The size and configuration of the Cheyenne Bottoms basin suggested the potential for an uninterrupted accumulation of sediments extending back in time into the late-Pleistocene. Although this assumption was not entirely borne out, Cheyenne Bottoms nevertheless contains one of the more complete pollen records thus far recovered from the central Great Plains.

A final consideration in selecting Cheyenne Bottoms for analysis was geographical. In keeping with regional objectives, Cheyenne Bottoms was selected because it is located in the heart of the modern grasslands (Figure 1.1). Few other localities with potential for adequate pollen preservation and a pre-Holocene history occur in the region. Given the objective of the research, Cheyenne Bottoms was by far the most promising locality.

Hypothesized Regional Chronology

The paleobotanical evidence (Fredlund and Jaumann, 1987; Wells and Stewart, 1987a; 1987b), paleontological evidence (e.g., Martin and Neuner, 1978; Graham, 1987), and the chrono-stratigraphy of both upland eolian and alluvial sediments (e.g., Fredlund et al., 1985; Souders and Kuzila, 1990; Martin, 1990) shape our expectations of the Cheyenne Bottoms chronology. The chronology of paleo-environmental changes observed in these types of evidence generally conforms with the late Quaternary chrono-stratigraphy developed in the Midwestern United States. This chrono-stratigraphy is informally extended into the central Great Plains for this study.

Three substages of the Wisconsin Stage are recognized (Willman and Frye, 1970). The Altonian (stadial) Substage extended from approximately 75,000 to 28,000 yr. B.P. The Farmdalian (interstadial) Substage comprises the period from approximately 28,000 to 23,000 yr. B.P. The Woodfordian (full-glacial) Substage extended from 23,000 to 12,500 yr. B.P. To accommodate the period of rapid climatic and biotic change apparent at the end of the Pleistocene, a Woodfordian-Holocene transitional period, used for the interval from 12,500 to 10,000 yr. B.P., is informally recognized.

Three climatically significant stages within the Holocene are also recognizable. Although a more detailed Holocene climatic chronology has been proposed for the Great Plains (Bryson et al., 1970), evidence supporting this chronology is not conclusive. The evidence for three major climatic periods within the Holocene is more widely accepted. The first of these periods, the Early Holocene, lasting from 10,000 to approximately 8,000 yr. B.P., was more mesic than the Mid-Holocene or Altithermal. The Middle Holocene drier period occurred from approximately 8,000 to 3,500 yr. B.P. In the Late Holocene, approximately 3,500 yr. B.P. to present, more mesic conditions are generally expected to have occurred. The timing of these climatic periods within the central Great Plains remains tentative. Even in the upper midwestern United States, where Holocene pollen records are abundant and well dated, the chronology of Holocene climatic periods varies (Winkler et al., 1986).

Regional Overview

Late-Quaternary paleobotanical data in the central Great Plains remains chronologically and spatially scant (Baker and Walen, 1986; Fredlund and Jaumann, 1987). Nevertheless, this paleobotanical evidence, along with other forms of corroborative evidence, provides the basis for constructing hypotheses of late-Quaternary vegetation and climate change in the region. The evidence from within each chronological period defined above is briefly reviewed below. Because of their common use as indicator species, and because the region is today treeless (Axelrod, 1985), particular attention is given to the presence or absence of major arboreal genera such as spruce or pine. The modification and refinement of the hypothesized vegetational changes awaits further studies.

The Altonian Substage (75,000 to 28,000 yr. B.P.)

Three small lenses of organic-rich deposits, each from a different locality within the Sand Hills of Nebraska, have been analyzed for pollen. Radiocarbon assays of these samples range from

38,000 to 28,000 yr. B.P. (Swinehart, pers. comm., 1990). The compositions of all three of these pollen assemblages are consistent with modern grassland pollen assemblages (Fredlund and Jaumann, 1987; Fredlund, 1990). These samples suggest that pine and spruce trees were absent from the Sand Hills region during the late-Altonian.

This is not true in the southern High Plains. Pollen evidence there suggests that pine parklands dominated the Llano Estacado throughout the Altonian (Hafsten, 1961; Martin and Mehringer, 1965; Oldfield and Schoenwetter, 1975). Recent reassessments of these southern High Plains pollen data, which consider the potential pollen preservation problems (cf. Hall, 1981), have tended to modify the earlier interpretations of substantial, wide spread pine populations. Current thinking is that these pollen data represent pine populations limited to escarpments or other edaphically protected localities (Bryant and Holloway, 1985).

The pollen assemblage from the Altonian Jinglebob Site in Meade County, Kansas, presents an analogous situation (Kapp, 1970). Although high percentages (ca. 50%) of pine pollen are present, questions of preservation suggest that this number may not be directly interpretable by comparison to modern pollen assemblages (Fredlund and Jaumann, 1987). Nevertheless, the presence of even restricted tree populations in this now treeless region is a significant finding (Axelrod, 1985).

The Farmdalian Substage (28,000 to 23,000 yr. B.P.)

That the Farmdalian Substage was regionally distinct from the Altonian substage is most widely evident in the upland loess and paleosol records of the central Great Plains. The Gilman Canyon Formation, which appears to be a cumulic A-horizon in many loess sections of the region, has been correlated to the Farmdalian (e.g. Fredlund et al., 1985; Johnson, 1990). How this hypothesis may translate into regional vegetation and climate remains unclear. It does suggest that climatic conditions during the Farmdalian were distinct from those that preceded or followed.

During the Farmdalian substage, pollen and macrofossil evidence suggests that open forest dominated by jack pine (*Pinus banksiana*) characterized the northern Ozarks (Mehringer et al., 1970; King, 1973) and much of Iowa (Mundt and Baker, 1979; Hallberg et al., 1980; VanZant et al., 1980). The westward range of *Pinus banksiana* during this period remains unknown. Farmdalian pollen assemblages from eastern Kansas suggest that if jack pine did extend into Kansas, its population remained small and was probably restricted to specific edaphic situations (Fredlund and Jaumann, 1987). These eastern Kansas pollen data, both from Sanders' Well and from Muscotah Marsh, have been interpreted as representing a mosaic of prairie and oak-hickory forest (Fredlund and Jaumann, 1987)

Published Farmdalian data from within the heart of the central Great Plains are lacking. The evidence discussed above suggests that there may have been an east-to-west regional moisture gradient during the Farmdalian parallel to that experienced today. If so, fewer trees would be expected to occur in the western part of the region; however, if the pollen evidence of pines found in the southern High Plains is representative, then even this region would not have been treeless in the Farmdalian substage.

The Woodfordian Substage (23,000 to 12,500 yr. B.P.)

Like the Farmdalian, the Woodfordian substage is also best defined in the regional upland eolian deposits: the Peorian Loess (e.g., Fredlund et al., 1985; Welch and Hale, 1987). Again, although the changes in eolian sedimentation suggest regional conditions different from those of either the Farmdalian or Holocene periods, the implications of this depositional difference for vegetation and climate are ill defined.

The most direct discussion of the climatic significance of central Great Plains Peorian Loess deposition relates to the formation of the Sand Hills of Nebraska. Kutzback and Wright (1985) argue that the Sand Hills of Nebraska is the source for much of the Peorian Loess in the region. Formation of the huge transverse dunes within the Sand Hills, they argue, must have taken place during a period of extreme aridity. Although strong circumstantial evidence links the Sand Hills to the adjacent body of Peorian Loess, this hypothesis is not universally accepted (Ahlbrandt et al., 1983).

The question of the Sand Hills formation and Peorian Loess deposition is germane to the investigation of Cheyenne Bottoms for two reasons. First, it suggests that the Woodfordian substage was a period of increased eolian sedimentation that may have affected the Cheyenne Bottoms wetland. Secondly, if the arguments of Kutzbach and Wright (1985) are correct, the Woodfordian, or at least some portion of it, was relatively xeric.

This hypothesized Woodfordian aridity conflicts with at least some paleobotanical evidence in the region, particularly in regard to the widespread occurrence of spruce and other taiga-like plant taxa. These taxa, typically associated with the modern boreal forest, do not suggest increased aridity and moisture stress. The Woodfordian fossil record from the central Great Plains includes several well documented occurrences of spruce (Fredlund and Jaumann, 1987; Wells and Stewart, 1987a; 1987b). The radiocarbon ages of these spruce fossils range from 19,000 to 11,000 yr. B.P. Most of the spruce fossils identified in the region are white spruce (*Picea glauca*). A possible example of blue spruce (*Picea pungens*) has been reported from west-central Kansas (Wells and Stewart, 1987a). This single fossil may represent an eastward extension of this Cordilleran species during the Woodfordian. Woodfordian-age spruce pollen, possibly from blue spruce, occurs in the southern High Plains. Problems arising due to poor pollen preservation and the lack of corroborative evidence have raised doubts about the extent of these southern High Plains spruce populations (Bryant and Holloway, 1985; Holliday, 1986)

On the opposite, eastern, fringe of the central Great Plains, in Iowa and Missouri, pollen and macrofossil evidence suggests that the open jack-pine forest of the Farmdalian period yielded rapidly to open white-spruce forest around 22,000 yr. B.P. (Fredlund and Jaumann, 1987). A similar record of Woodfordian spruce forest comes from Muscotah Marsh in northeastern Kansas (Gruger, 1973). The western extent of these open, white-spruce forests is unknown.

Other white-spruce macrofossils, often with associated pollen assemblages, are found along many major rivers of the central Great Plains. One such find is the peat balls found in the Wichita River valley near Wichita, Kansas (Fredlund and Jaumann, 1987; Jaumann, 1991). Pollen samples analyzed from peat balls containing white-spruce macrofossils, typically contain moderate levels (ca. 35%) of *Picea* pollen. A very similar occurrence of white-spruce macrofossils accompanied by moderate levels of *Picea* pollen is documented from the Republican River valley at North Cove, Harlan County, Nebraska (Fredlund and Jaumann, 1987; Wells and Stewart, 1987a; 1987b; Fredlund, 1989). Although these and other isolated Woodfordian fossils document the wide range of white spruce along the more mesic river valleys, the extent of spruce encroachment in the uplands is still debatable (see Fredlund and Jaumann, 1987; Wells and Stewart, 1987a; 1987b; Jaumann, 1991).

Using the more widespread Woodfordian land-snail assemblages associated with the North Cove and other botanical macrofossil localities, Wells and Stewart (1987a; 1987b) have argued that taiga-like, spruce-dominated vegetation extended across the central Great Plains throughout the Woodfordian. While their approach has great merit, their conclusions may be over-stated. First, these Woodfordian land-snail assemblages are not chronologically or spatially ubiquitous. Leonard (1959) presented data which shows that much of the great diversity of the Woodfordian land-snail assemblages observed in central Nebraska and northern Kansas is not regionally valid. He also documented lower snail assemblage diversity with depth (time) within the Woodfordian-age Peorian Loess of the region. In the thicker Woodfordian loess deposits of the region, Leonard (1959) showed that land-snail assemblages are typically absent toward the base of the Woodfordian loess. Finally, as Wells and Stewart (1987a; 1987b) themselves pointed out, the Woodfordian land-snails are adapted to deciduous, not coniferous, vegetation. Nevertheless, it is difficult to deny that these abundant land-snail assemblages represent some type of wooded vegetation on the uplands.

The Woodfordian land-snail data suggest an alternative hypothesis. Rather than spruce taiga, an aspen parkland-covered upland would be more parsimonious with the evidence currently available. This alternative hypothesis of upland aspen parkland is consistent with the interpretations of both the North Cove and the Wichita peat pollen assemblages (Fredlund and Jaumann, 1987; Fredlund, 1990; Jaumann, 1991). It is further supported by the Sanders' Well fossil pollen record (Fredlund and Jaumann, 1987). Assemblages from the Woodfordian pollen zone at Sanders' Well are very similar in composition to modern aspen parkland assemblages. The Sanders' Well record contains relatively high percentages of both *Populus* (aspen) and *Betula* (birch). Also in keeping with this hypothesis is the low percentage of *Picea* (spruce) pollen. These low percentages of *Picea* pollen suggest that no spruce grew on the uplands surrounding the Sanders' Well locality.

Pines are also potentially important in the Woodfordian vegetation in the central Great Plains. Given the floristic similarities between the Woodfordian plant community and the modern boreal forest discussed above, it is reasonable to expect one or more pine species. Pines (i.e. *P. banksiana* and *P. strobus*) after all are an important constituent of the modern boreal forest (Larsen, 1980; Elliott-Fisk, 1988). However, it has long been observed that the full-glacial, open, white-spruce forest which characterized midwestern North America, lacked pine (Wright, 1981; 1987). Curiously, jack pine (*P. banksiana*) had been regionally important in the midwestern region during the Farmdalian, but disappeared from most fossil records about 24,000 yr. B.P. The main Woodfordian populations of boreal-forest pines appear to have been far to the east of the central Great Plains (Delcourt and Delcourt, 1987; Jacobson, et al., 1987).

Confirmed macro-fossil records of boreal-forest pines are lacking from the Central Great Plains. Pollen records from the eastern side of the region contain low pine percentages (less than 20%). Two explanations are possible. First, these low pine percentages could have resulted from long-range transport of pine pollen (Fredlund and Jaumann, 1987; Fredlund, 1990; Jaumann, 1991). Alternatively, these low pine pollen percentages may have come from very limited, local Woodfordian pine populations. The former interpretation is more consistent with evidence from the Midwest region (cf. Wright, 1981; 1987).

There is better evidence for Woodfordian pine in the western central Great Plains. The remarkable find of limber pine (*Pinus flexilis)* needles in western Kansas (Wells and Stewart, 1987a, 1987b) is undeniable evidence of expansion of this western pine species during the Woodfordian. This macrofossil discovery is supported by Woodfordian fossil pollen assemblages (reviewed in Fredlund and Jaumann, 1987). A persistent problem with these supporting Woodfordian pollen assemblages is the potential error resulting from differential pollen preservation and recognition (Delcourt and Delcourt, 1980). The potential over-representation of pine pollen resulting from poor preservation of other species, coupled with the problems inherent in the interpretation of this widely dispersed pollen taxon, precludes valid estimation of the relative importance of pine in the Woodfordian vegetation (Hall, 1981; Fredlund and Jaumann, 1987). Consequently, although we know at least one Cordilleran pine species was regionally present during the Woodfordian, we do not yet have evidence for its importance or its chronological and geographical limits. Given this level of regional data, the hypothesized Woodfordian pine parkland vegetation in the western central Great Plains (Martin and Neuner, 1978; Rogers and Martin, 1984), while consistent with the data, remains unproven.

The Woodfordian-Holocene Transition **(12,500 to 10,000 yr. B.P.)**

The Woodfordian-Holocene transition in the central Great Plains encompasses a period of rapid and substantial change in climate and vegetation (Wright, 1970, 1981; Fredlund and Jaumann, 1987). The pollen record from Muscotah Marsh in northeastern Kansas (Gruger, 1973) documents the expansion of several deciduous tree species, coinciding with a decrease in spruce pollen. A contemporary pollen record from Rosebud, South Dakota, documents the expansion of white spruce along with some deciduous arboreal pollen in the northern Sand Hills region (Watts and Wright, 1966). The most reasonable hypothesis for this Woodfordian-Holocene transitional pollen signature is that it represents an open parkland similar to the aspen parklands bordering the boreal forest today, but with a greater diversity in arboreal taxa, even retaining white spruce (Wright, 1970; Jacobson et al. 1987; Barnosky et al., 1987). Based on scattered evidence in central Kansas, Fredlund and Jaumann (1987) have suggested that these records represent an expansion of an aspen parkland-like commuity across the Great Plains.

The Holocene (10,000 yr. B.P. to Present)

Palynological documentation of vegetation and climatic change within the Holocene presents some special challenges (Fredlund and

Jaumann, 1987). These problems are the result of the taxonomic limitations of pollen analysis. Many major grassland pollen types encompass entire families of plants. For example, except for domesticated grains, pollen grains from all grasses are indistinguishable. This means that large changes within grasslands can occur but not be readily apparent within the pollen record (e.g. Wright et al., 1985). It is hypothesized that this taxonomic limitation explains the lack of evidence for mid-Holocene climatic drying in central Great Plains pollen records. Evidence for the middle Holocene drying has, however, been reported at several sites in the northern Great Plains (Barnosky et al., 1987).

Anticipated Results from Cheyenne Bottoms

The evidence outlined above and presented elsewhere (Fredlund and Jaumann, 1987) represents the hypothesized chronology of late-Quaternary vegetation and climatic change in the central Great Plains. The pollen analysis of the Cheyenne Bottoms sedimentary record was undertaken to expand and refine, or refute, this chronology. The Cheyenne Bottoms pollen record was anticipated to extend at least into the mid-Wisconsinan (Farmdalian). General regional hypotheses that are tested with the Cheyenne Bottoms study include:

> 1). Altonian and Farmdalian vegetation comprised grasslands or a mix of grassland and open parkland vegetation. Both Altonian and Farmdalian vegetation is anticipated to have accommodated a greater variety of deciduous trees than regionally present in the late

Holocene. The relative importance of pines in the Altonian and Farmdalian vegetation remains uncertain.

2). The Woodfordian was characterized by parklands including spruce and deciduous trees (i.e., *Quercus, Betula, Fraxinus,* and *Populus*). Throughout the Woodfordian period, the relative importance of all trees continued to increase. Spruce was confined to river valleys and escarpments throughout much of the Woodfordian. Cordilleran pine species (e.g. *P. flexilis*) were present, but probably limited, in the western Great Plains. Eastern or boreal-forest pine species were regionally absent.

3). Woodfordian-Holocene transitional vegetation change included a brief but significant population expansion of all tree taxa, including spruce, as climatic conditions ameliorated. Termination of the Woodfordian parkland vegetation and the rapid rise of Holocene grassland vegetation occurred around 11,000 yr. B.P.

4). Holocene vegetation responded to a middle Holocene period of aridity. The expression of this response in central Great Plains non-arboreal pollen records varies with each situation. At Cheyenne Bottoms, a rise in Cheno-Am pollen is expected to be the most likely response.

CHAPTER 2

RESEARCH METHODOLOGY

Description of Study Site

Location

Cheyenne Bottoms is a large wetland located in Barton County, Kansas (Township 18 South, Ranges 12 and 13 West). The largest wetland in Kansas, Cheyenne Bottoms is centrally located both within the state and within the central Great Plains region (Figure 1.1). The Cheyenne Bottoms Wildlife Management Area, which includes the coring site for this study, covers 19,000 acres in the lower portions of the 41,000-acre basin (Figure 2.1).

Hydrology and Geology of Cheyenne Bottoms

One reason for selecting Cheyenne Bottoms for this study was its potential for containing a deep, uninterrupted sequence of late Quaternary sedimentation. To appreciate this potential, one must understand the geology and hydrology of the locality. Cheyenne Bottoms is a large, structural basin (Latta, 1950; Bayne, 1977). It is not clear when the deep collapse that resulted in

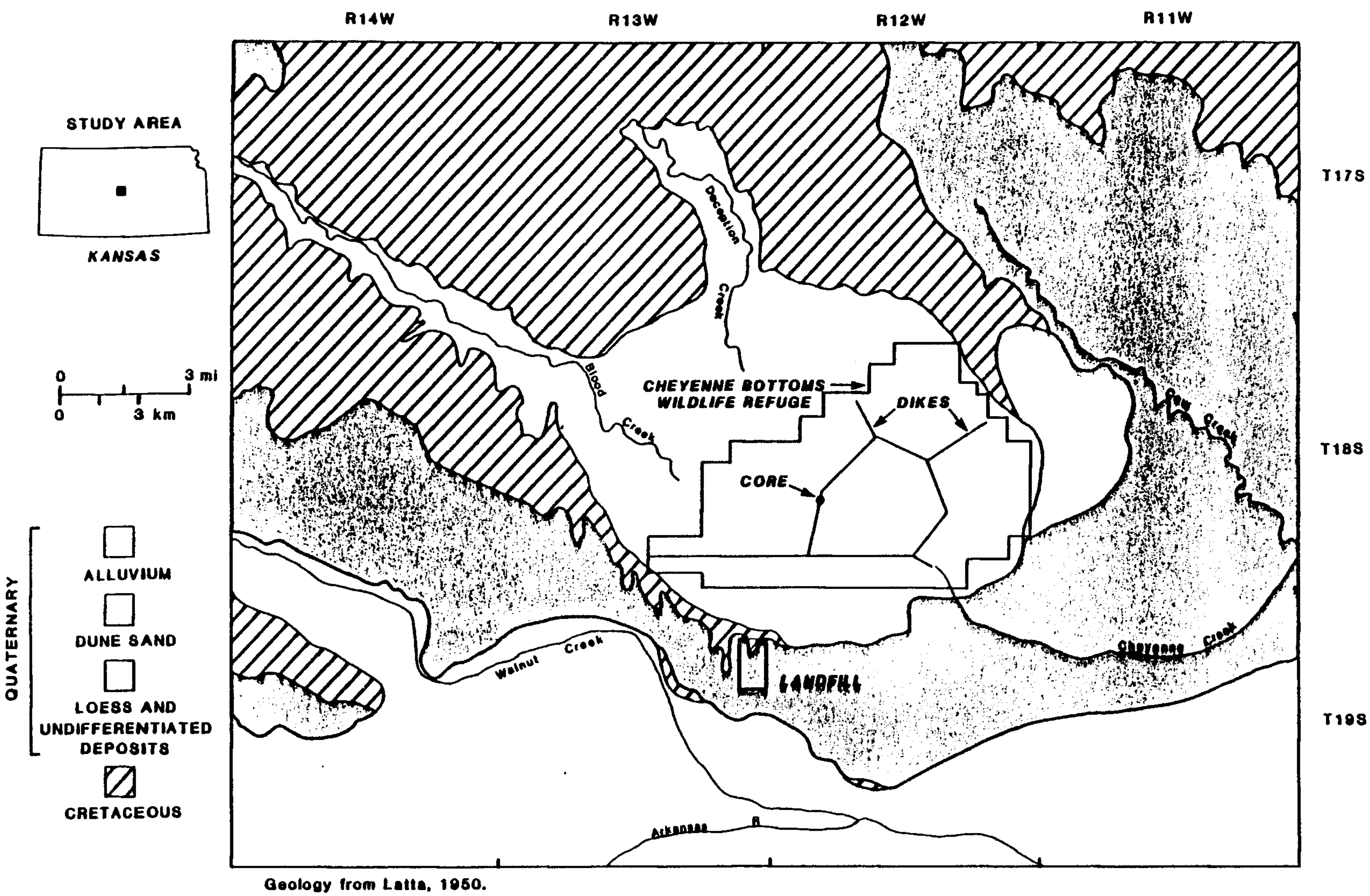


Figure 2.1: Geology and surface hydrology of Cheyenne Bottoms and surrounding area. Location of 1985/87 coring site is shown near the center of the Cheyenne Bottoms Wildlife Refuge.

this basin occurred. To the extent the data allow, the general history of the basin formation and subsequent sedimentation will be explored. A complete geological history of the Cheyenne Bottoms basin is beyond the scope of this study, and is not essential to the study objectives.

Along its southern rim, Cheyenne Bottoms is separated from the Arkansas River by a bedrock-defended, 15-meter-thick loess divide (Figure 2.1). This divide includes both pre-Wisconsinan and Peorian loess units. The same Quaternary deposits also appear in the Cow Creek drainage basin east of Cheyenne Bottoms. The apparent age and topography of these deposits suggest that the basin has never been a part of the Arkansas River valley. Also to the east of the basin proper is a small field of fossil sand-dunes of unknown age. To the west and north, Cheyenne Bottoms is flanked by Cretaceous sandstones, limestones, and shales, some of which are blanketed by thin Quaternary sediments (Figure 2.1).

The *Typha* marshlands within the Cheyenne Bottom basin serve as a major stop-over for migratory waterfowl along the central North American flyway (Kansas Biological Survey and Kansas Geological Survey, 1987). Because of their importance to migratory waterfowl, the hydrology of these marshlands has been managed since the early 1950s. At that time, extensive water-control structures were built. This artificial management of the hydrology of the basin includes importing water from the Arkansas River drainage and creation of an outflow via Cheyenne Creek into Cow Creek watershed (Figure 2.1).

Prior to this management of the basin, the marshes were watered only by Blood Creek and Deception Creek, both of which have relatively small drainage basins when compared with the size of the Cheyenne Bottoms basin. The combined, meager mean annual discharge of these small drainage basins is not sufficient to perpetuate the wetlands in the present climatic regime (Sadeghipour and McClain, 1987). The surface flow of these two creeks may, however, have been significantly reduced by recent human modification of the landscape.

On the southeastern side of the Cheyenne Bottoms basin, a gap in the divide separating the Bottoms from the Arkansas River valley is occupied by Cheyenne Creek (Figure 2.1). Cheyenne Creek drains into Cow Creek, which flows into the Arkansas. The Cheyenne Creek drainage was straightened and deepened as part of the water-control improvement project. Prior to this improvement, Cheyenne Creek terminated two miles southeast of the basin. Its headwaters at that time were approximately 30 feet above the floor of Cheyenne Bottoms. As part of the initial field investigations of the Cheyenne Bottoms basin, the gap associated with Cheyenne Creek was investigated as a potential paleo-spillway for the basin. No evidence was found that this gap had ever served as a spillway for the basin.

Cheyenne Bottoms Soils

Also sought at that time were any indications of beach deposits around the basin which would be associated with Quaternary high-water stands. Especially intriguing in regard to potential paleo-high-water stands were the concentric zones of coarser (loamy) soils around the southern and eastern sides of the basin (Dodge et al., 1981). Drummond silt loam occupies the broad area of mud-flats and marshlands of the central Cheyenne Bottoms basin. Only slightly higher in elevation above the Drummond soil is the coarser Tabler silt loam. This soil also forms a ring around the southeastern side of the basin. At its highest, this zone is only about one foot above the modern level of water fluctuation. The coarser texture and distribution of this soil suggests that it may be the result of low energy littoral deposition or sorting during the late Quaternary.

The Naron fine sandy loam along the eastern side of the basin may also be the remnant of littoral deposits from a higher water stand. The Naron soil rings the basin at about 1800 ft. (a.m.s.l.), or 5 feet above the lower Tabler soil zone. Following this 1800-foot contour around the southern side of the basin, the Naron soil is replaced by the slightly finer textured Harney silt loam. Farther west along this same contour, the Harney appears to grade into the yet slightly finer Geary silt loam.

Two hypotheses could explain this textural gradation of soils in the basin. First, higher littoral wave energy along the eastern and southern sides, due to prevailing wind direction, may have resulted in coarser textured beach deposits. Second, eolian deposition by prevailing winds out of the northwest may have resulted in spatially sorted eolian deposits along the southern and eastern sides of the basin. Both of these processes may have affected the modern distribution of soils around the basin. The effects of eolian sorting of sediments are especially evident along the western side. There Naron soils not only exist as a concentric zone parallel to the modern shoreline, but are also interspersed with other soils in the small sand dune field (Dodge et al., 1981).

Based on these preliminary field investigations, it does not appear that water levels in Cheyenne Bottoms ever exceeded the 1800-foot level. Nor does it appear likely that the Cheyenne Creek drainage ever served as a spillway for Cheyenne Bottoms. However, eolian movement of material along the southeastern side of the basin makes the identification of higher, and perhaps older, beach deposits problematic. Any shoreline deposits here could have been subsequently obscured by eolian processes.

Soils and Quaternary sediments within the Cheyenne Creek and Cow Creek drainages support the hypothesis that these creeks did not act as a spillway for the basin. Instead of high-energy alluvial sediments, the soils of these drainages are developed on broad flat areas of finer textured sediments (Dodge *et al.*, 1981). Higher energy alluvial sands and gravels within these drainages are deeply buried. Previous investigators have correlated these deeply buried alluvial sediments with others in the region as part of the ancient Chase Channel (Fent, 1950; Latta, 1950). The relationship, if any, between these deep alluvial sediments and the Cheyenne Bottoms basin remains unknown.

Local and Regional Vegetation

Cheyenne Bottoms is located in the mixed-grass region of the central Great Plains (Kuchler, 1964, 1974). The natural vegetation of the uplands of the region is dominated by little bluestem (*Andropogon scoparius*), big bluestem (*Andropogon gerardi*), sideoats grama (*Bouteloua curtipendula*), and blue grama (*Bouteloua gracilis*). Edaphic conditions in the broad Arkansas River valley and Great Bend sand-dune region to the south of Cheyenne Bottoms support a slightly different natural vegetation. The dominant native grasses of these sandy lowlands include little bluestem (*Andropogon scoparius*), big bluestem (*Andropogon gerardi*), sandreed (*Calamovilfa longifolia*), and switchgrass (*Panicum virgatum*). Common in the western portion of the Great Bend of the Arkansas River is sandhill sage (*Artemisia filifolia*). Documentation of the grasslands throughout periods of varied moisture conditions make it clear that the relative dominance of these species within a community is subject to major, rapid fluctuations in response to short-term climatic changes (Kuchler, 1974).

The distribution of plant communities within the Cheyenne Bottoms wetlands has been significantly altered by the construction of dikes and other water-control structures. Today, three associations or communities of native vegetation are recognized within the wetlands: 1) open-water/mud-flat community, 2) cattail/bullrush community, and 3) saltgrass/wheatgrass/spikesedge community (Brooks and Kuhn, 1987). The constitution of these communities is primarily controlled by water depth and permanence of the standing water-body, although water salinity and other edaphic effects are also important. Prior to the construction of the dikes, these communities formed more or less concentric zones around the central deep pool (Brooks and Kuhn, 1987).

Fluctuations of water level within the wetlands causes the lowest, central areas of the Cheyenne Bottoms basin to alternate between open water and barren mud-flats, depending on the total annual precipitation within the drainage basin (Brooks and Kuhn, 1987). Since the building of water-control structures, the open-water community of the central pool has become somewhat more stable. Even so, submersed and floating-leafed plants, such as naiad (*Najas quadalupensis*) and pondweed (*Potamogeton* spp.), are almost non-existent. As the water level is drawn down over the course of a typical summer, a community of annual plants becomes temporarily established on the newly-exposed mud-flats. This mud-flat community includes a number of Chenopodiaceae species, Asteraceae species, other grasses, and forbs which tolerate moderate salt concentrations. Looking toward the interpretation of the pollen record, it is important to note that many of the species of the mud-flat community, including kochia (*Kochia scoparia*), Russian thistle (*Salsola iberica*), sea-blite (*Suaeda depressa*), chenopods (*Chenopodium* spp.), and pigweeds (*Amaranthus* spp.), all produce pollen of the Cheno-Am type. Plants of the Asteraceae family include the saltmarsh aster (*Aster subulatus*), beggar's tick (*Bidens* spp.), and sumpweed (*Iva* *annua*). Grasses of the open-water/mud-flat community include the salt-tolerant barnyard grasses (*Echinochloa* spp.) and sprangletop (*Leptochloa fascicularis*). Also present are forbs including annual smartweeds (*Polygonum* spp.), snow-on-the-mountain (*Euphorbia marginata*), and carpetweed (*Mollugo verticillata*).

On the slightly higher zone fringing the open-water/mud-flat community, the vegetation is dominated by cattail (*Typha angustifolia* and to a lesser extent *T. latifolia*). Today this community by far dominates the largest area of the wetlands (Brooks and Kuhn, 1987). The dominance of *Typha* may, however, be a recent phenomenon. Expansion of *Typha* since the construction of the water-control structures is well documented. The recent increase of *Typha* seems to have come about to the detriment of the large bullrushes (*Scirpus* spp.). Today only scattered islands of Scirpus occur throughout the cattail zone.

The third community, saltgrass-wheatgrass-spikesedge, dominates the higher ground surrounding the *Typha/Scirpus* marshland (Brooks and Kuhn, 1987). Within this community, wheatgrass (*Agropyron smithii*) typically dominates the more xeric sites and saltgrass (*Distichlis spicata*) the more mesic localities. In depressions that remain saturated even during the summer, saltgrass may eventually be replaced by spikesedge (*Eleocharis xyridiformis*). Other grasses of this community include cheatgrass (*Bromus tectorum*) and barley grasses (*Hordeum* spp.). Common forbs within this community include yarrow (*Achillea millefolium*), prickly poppy (*Argemone polyanthemos*), wild licorice (*Glycerrhiza lepidota*), hemp dogbane (*Apocynum cannabinum*), inland rush (*Juncus interior*), woolly vervain (*Verbena stricta*), silver nightshade (*Solanum elaeagnifolium*), western ragweed (*Ambrosia psilostachya*) and curlycup gumweed (*Gindelia squarrosa*).

Methodology for Interpretation of Pollen Assemblages

Problems Affecting Local Variability

The reconstruction of past regional vegetation and climate from the Cheyenne Bottoms pollen record is predicated on an understanding of local conditions and how they have affected pollen assemblages. Three local variables are recognized: 1) the size of topographic feature being sampled and its relationship to pollen source area, 2) the nature and history of the depositional environment, and 3) "over-representation" of pollen taxa produced by local vegetation. Each of these local variables can greatly affect pollen assemblage composition (e.g., Cushing, 1967; Jacobson and Bradshaw, 1981). These three factors will be considered separately below.

Source Area for Cheyenne Bottoms Pollen Assemblages

The primary variable in defining the relationship between a pollen sampling locality and the source area for pollen assemblages is simply the size of the sedimentary basin. The diameter of the topographic feature (opening in forest canopy) sampled for pollen correlates directly with the size of the geographical region sampled by this pollen locality (Jacobson and Bradshaw, 1981; Webb et al., 1981; Prentice, 1985). For example, pollen assemblages from large, open lakes with diameters greater than 300 meters typically reflect the homogenized regional vegetation, while pollen assemblages from lakes with diameters of less than 100 meters primarily reflect local vegetation.

In ideal situations, researchers can choose the depositional situation which will enable them to answer specific questions about past vegetational change (Jacobson and Bradshaw, 1981). Most researchers interested in regional vegetation change choose medium-sized, deep-water lakes (Davis, 1963; Webb et al., 1978; MacDonald and Ritchie, 1986). Many recent modern analog studies have focused on the problems of interpreting pollen assemblages from such open-water sites surrounded by forested areas. The size of area not covered by the tree canopy is a critical measure for fitting the pollen catchment area to the site (Jacobson and Bradshaw, 1981). Because these relationships have been explored primarily in large open lakes surrounded by forest, they are difficult to apply directly to Cheyenne Bottoms.

Cheyenne Bottoms is a large oval basin roughly 14 kilometers in diameter. The flat lake bed in the center of the basin is approximately 9 kilometers in diameter and covers 41,000 acres. Historical accounts written between 1800 and 1900 suggest that the size of the open water surface in the center was probably very small (see Brooks and Kuhn, 1987). The 1889 topographic reconnaissance map (1:125,000) made by the U.S. Geological Survey, shows only a small open pool, perhaps several hundred meters across, occurring in the center of flats. The rest of the low, flat lake bed was covered by giant rushes (*Scriptus*) and cattail (*Typha latifolia*, and *T. angustifolia*). Prior to the construction of the water-control structures, the water depth was highly variable and probably seldom, if ever, exceeded a meter. This large, shallow marsh differs significantly from the medium-sized, deep lakes traditionally preferred by Quaternary palynologists.

Several models of pollen transportation into depositional sites have been proposed (Tauber, 1965, 1977; Janssen, 1966; Jacobson and Bradshaw, 1981; Prentice, 1985). These models provide a means for exploring how Cheyenne Bottoms pollen assemblages may differ from those from traditionally-preferred lakes. Tauber (1965, 1977) defined four basic mechanisms for pollen deposition: 1) alluvial or colluvial runoff (C_w), 2) below-canopy or trunk-space eolian transportation (C_t), 3) above forest canopy eolian transportation (C_c), and 4) the component deposited during rainfall (C_r). Jacobson and Bradshaw (1981) added a fifth mechanism that allows Tauber's model to be reconciled with Janssen's (1966) model. This fifth mechanism of pollen deposition is direct (undispersed by wind), gravitational fall from plants growing within or along the edge of the depositional site (C_g).

It is hypothesized that, under modern conditions, the contribution of pollen by alluviation (C_w) into the central wetlands at Cheyenne Bottoms is relatively less important than eolian deposition of pollen. This hypothesis is based on the relatively small drainage areas and low discharges of the primary natural fluvial systems entering the basin, Blood Creek and Deception Creek (Sadeghipour and McClain, 1987). Historically, the discharge from these small creeks emptied into smaller, peripheral wetlands; not into the central wetland where the sampling was done. Although some of the alluvial sediments transported to the basin by these small fluvial systems are reworked across the entire basin, the amount of pollen and sediment reaching the coring site by this mechanism is hypothesized to be far less important than eolian (C_c) influx of pollen and sediment at the coring location in the central basin.

The below-canopy or "trunk space" mechanism (C_t) for pollen transportation and deposition is not relevant to the Cheyenne Bottoms situation. Even if the basin were in the past surrounded by closed upland forests, the size of the marsh itself would likely render this component insignificant. Within mid-latitude forest, the environment for which this model was conceived, the C_t component is the primary factor distinguishing "extra-local" pollen sources from local and regional source areas (Jacobson and Bradshaw, 1981).

Thus eliminating the two components normally considered as extra-local, Cheyenne Bottoms pollen assemblages must therefore represent some balance between the local, gravity component (C_g), and regional components, rain-wash (C_r) and eolian or air-fall (C_c). As Cheyenne Bottoms is compared with modern analog data these differences must be taken into account. Ways in which specific pollen taxa could be affected by this altered model are discussed below.

The Cheyenne Bottoms Depositional Environment

"Depositional environment" here refers to both the sedimentation processes and the geomorphological situation of a sampling locality. As discussed above, depositional factors directly affect how pollen reaches the sampling locality (i.e. pollen rain versus alluvial deposition [Peck, 1973; Bonny, 1978]). It is therefore important to take into account the history of the depositional environment. Evidence for variation in the depositional environment could indicate a change in pollen source areas. For example, a locality may have incorporated the regional pollen components during one period, but have been dominated by the local vegetation component during another. Secondarily, evidence for changes in depositional environment may also be a key in detecting potential problems in pollen preservation (Cushing, 1964, 1967a).

Six forms of evidence contribute to our understanding of the history of the Cheyenne Bottoms depositional environment: 1) sedimentological evidence, 2) the rate of deposition as determined by the radiocarbon chronology, 3) the relative frequency of redeposited pre-Quaternary palynomorphs, 4) the relative frequency of deteriorated or indeterminate pollen, 5) changes in pollen concentration, and 6) changes in the local aquatic and marsh vegetation as documented in the pollen record. Detailed sedimentological laboratory analyses are beyond the purview of this study. Sedimentary evidence at this time is based primarily on visual observation of color and texture.

Distinguishing Local from Regional Pollen Sources

The third major local variable affecting the Cheyenne Bottoms pollen assemblage composition is the local vegetation and its contribution to the pollen assemblage. This is primarily a taxonomic problem, distinct from the basin-size variable discussed above. It is analogous to the problem encountered in distinguishing local from regional pollen source areas in bogs. Mature, stable bog surfaces often grow to support a variety of trees and shrubs. These same tree and shrub taxa are often important pollen producers in the regional forests. Because of this overlap in pollen source areas, it can be difficult to distinguish this local successional process from changes in the regional forest in the pollen record (Janssen, 1966, 1967; 1984; Donner et al. 1978; Jacobson and Bradshaw, 1981).

The Cheyenne Bottoms pollen record presents an analogous problem. Because of the taxonomic limitations of pollen analysis, many of the NAP taxa produced within the local marsh and marsh-fringe plant communities are also the dominant regional pollen taxa. Because the Cheyenne Bottoms situation - an extremely large marsh surrounded by grasslands - is unique, this potential problem has not been thoroughly explored in the literature. There are four important NAP types at Cheyenne Bottoms which are sensitive to both regional and local processes of vegetational change: Cheno-Am, Poaceae, *Ambrosia*-type, and Cyperaceae. The record of each of these will be examined in an effort to distinguish local from regional source areas. Although the recognition of this problem helps mitigate the bias and inaccuracy of pollen assemblage interpretations, it also introduces an additional degree of imprecision. In other words, it may not be possible to exclude alternative, but less likely, interpretations for the same pollen assemblage.

Field and Laboratory Methods

Field Methods

With the cooperation of the Kansas Geological Survey, a nearly continuous, complete sampling of the Quaternary sediments filling the Cheyenne Bottoms basin was obtained. In order to sample from near the central portion of the marsh, cores were taken by drilling through one of the dikes built to impound water within the marsh (Figure 2.1). There was some concern that the construction of the dike could have disrupted the upper portion of the sedimentary record. This does not appear to be the case. The dike was constructed by dredging material from the sides and dumping them in the center over the original surface. The boundary between the disturbed dike materials and *in situ* marsh deposits was well marked by the organic detritus and a zone of roots buried when the dike was constructed. It appears that the pre-dike surface was intact at the core site. The entire section sampled encompasses some 37 meters of Quaternary deposition; however, only the upper 20 meters were suitable for pollen analysis.

A continuous sample of the upper 19 meters of these Quaternary deposits was obtained with a 3-inch-diameter Shelby tube sampler within a hollow-stem auger in 1985. The lower half of the Quaternary sediments, unreachable with the hollow-stem auger, was sampled with a 4-inch-diameter, hollow-barrel coring tube driven by a rotary-drill rig in 1987. Samples of these deeper sediments are less complete and more disturbed than those taken with the Shelby-tube sampler. These deeper core samples do provide a valuable sedimentolgical record of the lower half of the Quaternary section. All cores were measured and described as to Munsell color, structure, and texture as they were recovered from the sampling device. Core segments were then individually wrapped in plastic and aluminum foil, labeled, and stored in core boxes for transportation to the laboratory. In order to retard any deterioration, all cores were curated intact under refrigeration until pollen sampling was complete.

After the 1987 coring was completed, a natural gamma log was taken through the core hole. This gamma log, together with the sedimentological description, provides a general record of change in sedimentation. As is typical of gamma logs, at Cheyenne Bottoms there appeared to be good correspondence between the amount of clays in a stratum and the level of natural gamma radiation. There were, however, a few unexplained situations where this correlation did not appear to hold. This natural gamma log record has proved very useful in describing the overall stratigraphy of the Quaternary sediments which accumulated in the Cheyenne Bottoms basin (Figure 2.2).

Laboratory Sampling of Cores

The first stage of analysis was a reconnaissance of the potential for pollen recovery throughout the section. Eight samples, reflecting the diversity of sediment types, were subjectively sampled from representative horizons from Shelby-tube cores which represent the upper 19 meters of sediment. Similarly, a set of eight samples was processed from the 4-inch diameter cores from the lower portion of the Quaternary section. The objective of these reconnaissance samples was two-fold: first, the confirmation that fossil pollen was preserved and, secondly, to develop efficient methods for the extraction and concentration of fossil pollen from these sediments. As a result of this initial survey, it was discovered that except for one thin clay lens, the lower samples were barren of pollen. The pollen analysis has therefore focused on the upper 19 meters of Shelby-tube core samples.

The final data set used in the analysis consists of 100 samples taken at near-equal (15 cm) intervals throughout the core. Where sedimentary stratigraphy dictated, such as near boundaries or within small, distinct, organic-rich lenses, additional samples were taken. Although subjective sampling methods such as these have been criticized as statistically inappropriate (Birks and Gordon, 1985), given the general lack of regional and local Quaternary palynological

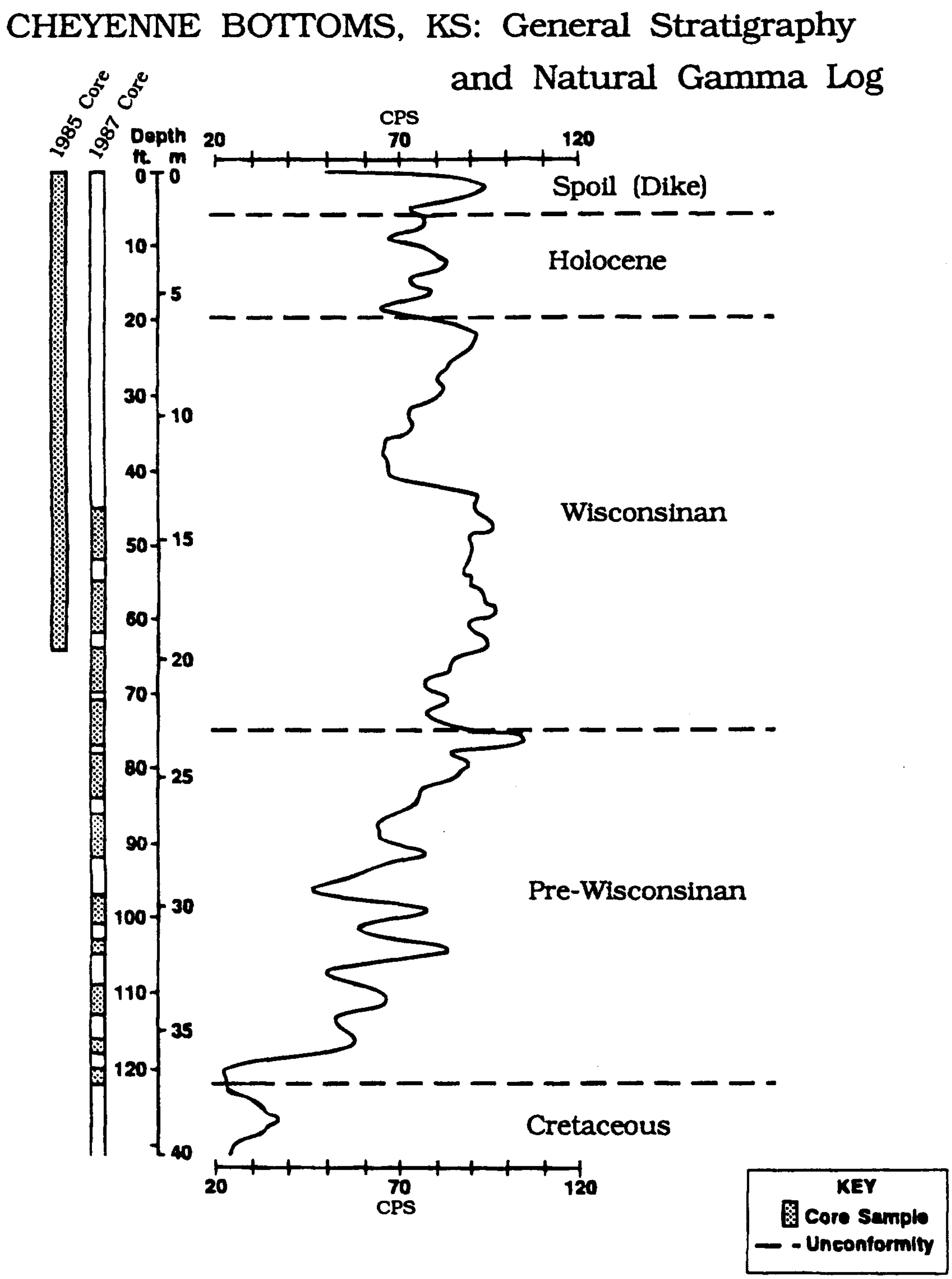


Figure 2.2: General stratigraphy of the Cheyenne Bottoms Quaternary section. Core samples collected in the 1985 and 1987 field seasons shown at left of depth scale and natural gamma log shown to the right. Radiocarbon dating of this record is discussed below (see Figure 3.2).

data, this approach is justifiable. Such subjectively placed samples provide important evidence for palynological differences attributable to local, short-term changes in the depositional environment of Cheyenne Bottoms.

At each sample depth, six 1-cc volumetric samples were taken using a small cylindrical brass sampler (cf. Engstrom and Maher, 1972; Birks, 1976). Each of the volumetric samples was analytically weighed. Estimates of the bulk density of the sediments was made by averaging the weight of all six volumetric samples from each of the sampling depths. A high level of variability in the bulk density estimates is believed to be due to analytical error in the volumetric sampling, and variability of water content. The four most consistent of these volumetric samples were used for pollen and other microfossil analyses. Larger (ca. 200 grams) sediment samples for sedimentological analysis were later taken for each sampled horizon.

Sediment Analysis

Three sedimentological analytical procedures were used to better characterize the Cheyenne Bottoms sediments: 1) analysis of soluable salts, 2) loss on ignition (LOI) assay of organic matter and carbonates, and 3) Bouyoucos hydrometer analysis for texture (sand, silt, and clay). The complete results of these analyses are provided in Appendix II.

A simple centrifugation technique for extraction of soluble salts was used (modified from Davies and Davies, 1963). The relative amount of salts in the extracted solution was measured with a conductivity meter and the results are reported in milli-mhos. This procedure provides a relative measure of the soluble salts in the sediments rather than an estimate of salt concentration in soil solution.

The LOI procedure is a modification of that outlined by Dean (1976). Because of differential drying of the cores, the air-dry weight, rather than the wet weight, is used as the basis in the estimates reported for Cheyenne Bottoms. Temperatures of 550 and 1000 degrees C were used for the determination of organic matter (OM) and carbonates, respectively. Three components are included in the LOI carbonate determination: 1) detrital dolomite and other carbonate rock, 2) carbonate shells of gastropods and ostracods, and 3) a minor amount of crystal lattice water from the clays (Dean, 1976). The LOI data reported are the percent of air-dry weight.

A modified hydrometer method was used to estimate the relative proportions of sands, coarse silts, medium silts, fine silts, and clays in each sample (Bouyoucos, 1962; Day, 1965). The coarse and medium silts are combined in Figure 3.2. The data are reported in their entirety in Appendix II.

Pollen Extraction

Concentration of pollen and other botanical microfossils was achieved using the heavy-liquid flotation methods outlined by Johnson and Fredlund (1985) and Fredlund (1986). This method was preferred over selective oxidation methods employing hydrofluoric acid (HF) because of its efficiency in recovering a broad range of microfossils. Experiments using both heavy-liquid and HF procedures on Cheyenne Bottoms sediment indicated that, although the HF procedures frequently resulted in a somewhat cleaner pollen residue, other microfossils such as diatoms, phytoliths, and fragments of leaf cuticle were damaged or destroyed. As these additional sources of data are also of interest, heavy-liquid flotation was the preferred method. The heavy-liquid flotation procedure used on the Cheyenne Bottoms sediment samples consisted of four stages: 1) clay and organic colloid removal, 2) carbonate removal and acidification, 3) specific gravity fractionation (heavy liquid flotation of pollen and other organics), and 4) stabilization and storage of residues.

Clay and Organic Colloid Removal: In this first stage, each 4-cc sample was treated with 50 ml of sodium pyrophosphate (0.1 molar solution) and agitated for twelve hours. This treatment served two purposes: dispersal of clays and organic colloids, and oxidation of fine organics. Following the twelve-hour period of agitation, the silt- and sand-size particulates were allowed to settle and the clays and oxidized organics were decanted. To insure that no pollen or other microfossils were lost during the decanting of the clays, the suspension was poured through a 5-micron mesh screen and the material caught was back-washed into the sample. This process of decanting materials in suspension was repeated until all of the clays had been removed.

Carbonate Removal and Acidification: The second stage was the treatment of the remaining sample with 25 ml of 10% hydrochloric acid. This reagent has two purposes: 1) it results in the oxidation of carbonates and similar soluble material, and 2) it also lowers the pH in preparation for the heavy-liquid flotation. This treatment was followed by two washes with distilled water.

Specific Gravity Fractionation: Zinc bromide solution was used to fractionate the remaining materials. Pollen and other light organics were floated out of the sample in a 2.00 specific gravity solution. This flotation was repeated three times. Heavier microfossils, including phytoliths, charcoal, and leaf-cuticle fragments, were then recovered from the remaining clastic minerals by flotation in a 2.35 specific gravity zinc bromide solution.

Stabilization and Storage of Residues: The 2.00 and 2.35 specific gravity fractions were then washed with distilled water in preparation for storage. The lighter, pollen-rich fraction was dehydrated with isobutal alcohol and stored in a 2-dram vial in silicon fluid (viscosity 2000 c.s., refractive index about 1.45). The heavier, 2.35 fraction was washed and stored dry in a separate 2-dram vial.

Pollen Identification and Counting:

Pollen identification and counting followed standard procedures (Birks and Birks, 1980). Permanent mounted slides of the residues were systematically searched using a Leitz photomicroscope under 400X magnification with up to 1000X magnification used during actual identification of grains. The identification of pollen taxa utilized both published descriptions and modern pollen reference samples. The latter samples included a number of boreal forest taxa taken from herbarium sheets on loan from Alberta Provincial Herbarium. Other modern taxa used came from herbarium sheets of plant specimens collected at Cheyenne Bottoms by the University of Kansas Herbarium staff.

Except for a few samples with extremely low pollen concentration and poor preservation, which will be discussed more fully below, a minimum of 300 pollen grains was identified for each sample. The relative frequency (percentage) of each taxon for each sample was based on the unmodified pollen sum including known aquatics, which were relatively rare, as well as pollen taxa from plants which have a more ambiguous climatic signal (e.g Cyperaceae). The pollen counts for all taxa are presented in Appendix III.

Size Analysis of Pine Pollen:

During preliminary counting of exploratory pollen samples, it became apparent that several species, or sub-types of *Pinus* pollen, were present in Cheyenne Bottoms. Differences in the size of the pollen grains was the most obvious means of distinguishing among species or types (Whitehead 1964; Hansen and Cushing, 1973). During normal pollen counting, *Pinus* grains were roughly classified as "small" (maximum cap diameter less than 40 microns) or "large" (maximum cap diameter greater than 40 microns). The smaller *Pinus* sub-type, lacking distal verrucae (section Diploxylon) is probably *P. banksiana*. Rarely did the larger-diameter *Pinus* grains have distal verrucae (section Hyploxylon), but most did not or were indeterminable. The larger Hyploxylon type which exhibited distal verrucae may be *Pinus flexilis* (Hansen and Cushing, 1973). There are undoubtedly a number of pine species represented by this group (labeled "*Pinus* other" on Figure 3.7).

Zonation of Pollen Data

The grouping of the percentage pollen data into stratigraphic zones was based on the results of CONISS, a stratigraphically constrained cluster analysis program utilizing the incremental sum of squares method (Grimm, 1987). The CONISS clustering was made using the 18 primary taxa and taxa-groupings shown on the primary pollen percentage diagram. A square-root transformation was made of the data, thereby utilizing the Edwards and Cavalli-Sforza's cord distance for generation of the dissimilarity coefficients used in the final cluster analysis (Grimm, 1987).

Estimation of Pollen Concentration

Estimates of pollen concentration were calculated by introducing a known number of exotic *Lycopodium* spores (2 tablets from batch 201890 from the Kvartarbiologiska Laboratory) into each sample during the initial stage of pollen extraction. The ratio of identified introduced spores to identified fossil grains was then used to estimate the total number of fossil pollen grains and spores in each sample (Benninghoff, 1962).

Observations on Pollen Preservation

Data on pollen preservation were collected by counting the occurrence of indeterminate (unidentifiable) pollen grains in each sample. A system of four categories, modified from Cushing (1967a), was used to better understand the causes of indeterminability. These categories are: 1) grains which had been chemically degraded or corroded, 2) grains which were broken or fragmented, 3) grains which had been folded or collapsed in on themselves, and 4) grains which were obscured or concealed by organic detritus or mineral grains. Each indeterminate grain was subjectively categorized as to which of these causes appeared to be the primary reason it could not be identified. Although it is recognized that more than one factor often affects our ability to identify any single grain (Delcourt and Delcourt, 1987), this simplified system greatly facilitated the collection of data on pollen preservation. The tallies for these categories of indeterminablity are reported as percentages of the total number of fossil palynomorphs counted.

Other Analysis

Although other botanical microfossils, including opal phytoliths, charcoal, and leaf cuticle fragments, were also collected for each sample, it was beyond the purview of this dissertation to fully analyze these data. This is likewise true of recovery.

Macrofossils, however, appear to be rare in the Cheyenne Bottoms sediments. During the sampling of the cores for microfossil analysis, only a precious few macrofossils were recovered. The recovered fossils were seeds, likely from semi-aquatic marsh plants. Although there were layers of fine charcoal and other carbonized plant fragments in the cores, there were no obvious layers of larger fossils such as leaves or wood. The recovery of even rare botanical macrofossils is important for they provide materials suitable for dating through accelerator mass spectrometry.

Radiocarbon Dating of Sediments

The selection of core segments for radiocarbon dating was made only after the biostratigraphic (palynological) framework of the section had been established and close-interval sampling of the core segment was completed. Several of the core segments submitted for radiocarbon assay were specifically chosen because both the lithology and biostratigraphy suggested the possibility of a Pleistocene-Holocene unconformity.

The selection of core segments for radiocarbon dating was not based solely on the stratigraphy. The nature of the sediments themselves greatly affected this decision. The sedimentological characteristics which governed sampling decisions were: 1) the low organic matter content of the core and 2) potential contamination of sediments with "old carbon" from the surrounding calcareous country rock. Together, these sedimentary characteristics may result in radiocarbon assays thousands of years older than actual ages (Olsson, 1979; Davis, 1989; MacDonald *et al.*, 1991). In order to minimize potential old carbon contamination, core segments containing higher organic content and coarser organic materials were given preference for dating (Bjorck and Hakansson, 1982; Davis, 1989; MacDonald *et al.*, 1991). The only means to totally avoid this potential contamination is the use of accelerator mass spectrometry (AMS) dating of terrestrial macro-fossils. Grant support for AMS dating of the Cheyenne Bottoms core is currently being sought.

CHAPTER 3

RESULTS OF INVESTIGATION

Description of Quaternary Section

Evidence from the 1985 and 1987 coring operations indicates that just over 37 meters of unconsolidated sediments, presumably Quaternary in age, fill the Cheyenne Bottoms basin at its center. Interpretations of changes in depositional environment throughout this 37-meter section are based on 1) the natural gamma log taken through the 1987, 4-inch diameter, core hole and 2) observations made on the sequence of core samples from the 1985 and 1987 field seasons (Figure 2.1).

The sedimentary evidence from the 1985/87 cores is generally corroborated by the only other description of the entire Quaternary section of Cheyenne Bottoms, that from the 1946 driller's log published by Latta (1950:178). This 1946 boring was done at the southwest corner of section 21, T. 18 S., R. 12 W., within what is now the central enclosed pool of the Cheyenne Bottoms Wildlife Management Area. The 1985/87 coring site is located on the dike only 1.2 kilometers northwest of the 1946 coring site. The 1946 core documented 112 feet (34.2 meters) of Quaternary sediments. This is approximately the same depth (34.1 meters) documented by the 1987 core, after accounting for the thickness of the dike. Most of the sedimentological changes observed in these two independent records occur at roughly the same depths. This general correspondence between the two measured sections suggests that the major stratigraphic units observed are representative of basin-wide phenomena, rather than local depositional changes.

The 35 meters of unconsolidated sediments which lie between the buried pre-dike surface and the Cretaceous sediments below are divided into three major stratigraphic units: 1) a lower pre-Wisconsinan unit, 2) a Wisconsinan unit, and 3) a Holocene unit (Figure 2.2). Chronological labels given to these stratigraphic units are based on results presented below (see Radiocarbon Analysis of Sediments).

The Pre-Wisconsinan Unit

Preliminary investigations of the pre-Wisconsinan sedimentary unit showed that it was by and large unsuitable for pollen analysis. Pollen is not preserved in these pre-Wisconsinan sediments. The pre-Wisconsinan sedimentary record does not bear on the primary objective of the dissertation, but is interpreted as to the geological history of the basin. Using the modern dike surface as the origin, the base of the "Pre-Wisconsinan" unit lies approximately 37 meters below the dike surface (m.b.s.). Core samples taken from below this contact are comprised of consolidated Dakota Sandstone of Cretaceous age.

From approximately 37 m.b.s. to 24 m.b.s., the sediments are composed of layers of sands and gravels alternating with layers of finer silts and clays. These fluctuations in sediment texture are readily distinguishable in the natural gamma log record (Figure 2.2). These textural fluctuations, especially at the base of the pre-Wisconsinan unit where coarse sand and gravel units are most pronounced, are good evidence of rapid alluvial deposition. These episodes of alluvial deposition show up in the natural gamma log as large alterations between 40 (representing sandy strata) and 80 (representing clayey strata) Curies per second (CPS). Within the pre-Wisconsinan unit, particle size generally fines upward from gravels and sands at the Quaternary-Cretaceous unconformity to silts and clays at about 24 m.b.s., the upper boundary of the unit (Figure 2.2).

Capping the pre-Wisconsinan unit is an approximately one-meter-thick sedimentary unit (23 and 24 m.b.s.) These sediments exhibit a distinctive peak of over 100 CPS in the natural gamma log (Figure 2.2). Core samples from the 1987 boring show this unit to be a dense, clay-rich stratum. The genesis of this sedimentary unit is not known. It is hypothesised that this unit may represnt a trucated paleosol. Whatever its origin, this unit represents a major change in the type of sedimentation occurring in the basin.

The Wisconsinan Unit

The sedimentary unit described above, a hypothesized paleosol, divides the alluvially deposited pre-Wisconsinan unit from the Wisconsinan unit of very different sediments (Figure 2.2). Results of the sedimentological analysis of the Wisconsinan and Holocene units from the 1985 core are presented on Figure 3.1. Sedimentological observation of the Wisconsinan unit based on the 1985 core are summarized on Table 3.1.

The Wisconsinan sedimentary unit extends from about 23 m.b.s at its base to 5.88 m.b.s at what is believed to be the Pleistocene-Holocene boundary. Although varied in color and structure, the sediments are predominantly silty clays. Lacking from the Wisconsinan sedimentary unit are any major bedding features which would suggest episodic alluvial deposition. This suggests that the processes of sediment transportation and deposition remained more or less constant throughout the time of accumulation of the Wisconsinan unit.

A curious feature observed within much of the Wisconsinan sedimentary unit are fine sedimentary laminations, alternating from sandy to silty clay texture. Although thin stringers of sand, which represent one phase of these laminae, had been observed during the pollen sampling, the stratigraphic extent of these sedimentary structures was not appreciated until the cores had been allowed to air dry. These sand stringers occur throughout most of the lower half of the Wisconsinan sedimentary unit (ca. 10.24 to 19.21 m.b.s.), but

CHEYENNE BOTTOMS, KS: Sediment Analysis

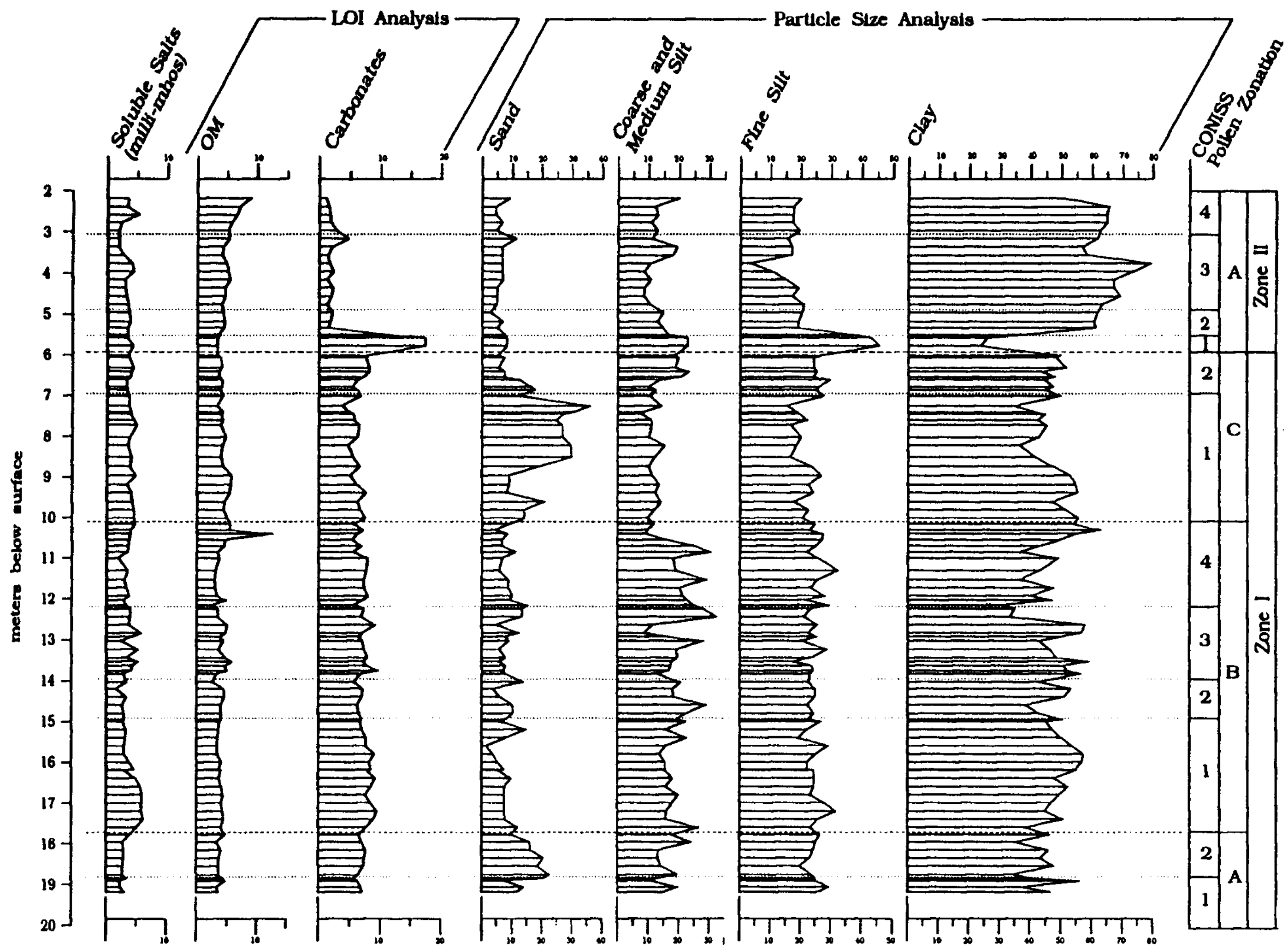


Figure 3.1: Sedimentological analysis of 1985 core. LOI and particle size data reported as percent dry weight. Pollen zonation, shown at right, is discussed below (see Figure 3.3).

Table 3.1: Sedimentary description of 1985 core based on the pollen zonation (see Figure 3.3). Pollen Zone I is equivalent to the Wisconsinan sedimentary unit, while pollen Zone II conforms stratigraphically with the Holocene sedimentary unit.

Depth m.b.s (& length)	Sedimentary Unit Description	Pollen Zone
0.0 to 2.18 (2.18)	Clay, black (10YR 2/0), structureless, compact (Dredged dike materials).	None
2.18 to 3.06 (0.88)	Clay, very dark grayish brown (10YR 3/2), medium blocky structure (Drummond Soil).	IIA4
3.06 to 4.86 (1.80)	Clay, gray brown (10YR 4/2), fine angular blocky structure.	IIA3
4.86 to 5.54 (0.68)	Clay, very dark grayish brown (10YR 3/2), medium blocky structure (Early-Holocene Paleosol).	IIA2
5.54 to 5.88 (0.34)	Silty loam, gray (7.5 Y 7/2), lacking structure, containing broken mollusc shells, diatomaceous.	IIA1
5.88 to 6.95 (1.07)	Silty clay, mottled dull orange (7.5YR 6/4) to dull brown (7.5YR 5/4), laminated sedimentary structure and sand stringers rare.	IC2
6.95 to 10.10 (3.15)	Clay loam, grading from yellow brown (10YR 5/4) at base to dull orange (7.5YR 6/4) towards top.	IC1
10.10 to 12.26 (2.16)	Silty clay, dull yellow brown (10YR 3/4) to brown (10YR 4/4), zones of fine angular blocky structure alternating with zones of laminated sedimentary structure, numerous thin stringers of charcoal occur at the base of unit	IB4
12.26 to 14.98 (2.72)	Silty clay, shades of brownish gray (10YR 3/3 to 5/3), laminated sedimentary structures including 1mm-thick sand stringers	IB3 & IB2
14.98 to 17.88 (3.10)	Silty clay, gray (10YR 5/1) with several 10cm-thick zones of olive gray (5Y 5/2), zones of fine blocky structure typical but laminated sedimentary structure including thin lenses of charcoal and OM also occur.	IB1
17.88 to 19.21 (1.42)	Silty clay, olive gray (5Y 5/2) at top to grayish brown (2.5Y 5/2) at base, fine blocky structure toward top with base more compact and structureless.	IA1 & IA2

are apparent only rarely in the upper half of the unit (5.88 to 10.24 m.b.s.). These sedimentary structures are most pronounced from approximately 11 to 13 m.b.s. Within this area of the core, individual lamina measure from 6mm to 8mm in thickness. Thin stringers of charcoal also occur within the laminae of this zone. Typically these laminae have thicknesses of 1 to 2 mm throughout the Wisconsinan sedimentary unit. The origin of these finely laminated sediments remains unclear. They do not appear to conform with the expected color and textural oscillations of classical varves.

Observations of color and textural changes within the Wisconsinan sedimentary unit reinforce differentiation between upper and lower Wisconsinan sub-units. The lower Wisconsinan sub-unit is characterized by grayish (reduced?) sediments (ca. 19.21 to 10.24 m.b.s). The upper Wisconsinan sub-unit is characterized by sediment ranging in color from browns to orange (oxidized?) and lacking any structure (ca. 10.24 to 5.88 m.b.s). The stratigraphic break between these sub-units appears gradational both in sedimentary change (Table 3.1), and in the pollen record, discussed below.

A change in the natural gamma log further supports this subdivision of the Wisconsinan unit. Approximately at the boundary between these Wisconsinan sub-units (ca. 12 to 13 m.b.s) a significant break occurs in the natural gamma log (Figure 2.2). At about 13 m.b.s the gamma log begins to fall from approximately 90 CPS, characterizing the lower half of the Wisconsinan unit, down to almost 60 CPS at about 12 m.b.s. Following this sharp drop, the gamma log again begins to climb as if in response to an upward fining in the texture. The cause of this sharp break in the natural gamma log is unknown. Although the color of the sediments does begin to change around this depth, a corresponding abrupt change in texture is not visually apparent (Figure 3.1).

The Holocene Unit

The Holocene sediments are distinctly different from those of the Wisconsinan unit previously described. The Holocene unit is divided into three sub-units: 1) a lower Holocene silty textured unit (5.88 to 5.54 m.b.s.), 2) an upper Holocene clay-loam unit (5.54 to 2.18), and 3) the compacted sediments which comprise the 1940 constructed dike (2.18 to 0.00 m.b.s). The upper Holocene sedimentary unit (5.54 to 2.18 m.b.s.) is divisible into three finer sedimentary units which are reflected in the pollen record as well (Table 3.1).

The lower Holocene unit is defined by sharp changes in sedimentology at its base (5.88 m.b.s.) and at its top (5.54 m.b.s.). This unit is significantly siltier in texture than either the Wisconsinan sediments which lie below or the remainder of the Holocene unit which lies above. The most striking feature of the lower Holocene sedimentary unit, however, is the abundance of faunal material. This unit is littered with whole and broken mollusk shells from both snails and bivalves. Microscopic inspection of these sediments shows a significant component of diatom frustules.

Ostracods, among other as-yet unidentified fossils, are also abundant. The abrupt sedimentological breaks in this portion of the core suggest that the record might not be continuous as originally assumed. Rather, it might include at least one unconformity at or near the Pleistocene-Holocene boundary. The depositional environment represented by this unit remains a puzzle. The coarsening of these sediments appears to come primarily from the silts, rather than sands.

The upper Holocene sedimentary unit (5.54 to 2.18 m.b.s.) is divided into three sub-units based on color, primarily due to organic matter, and structure (Table 3.1). It is hypothesized that these observed sedimentary changes are a reflection of changes in the pedogenic regime during the Holocene. The age determination included in these descriptions is based on radiocarbon analysis discussed below. The lower Holocene sub-unit (5.54 to 5.00 m.b.s.) appears darker in color (10YR 3/2), and has stronger blocky structure than the sediments above or below. The middle sub-units (5.00 to 2.90 m.b.s) are typically grayish brown (10YR 4/2) and exhibit a tabular or weak blocky structure. The upper Holocene sub-unit (2.90 to 2.18 m.b.s) appears very much like the early-Holocene paleosol unit described above. It is enriched in decayed organics and has a strong blocky structure. A thin zone of rootlets and undecayed plant fragments (2.20 to 2.18 m.b.s.), representing the old, pre-dike surface, caps this stratum.

The 2.18 meters of sediment above the Holocene sedimentary unit represent the dike which was constructed around 1940. The dike material is readily distinguishable from undisturbed sediments below it. The dike material is compact, mottled or blotchy in color, and structureless (Table 3.1)

Radiocarbon Analysis and Rates of Sedimentation

Introduction to Dating

Radiocarbon age determinations were made on six samples from the continuous 1985 core (Table 3.3). These ^{14}C ages provide the basic late-Quaternary chronological outline for the Cheyenne Bottoms section. The center of each of the dated core segments (mid-depth), expressed in meters below surface (m.b.s), is presumed to be the horizon corresponding to that radiocarbon age. The total core-length of the dated segment is also provided (Table 3.3).

Radiocarbon ages were processed in two different labs: University of Texas Radiocarbon Laboratory (TX) and Dicarb Radioisotope Co. (DIC). The pretreatment of radiocarbon samples by these labs differs. While both labs use a hydrochloric acid pretreatment for the removal of carbonates, only the TX laboratory employs a base (potassium hydroxide) treatment for the extraction of organic carbon. It is this base-soluble organic fraction that is then dated by the TX laboratory. The two DIC radiocarbon ages are the results of burning bulk sediments including both the base-soluble and base-insoluble organic carbon. The TX radiocarbon ages have been corrected based on measured $\delta\ ^{13}C$ values relative to a non-depleted standard ($\delta\ ^{13}C$= -25 parts per mil).

Table 3.3: Radiocarbon age determinations of Cheyenne Bottoms core segments. Ages are reported in radiocarbon yr. B.P. Mid-depths reported for dated core segments are in meters below present ground surface. Where stable carbon isotope ratio analysis was done, the corrected dates were used. Uncorrected ages are provided in parentheses.

Mid-Depth	**Core-Length**	**Radiocarbon Date**	**Standard Error**	$\delta\ ^{13}C$	**Lab No.**
3.54	0.68	5,480 (5,410)	±130 (130)	-20.7	TX-6737
5.34	0.40	9,690	+210 -200	———	DIC-3323
6.51	0.20	24,470 (24,340)	±2030 (2000)	-17.14	TX-6266
11.94	0.12	25,730 (25,620)	±2160 (2130)	-18.50	TX-6267
12.56	0.64	30,220	+740 -810	———	DIC-3313
17.44	0.66	29,340 (29,240)	±1340 (1340)	-19.13	TX-6268

Potential Dating Problems

The additional pretreatment of radiocarbon sediment samples used by the TX laboratory is done to mitigate the potential contamination of these limnic sediments by older, pre-Quaternary carbon. This method of treatment works best if the contamination is from older detrital materials blowing or washing into the sedimentary basin. This material tends to be less base soluble, and therefore is excluded by the extraction process. One means of monitoring influx of older detrital contamination is by observing the changes in the concentration of pre-Quaternary palynomorphs (Nambudiri et al., 1980). These data for Cheyenne Bottoms are discussed below (see Figure 3.6).

Unfortunately, much of the old-carbon contamination is not detrital material, but dissolved materials carried by run-off and groundwater. Such old-carbon contamination is often called "hard-water" contamination (Deevey et al., 1954). The primary source of hard-water contamination at Cheyenne Bottoms is from the dissolution of older carbonate rock as surface and groundwater pass over and through it. Such inflow of dissolved materials can result in lake waters which are ^{14}C deficient and therefore not at equilibrium with atmospheric CO_2 (Turner et al., 1983; Stuiver, 1975). This ^{14}C-deficiency of lake water has been referred to as the "reservoir effect" (Stuiver and Polach, 1977). A recent investigation compared radiocarbon dates of terrestrial and aquatic macrofossils with limnic sediments in Canada. This study demonstrated that the propensity for a wide range of aquatic organisms to reflect the carbon isotopes of the lake water, rather than the atmosphere, is far greater than most had suspected (MacDonald et al., 1991).

Detection of ^{14}C deficiencies in limnic materials is difficult. One means which has proved useful is the monitoring of the $\delta\ ^{13}C$ of the dated materials (Stuiver, 1967; MacDonald et al., 1991). Terrestrial plant materials should have values of $\delta\ ^{13}C$ ranging from -24 to -34 parts per mill, while organic materials from salt marshes have depleted values of $\delta^{13}C$ ranging from -8.6 to -18.3 parts per mill (Stuiver, 1976). The $\delta^{13}C$ values reported for the TX radiocarbon dates generally fall into the latter, depleted range (Table 3.3).

At present, no universal solution exists for the detection and correction of erroneous ^{14}C dates from limnic deposits (MacDonald et al., 1991:1154). The best solution to the dating problems for the Cheyenne Bottoms sediments is accelerator mass spectrometry (AMS) of terrestrial macrofossils. Until AMS dating of terrestrial macrofossils has been completed, the exact magnitude of old-carbon error in the Cheyenne Bottoms radiocarbon chronology will remain unknown. Based on other research cited above, the Cheyenne Bottoms radiocarbon dates are probably around 2,000 to 3,000 years too old. While such an error is significant, the major chrono-stratigraphic distinctions made in this study (i.e. Farmdalian versus Holocene) remain valid.

The Holocene

In spite of the above caveat, radiocarbon dating of the Cheyenne Bottoms sediments has established a basic chronological framework with which to work. The Holocene portion of the Cheyenne Bottoms section is defined by two radiocarbon dates (Table 3.3). The youngest Holocene date obtained is 5480 yr. B.P. (TX-6737). Although the dated core segment does correspond with pollen subzone IIA3, its selection for dating was based primarily on the need for more chronological control on this portion of the section. The organic content of this portion of the section was relatively low. The $\delta^{13}C$ value obtained from the 68-cm-long core sample suggests that the organics are primarily upland material; however, its susceptibility to old-carbon error remains a concern.

One of the first radiocarbon dates obtained was of the base of the possible paleosol which overlies the beach-like sedimentary unit. This core segment was dated to 9,690±130 yr. B.P. (DIC-3323). The organic content of this 40-cm-long core segment was relatively high (ca. 4.5%) and occurred primarily in the form of organic colloids rather than plant fragments. This sample probably has lower old-carbon error than the older Pleistocene limnic sediments.

The Pleistocene-Holocene Unconformity

One of the most important findings of the radiocarbon analysis was the confirmation of the hypothesized Pleistocene-Holocene unconformity (Figure 3.2). Both lithologic and palynological evidence had suggested that some portion of the sedimentary record was missing, but the actual chronological extent of the unconformity was unknown. The radiocarbon analysis suggests that, between 5.34 and 6.51 m.b.s., more than 14,000 years is missing from the stratigraphic record. Within this 1.17-meter-thick zone between radiocarbon dates are two possible horizons which could be unconformities. The lower of the two (5.88 m.b.s.) lies at the base of the coarser-textured early-Holocene sedimentary unit (Table 3.1). The second possible horizon of

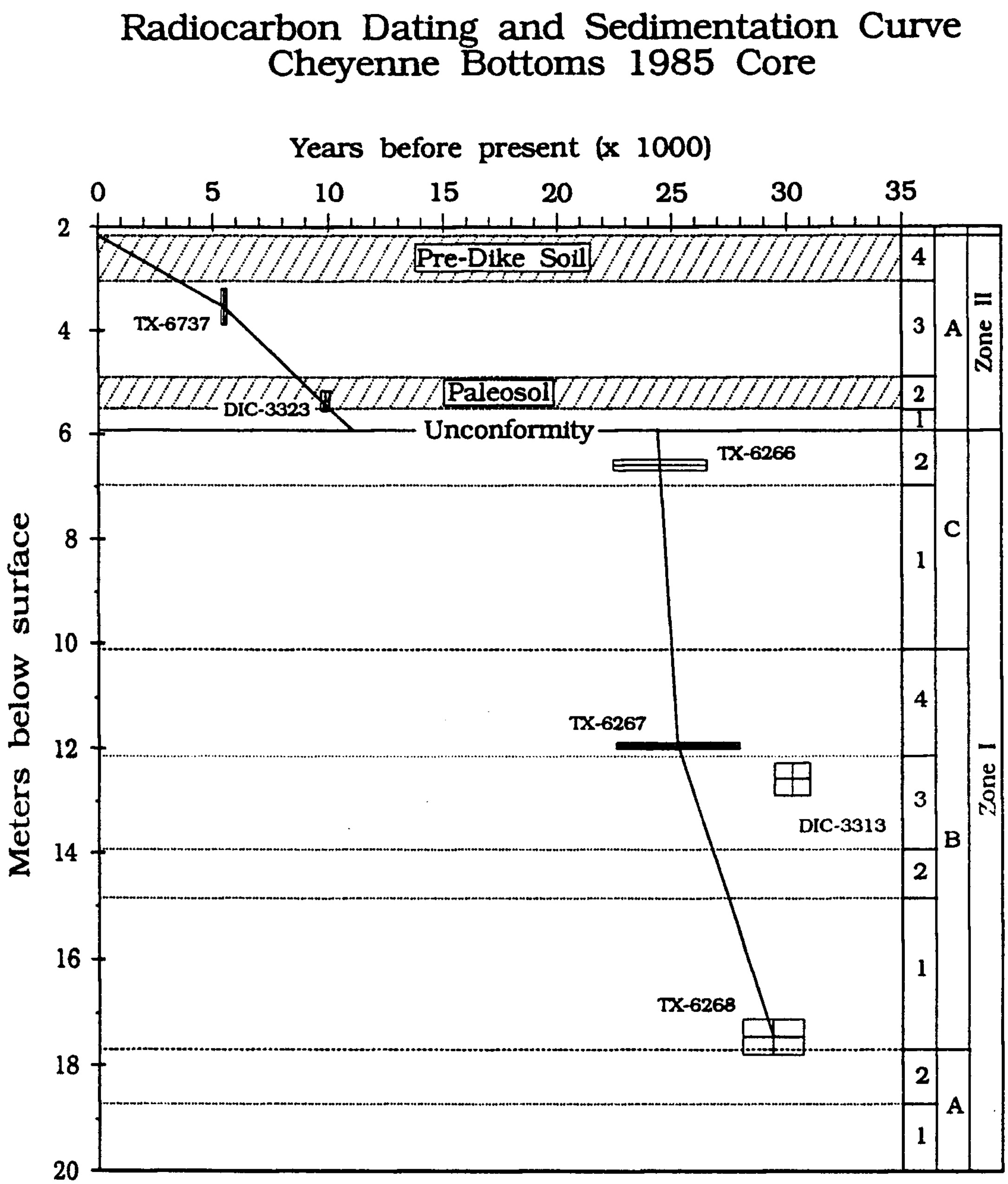


Figure 3.2: Sedimentation curve created by connecting the midpoints of accepted radiocarbon dates. Note that sample DIC-3313 has been omitted from this curve (see text for discussion). Box width represents +/- one standard error about the assayed radiocarbon age. The depth interval of each sample is illustrated by the box height. Pollen zonation from Figures 3.3 shown at right.

unconformity is the base of the hypothesized early-Holocene paleosol (5.54 m.b.s.). Based on palynological similarities (discussed below), the lower of the two horizons, the base of the coarser sedimentary unit appears to be the more likely unconformity.

Estimated rates of sedimentation surrounding the unconformity are projected up and down to this 5.88 m.b.s. horizon (Figure 3.2). From this extrapolation it is estimated that 13,370 years is missing from the Cheyenne Bottoms sedimentary record. This hypothesized hiatus, which extends from 24,324 to 10,953 yr. B.P., encompasses all of the Woodfordian glacial substage. The cause of this unconformity remains unclear.

The Wisconsinan

Below the Pleistocene-Holocene unconformity, four sediment samples have been radiocarbon dated. The most difficult portion of the section to date was that immediately below the Pleistocene-Holocene unconformity. Only one small 20-cm-long portion of the section, from 60 to 80 cm below the unconformity, exhibited any signs of increased organic mater. This short brownish gray segment contained barely enough organic matter to date with conventional radiocarbon techniques. The $\delta\ ^{13}C$ value obtained from this segment suggests that its carbon may be ^{14}C deficient, and therefore susceptible to significant old-carbon error. The relatively high occurrence of pre-Quaternary palynomorphs in this portion of the section only magnifies this concern.

From 11.6 to 12.8 m.b.s., numerous fine stringers of charcoal and several small lenses of apparently unburned plant fragments occurred. Because of this increase in organics within the sediments, two segments of this portion of the section were radiocarbon dated (Figure 3.2). The first sample dated (DIC-3313) was a core segment which included several thin stringers of charcoal. Microscopic examination of this charcoal revealed fragments of both woody tissues and partially burned grasses, sedges, and other leaf cuticles; however, these burned plant materials actually accounted for very little of the carbon in the 64-cm-long segment. These sediments yielded a date of 30,220 yr. B.P. A second radiocarbon sample (TX-6267), centered only 62 cm above the first dated segment, yielded a much younger age: 25,730 yr. B.P. This 12-cm-thick core segment included a 4-cm-wide band of brownish (partially burnt?) organic material. Because this second date contained a concentrated lens of organics, it may have a lower potential for old-carbon contamination. Furthermore, the pretreatments of this sample may have removed some of the old-carbon contamination. Of these two radiocarbon dates, the latter (TX-6267) is probably more reliable.

The stratigaphically deepest sediment sample (TX-6268) has yielded a radiocarbon date of 29,340 yr. B.P. This 66-cm-long core sample consisted of olive gray, reduced sediment. Organic content of these sediments, at about 4.5 percent as determined by loss on ignition, is typical of the Wisconsinan sediments at Cheyenne Bottoms. The $\delta\ ^{13}C$ value obtained from this segment (-19.4 parts per mill), although somewhat isotopically heavier, is in keeping with other values obtained from the Pleistocene portion of the section. These data only underscore the potential for old-carbon contamination in this section of the sedimentary record.

Potential old-carbon contamination may also explain the stratigraphic reversal of the two lowest dates (Figure 3.2). The stratigaphically deeper sample (TX-6268) has been assayed to a somewhat younger age (29,340 yr. B.P.) than the sample 5.88 meters above (DIC-3313, dated at 30,220 yr. B.P.). If, as suggested above, this DIC sample is more susceptible to old-carbon contamination than the base-extracted carbon TX date, then reversal of ages is more understandable. If only the TX series of dates are compared, no inconsistencies occur (Figure 3.2). This conflict within the radiocarbon chronology is most likely the result of the uncontrolled old-carbon contamination of radiocarbon dated materials.

Results of Pollen Analysis

Description of Pollen Record

The overall record of pollen percentages is presented in the primary pollen diagram (Figure 3.3). This presentation of the data has been simplified both by collapsing some taxonomic groups (e.g. Other Asteraceae Types) and by grouping some taxonomically unrelated types by general habit (e.g. Semi-Aquatic types). Further detail about these taxonomic and environmental groupings is provided on secondary pollen diagrams. The zonation shown on all of these

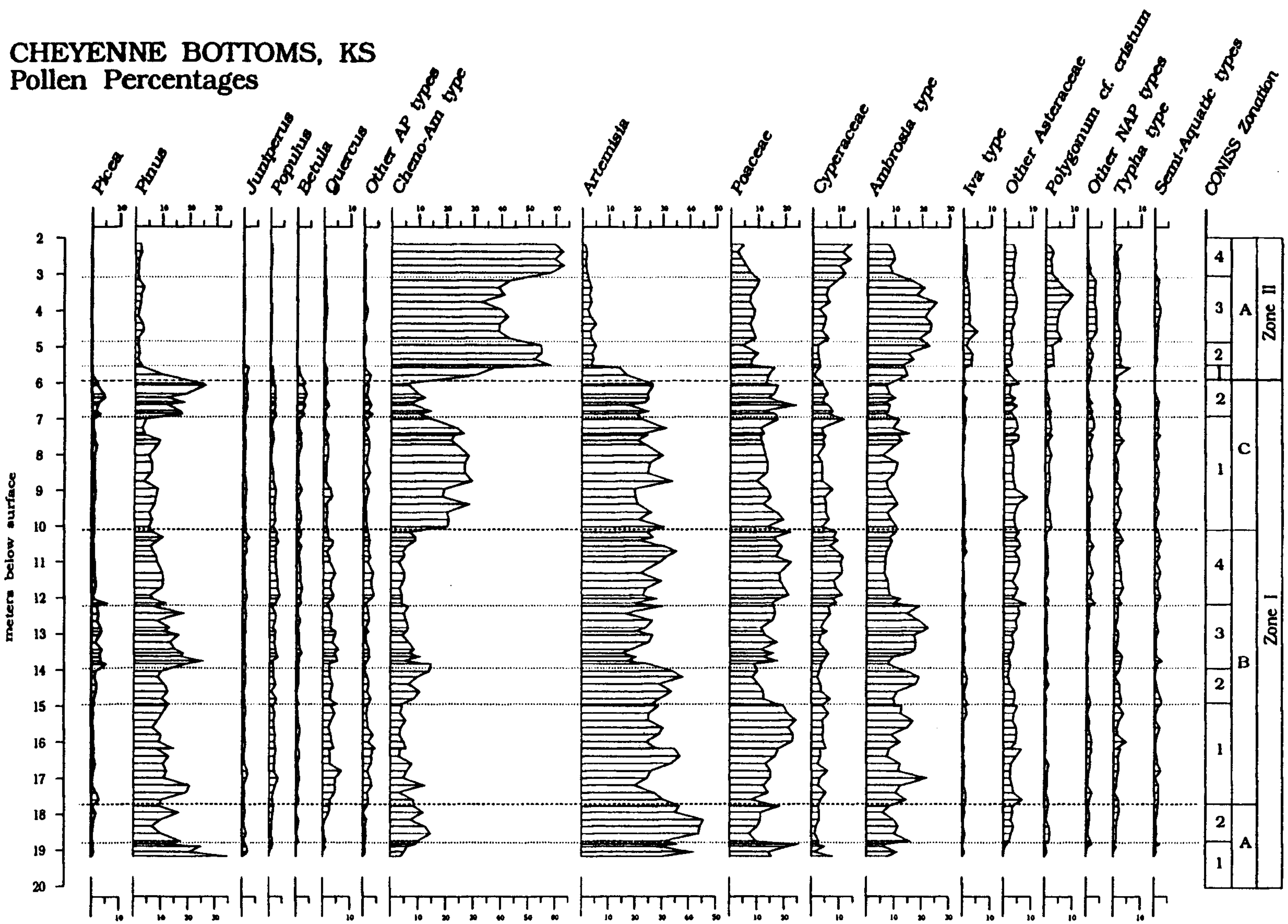


Figure 3.3: Primary pollen percentage diagram for 1985 Cheyenne Bottoms Core. Percent of total Quaternary pollen sum.

CHEYENNE BOTTOMS, KS:
Pollen Profile Zonation

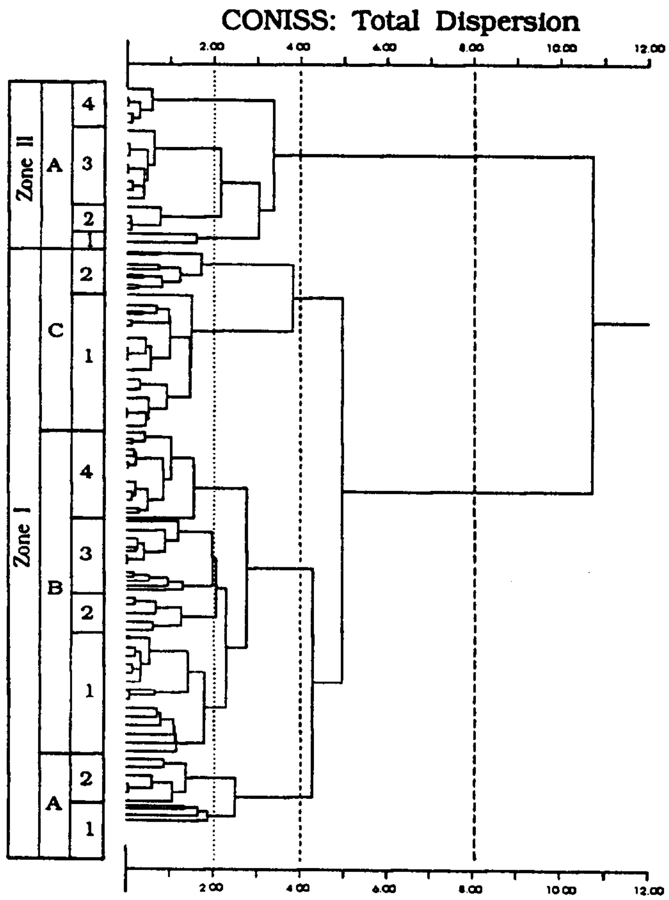


Figure 3.4: Zonation of primary pollen percentage diagram (Figure 3.3) by CONISS clustering algorithm.

diagrams is based on the CONISS zonation (Figure 3.4) on the 18 pollen taxa shown on the primary diagram (Figure 3.3). Also important to understanding the pollen stratigraphy of the Cheyenne Bottoms section are the estimates of pollen concentration (Figure 3.5), pollen preservation, and occurrence of recycled, pre-Quaternary palynomorphs (Figure 3.6).

Definitions of Pollen Zones

Based on the CONISS clustering of samples, a three-tiered hierarchical zonation is recognized (Figure 3.4). Zonation of this record follows time's arrow; that is, the zones are numbered from the bottom up. The primary break, dividing the entire pollen profile into two zones, was drawn subjectively at the 8.0 level of the total dispersion within the data set as determined by CONISS. Zone I, the Mid-Wisconsinan or Farmdalian, encompasses all of the pollen samples below the unconformity. Zone II, the Holocene, encompasses all of the pollen samples above the unconformity.

The second level of zonation is defined by cutting the remainder of total dispersion in half, or at the 4.0 level. This cut divides Zone I into three subzones: IA, IB, and IC. Zone II was not subdivided by this line; therefore, all of the Holocene is treated as a single subzone (IIA). The third, finer division of the data set was defined by halving the remainder of the total dispersion once again. This third cut, at the 2.0 level, divides all of the higher level

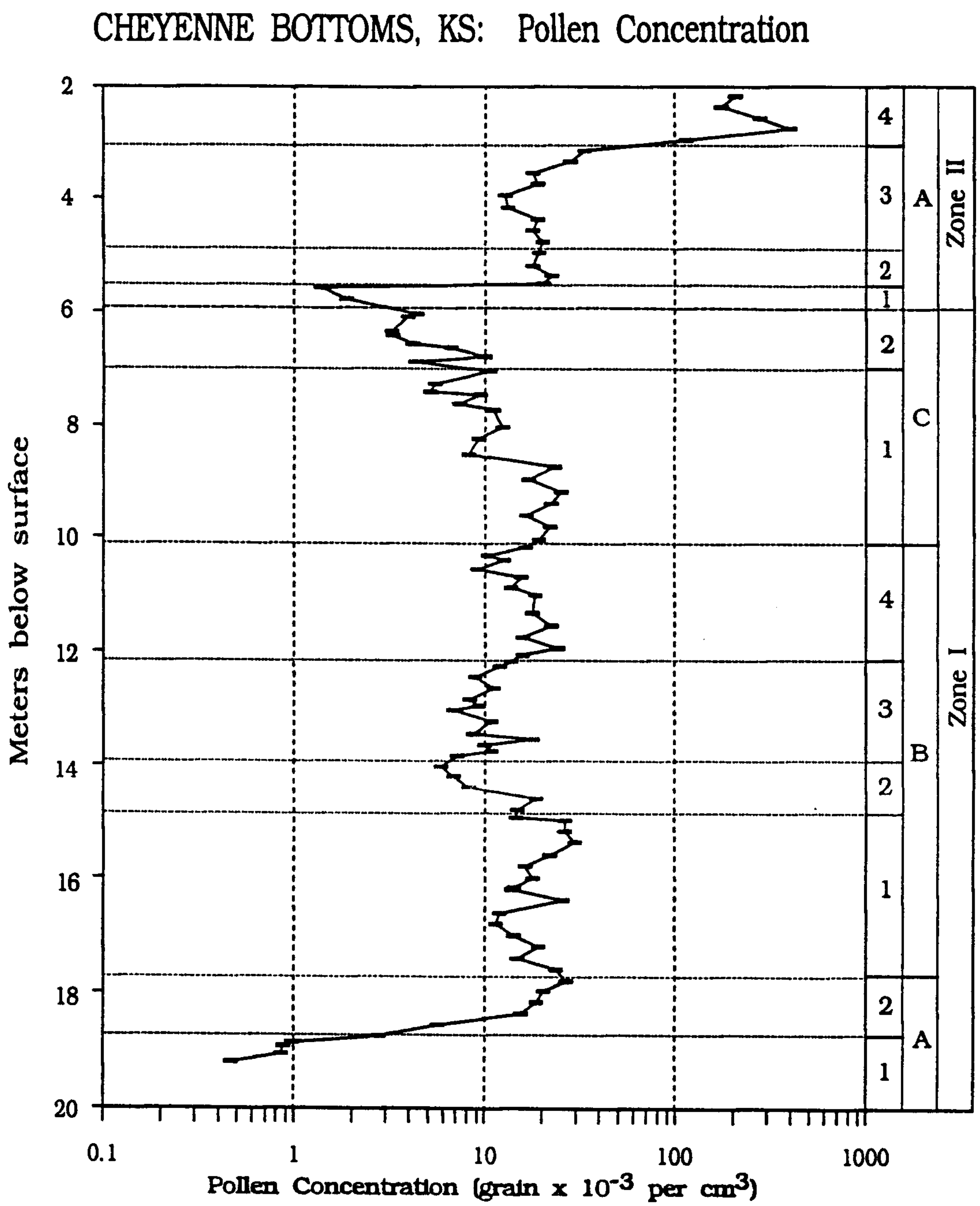


Figure 3.5: Estimates of pollen concentration for the 1985 core. Note that pollen concentrations are plotted on logarithmic scale. Pollen zonation from Figure 3.3 shown at right.

CHEYENNE BOTTOMS, KS
Pollen Preservation and Pre-Quaternary Palynomorphs

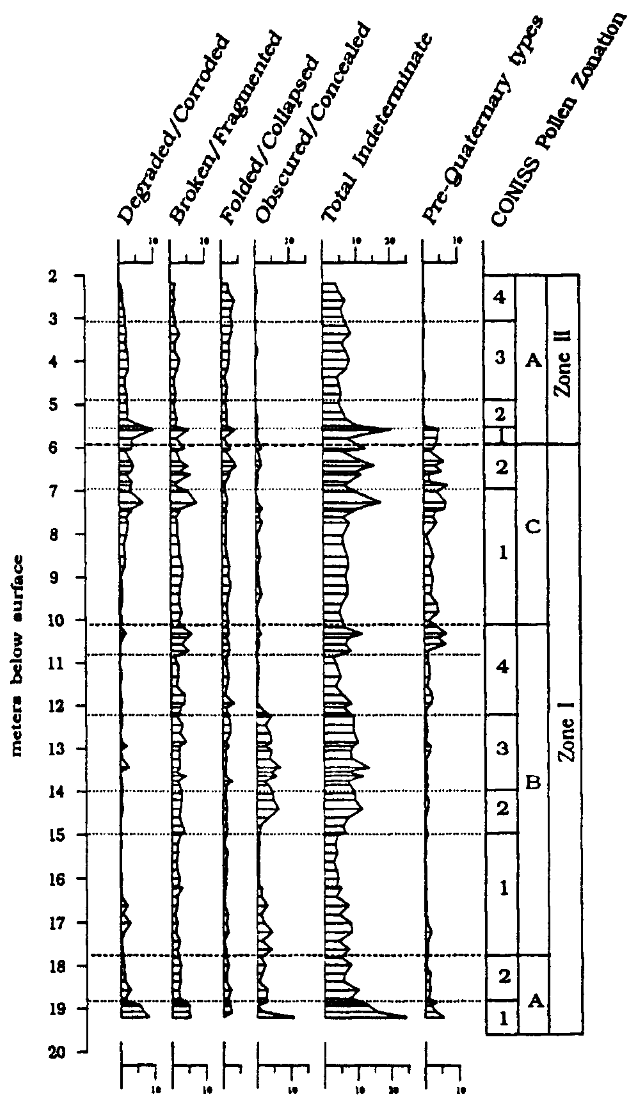


Figure 3.6: Evidence for change in pollen preservation and redeposition. Percentages of indeterminate pollen classes and pre-Quaternary pollen and spores based on the total sum including indentified, indeterminate, and pre-Quaternary palynomorphs. CONISS pollen zonation from primary percentage diagram (Figures 3.3).

sub-zones into several micro-zones. These micro-zones are designated with Arabic numbers, labeled from the bottom up (e.g. IA1, IA2).

Zone I (Depth Interval 19.21 to 5.88 m.b.s.)

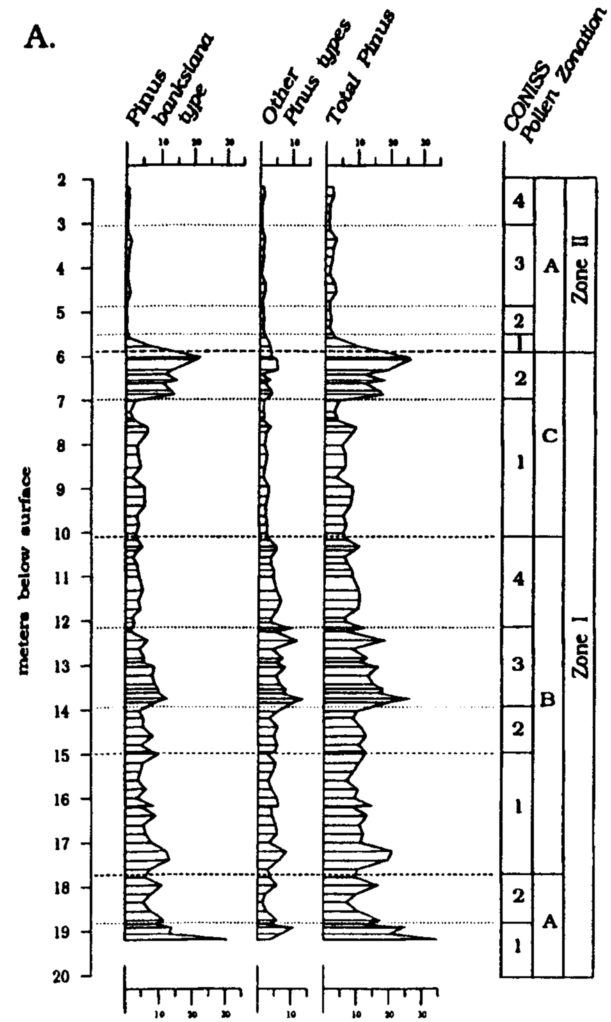
The Pleistocene pollen assemblages of Zone I (Figure 3.3) have several distinctive characteristics. First, these assemblages typically contain higher percentages of all arboreal pollen types than are found in the Holocene (Zone II) assemblage. Picea pollen occurs in consistently low percentages (2 to 5%) throughout the Pleistocene (Zone I), and is all but absent during the Holocene. The relative frequency of *Pinus* pollen is also more consistent in the Pleistocene than in the Holocene. Percentages of *Pinus* pollen exhibit a gradual decline from a high of ca. 35 percent in the lower assemblages, to a minimum of ca. 5 percent in the upper levels of Zone I. Several significant perturbations in the *Pinus* pollen signal interrupt this trend. The most significant of these is the *Pinus* peak recorded in the uppermost microzone (IC2). Also distinguishing Zone I are low, but significant, percentages of other AP types. Other arboreal pollen types that occur in significant percentages throughout Zone I include: *Juniperus, Populus, Betula, Quercus, Alnus, Salix,* and the *Acer negundo* type.

Pollen Zone I is also distinguishable from Zone II by its composition within the NAP spectra. Pollen assemblages of Zone I typically contain higher percentages of Poaceae (ca. 15%) and *Artemisia* (ca. 25%) than occur in Zone II. Conversely, pollen assemblages of Zone I typically have lower percentages of Cheno-Am and *Ambrosia* types. Cheno-Am pollen averages only 7% within Subzone IA and IB, and 20% within Subzone IC, compared with ca. 50% in Zone II. *Ambrosia* pollen, although very variable, typically ranges from 10 to 15% within Zone I, compared with 15 to 20% for Zone II (Figure 3.3).

Subzone IA (Depth Interval 19.21 to 17.88 m.b.s.). The lowermost subdivision of Zone I is distinguished from the rest of the zone by higher than average percentages (ca. 40%) of *Artemisia* type pollen. The lower horizons of this subzone (Micro-Zone IA1) are distinguished by higher percentages of Poaceae (ca. 18%) and *Pinus* pollen than documented for the upper portions of Sub-Zone IA (Microzone IA2). *Pinus* pollen occurs at the highest level documented anywhere in the profile, reaching up to 34%. These pine pollen grains may be disproportionately from one species, probably *P. banksiana* (Figure 3.7).

It would not be prudent to read too much into this relative increase in pine pollen. As noted before, because of the distinctive morphology of pine pollen, it is easily recognized even in sediments where decomposition has destroyed much of the pollen. Extremely low pollen concentrations (fewer than 1000 grains per cc), coupled with high relative frequencies of indeterminate pollen (up to 25%) indicate taphonomic problems in these lowermost sediments. The lowermost samples from this zone are among the few for which

CHEYENNE BOTTOMS, KS: Pinus sub-types



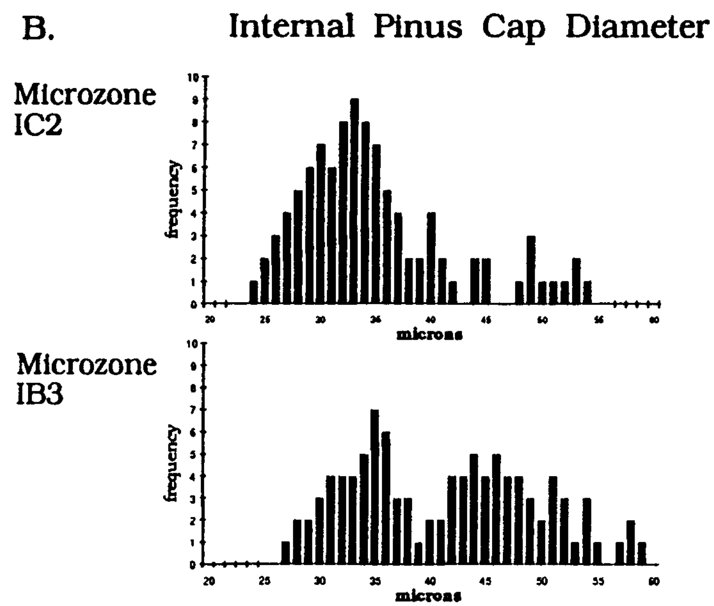


Figure 3.7: Distribution of Pinus sub-types.

A. (at left) Percentages of Pinus banksiana subtype and undifferentiated Pinus subtypes throughout the Cheyenne Bottoms column.

B. (above) Comparison of the internal cap diameter of 100 pine pollen grains from two samples. The upper sample (IC2) is dominated by the Pinus banksiana sub-type. The lower sample (IB3) is from a typical assemblage of mixed Pinus species.

identification of 300 Quaternary pollen grains per sample could not be achieved.

In the upper portions of Sub-Zone IA (Micro-Zone IA2), higher levels of pollen concentration and lower frequencies of indeterminate pollen indicate that differential pollen preservation is no longer a significant problem. These samples are much lower in *Pinus* pollen frequencies (10 to 15%) than were assemblages in Micro-Zone IA1. The pollen assemblages of Micro-Zone IA2 are dominated by a single NAP type, *Artemisia* (35-40%), but a variety of other NAP taxa remain important. These include Cheno-Am type (10-15%), Poaceae (10%), and *Ambrosia* type (10%).

Subzone IB (Depth Interval 17.88 to 10.10 m.b.s). This long, central subzone typifies the assemblages that compose all of Zone I. Pollen signals include low but consistent occurrence of many AP types. The zone continues to be dominated by the same NAP taxa. *Artemisia* pollen, although in lower relative frequencies (lower by 10 to 15 percent) than observed in Sub-Zone IA, continues to be the single most commonly occurring pollen type (ca. 25-30%). *Artemisia*, together with the other major NAP types (Cheno-Am type, Poaceae, *Ambrosia* type, and Cyperaceae), accounts for about 75 percent of all Quaternary pollen in this zone. Subzone IB is also distinguishable from the assemblages which preceded it by small but significant increases in other AP types (*Populus, Quercus, Salix,* and *Acer negundo* type) (Figure 3.3).

The division of Subzone IB into four microzones (IB1 through IB4) is derived from changes in the *Picea*, *Pinus*, Cheno-Am, Poaceae, *Artemisia*, *Ambrosia*, and Cyperaceae pollen types. Microzone IB1 (Depth Interval 17.88 to 14.98 m.b.s) is distinguished by a rise in Poaceae percentages. Through time (depth), Poaceae pollen percentages increase from a mere 10% to almost 25% within this microzone. In microzone IB2 (Depth Interval 14.98 to 13.94 m.b.s), Poaceae percentages fall back to ca. 10%, as percentages of Cheno-Am type pollen rise from 5% to ca. 15%. Microzone IB3 (Depth Interval 13.94 to 12.26 m.b.s) is characterized by significant jumps in coniferous pollen types. Within this microzone, *Picea* percentages more than double, from about 2% to about 5%. Relative frequencies of *Pinus* pollen rise from about 10% to about 15%, with a maximum of 25%. Microzone IB4 (Depth Interval 12.26 to 10.10 m.b.s) is characterized by the decline of the coniferous types back to their previous levels and by consistently low percentages of the *Ambrosia* type (ca. 7%). This interval also includes a distinctive bulge in the Cyperaceae percentage curve (from about 5% up to 10%).

Subzone IC (Depth Interval 10.10 to 5.88 m.b.s). Encompassed within this subzone are two major changes in the pollen record. The dissimilarity between the microzones (IC1 and IC2) is almost as great as that which defines subzones (Figure 3.4). The only common characteristics which bind these microzones together, as well as to all of Zone I, are consistently high relative frequencies of Poaceae (10-15%) and *Artemisia* (20-25%).

While these and most of the other NAP types remain at relatively stable levels throughout Subzone IC, the Cheno-Am type does not. The lower boundary of Subzone IC is defined by a sharp rise in Cheno-Am type pollen from 10% up to 20%. Percentages of Cheno-Am type pollen reach their maximum (ca. 30%) in the mid-portion of Subzone IC and then decline to around 10%. This rise and subsequent decline in Cheno-Am percentages in Subzone IC corresponds stratigraphically with the drastic decline in pollen concentration (Figure 3.5) and the evidence of increasing pollen preservation problems (Figure 3.6).

While Microzone IC1 (Depth Interval 10.10 to 6.95 m.b.s) is defined by the Cheno-Am type percentage curve, Microzone IC2 (Depth Interval 6.95 to 5.88 m.b.s) is defined by the *Pinus* curve. Through time, percentages of *Pinus* pollen rise from near 5% at the base of Microzone IC2 to 25% at the top of the zone, which appears to be truncated. Unlike the rise in Pinus pollen documented in Microzone IB3, this increase in *Pinus* percentages appears to be attributable to a single species (Figure 3.7). The distinguishing characteristics of *Pinus* pollen grains in this zone are their small size (mean internal cap diameter of 33 microns, see Figure 3.7) and absence of distal verrucae indicative of the Hyploxylon Subfamily. These observed characteristics strongly suggest that this represents *Pinus banksiana*. Increases in several other arboreal types were also observed in microzone IC2. Percentages of *Picea* increase significantly from not quite 2% to about 5%. Similar modest, but significant, increases in the *Populus* and *Betula* types were also documented for this microzone.

Zone II (Depth Interval 5.88 to 2.18)

Pollen Zone II, the Holocene portion of the pollen record, is dominated by a single pollen taxon, the Cheno-Am type. This pollen type comprises between 40% and 60% of the assemblages within this zone. This tremendous relative increase in the Cheno-Am type was matched by the relative decrease in other major NAP types (i.e. Poaceae and Artemisia), as well as almost all NAP spectra.

Poaceae and *Artemisia* pollen, which dominated assemblages in the Pleistocene portions of the record (Zone I), are typically much lower throughout the Holocene assemblages (Zone II). Typical Poaceae pollen percentages in the Holocene assemblages are around 7%, or about half of that documented for the Pleistocene. Even more dramatic are the differences between Holocene and Pleistocene levels of *Artemisia* pollen. During the Pleistocene (Zone I), percentages of *Artemisia* vary between 20% and 30%. During the Holocene (Zone II) this relative frequency falls to less than 5% throughout (Figure 3.3).

As mentioned above, other NAP types also increase within the Holocene portion of this pollen record. The principal additional taxon is the *Ambrosia* type. Ambrosia reaches its peak (ca. 25%) in the middle horizons of Zone I. Secondary pollen taxa which increase include the Iva-type, Polygonum, and some other Asteraceae forms such as the Bidens type.

Within Zone II, CONISS did not recognize any major subzones. All of Zone II is subsumed within the single Subzone IIA; however, four microzones are defined; IIA1 through IIA4. Microzone IIA1 (Depth Interval 6.04 to 5.54 m.b.s) consists of the two samples analyzed from the sandy beach deposits which separate the obvious Holocene samples from those of the Pleistocene. Pollen concentration in these two samples is very low, making adequate pollen sums difficult to achieve. This microzone possesses characteristics of both of the major zones. For example, although Microzone IIA1 lacks *Picea*, it still contains relatively high frequencies of *Juniperus*, *Populus*, and *Betula*. Also, even though it, like Zone II, exhibits increased percentages of Cheno-Am type pollen, it also retains the relatively high percentages of Poaceae and *Artemisia* pollen which characterize Zone I.

Microzone IIA2 (Depth Interval 5.54 to 4.86 m.b.s) is composed of the four samples taken from the early Holocene paleosol. Pollen concentrations within this microzone are similar to those realized during most of the Pleistocene deposition (ca. 20,000 grain per cc). Cheno-Am type pollen plateaus at 55% within this paleosol. Also, both *Iva* type and Polygonum type jump from trace amounts to 2 or 3%. Percentages of *Ambrosia* type pollen continue the increase begun in the previous microzone.

Microzone IIA3 (Depth Interval 4.86 to 3.06 m.b.s) conforms with the zone of lowered organic matter and tabular structure observed in the sediment analysis. Pollen concentration is slightly lower in these sediments. Cheno-Am type pollen percentages drop somewhat, but remain dominant at about 40% of the pollen assemblage. Within this microzone, the reciprocal of this decrease in Cheno-Am percentages is an increase in *Ambrosia*-type pollen.

Microzone IIA4 (Depth Interval 3.06 to 2.18 m.b.s) is essentially the modern (pre-dike) soil. Pollen concentrations in this zone skyrocket to over 100,000 grains per cc. Most of this increase in pollen concentration appears to be the result of increased production of Cheno-Am type pollen. Cheno-Am type pollen percentages increase to 60% within this pollen zone. Cyperaceae pollen also shows a significant rise from around 5% to almost 15% within this zone.

CHAPTER 4

INTERPRETATIONS

Interpretation of Identified Pollen Taxa

Introduction

Presented below, for each of the major pollen taxa (Figure 3.3) and some of the secondary forms, are 1) the general level of occurrence within the Cheyenne Bottoms record, 2) relevant modern analog evidence on which to base interpretations, and 3) the range of possible and probable interpretations based on the fossil and modern evidence. The first step is interpretations of the potential source areas (local, extra-local, regional, or extra-regional) for each pollen taxon. The source-area is, in essence, a question of floristics. This first step attempts to determine whether a specific pollen taxon represents part of the local plant association, or whether it is derived from some distant, regional plant community. Determination of probable size of this source population is the second step in the interpretative process. A persistent problem in the interpretation of pollen percentages is the difficulty in distinguishing small local populations from large distant ones. This is a problem especially for some specific taxa in this study. Systematically considering fossil pollen occurrence, modern analogs, and probable source area of each pollen taxon yields a range of reasonable and probable interpretations of regional and local vegetational change through time.

***Picea* (spruce):**

Picea pollen forms a small but significant percentage of the Cheyenne Bottoms pollen assemblage. Spruce pollen identified in the Cheyenne Bottoms record is most likely from *Picea glauca*, but pollen of both *P. mariana* and *P. pungens* may also be included. *Picea* pollen is all but absent in the Holocene sediments, but consistently occurs throughout the Pleistocene portion of the section in low (1-5%) relative frequencies (Figure 3.4).

Most of the data on the modern production and dispersal of *Picea* pollen suggest that its occurrence in limnic sediments is directly relatable to the relative importance of spruce populations within the region of the sample locale (McAndrews and Wright, 1969; Delcourt, 1979; Webb, *et al.*, 1981; Janssen, 1984). In the Great Plains, however, where arboreal pollen production is much lower than in the easten North America, pollen input from even distant spruce populations can be detected. Some modern pollen assemblages, taken hundreds of kilometers down-wind from regional sources, do contain low percentages (1-2%) of *Picea* pollen (e.g. McAndrews and Wright, 1969; MacDonald and Ritchie, 1986). Also, at least one Holocene pollen record from the central Great Plains, located hundreds of kilometers from known spruce populations in the Black Hills, South

Dakota, exhibits low (ca. 1%) but consistent relative frequencies of *Picea* pollen (Wright et al., 1985).

Based on modern evidence of spruce pollen dispersal, there is a range of acceptable interpretations of the Cheyenne Bottoms spruce pollen. On one extreme, it is possible that all of the Farmdalian (Zone I) spruce pollen resulted from long distance transport and that there are no local spruce populations. However, given 1) the persistence of the Farmdalian spruce pollen percentages, 2) the zones of higher occurrence (ca. 5% in microzones IB3 and IC2), and 3) the potential muting effect of the strong local pollen signal, it is also possible that the Cheyenne Bottoms spruce pollen comes from small local spruce populations located in river valleys or along escarpments. Given this weak pollen signal, it is highly unlikely that Farmdalian spruce would have extended into the central Great Plains uplands to form a spruce-parkland. Although I favor the latter interpretation, that of local but limited spruce populations, it should be remembered that there is no other fossil evidence for Farmdalian (not Woodfordian) spruce in the region. It is possible that either of these interpretations is correct.

Abies (fir):

Abies occurs as single grains in two adjacent samples within the IB1 microzone (Figure 4.1). Although regional effects of *Abies* pollen dispersal are even lower than *Picea*, random grains are dispersed long distances (e.g. Janssen, 1984). The rare occurrence of

Abies pollen in the Cheyenne Bottoms record is most likely from distant populations of fir, possibly *A. balsamea*.

***Larix* (tamarack):**

Larix pollen, probably from *L. laricina*, also occurs as isolated grains within microzone IB1 (Figure 4.1). Like *Abies*, these are probably stray grains from a distant source. Pollen production of *Larix* is, however, notoriously low (Janssen, 1984); thus, even these few grains could reflect local populations of the species within the Pleistocene wetlands of Cheyenne Bottoms.

***Pinus* (pine):**

Pinus pollen occurs in modest relative frequencies throughout the Farmdalian portion of the Cheyenne Bottoms section (Zone I). As noted previously, in spite of short-term variability, *Pinus* percentages appear to undergo a general decline throughout Zone I (Figure 3.3). Percentages of *Pinus* are typically higher (ca. 15%) at the base (microzone IA2) and trend relatively lower (ca. 5%) toward the top of the Farmdalian (microzone IC1). The exception to this trend is the moderate increases in *Pinus* pollen percentages documented in microzones IA1 (ca. 25%), IB3 (ca. 15%), and IC2 (15-25%).

Pine pollen occurs in significantly lower relative frequencies (less than 5%) throughout the Holocene (Zone I). The difference between Pleistocene and Holocene *Pinus* percentages is in part due to a stronger local pollen signal during the Holocene (primarily from

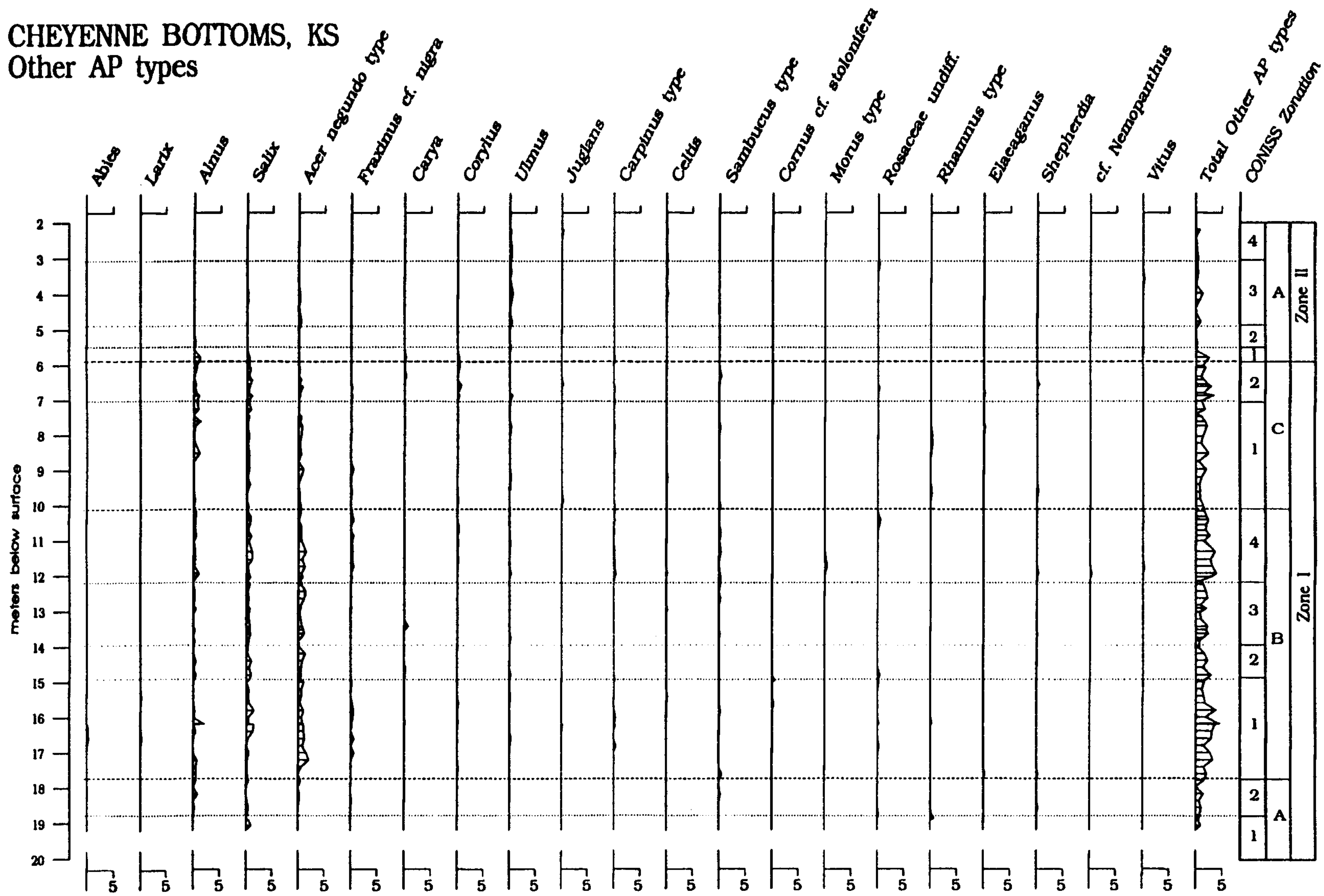


Figure 4.1: Percentages of secondary Arboreal Pollen (AP) types. Percentage scale 2X that shown on Figure 3.3.

the Cheno-Am type) which dilutes the regional pollen rain. Recalculation of Holocene pollen percentages with the Cheno-Am type removed from the pollen sum results in only a 2 or 3% increase in Holocene *Pinus* percentages. Even with this adjustment, Holocene *Pinus* pollen percentages remain well below 10%.

Further complicating the interpretation of the pine pollen from Cheyenne Bottoms is evidence for multiple species of pine. This evidence comes primarily from observations of the variability of pine pollen size within samples (see discussion in Chapter 2). Throughout most of the Cheyenne Bottoms record, relative proportions of small to large *Pinus* sub-types are not significantly different (Figure 3.7). Even in microzone IB3, with higher relative frequencies (ca. 15%), the proportion of large and small pine pollen grains remains about the same (Figure 3.7). In two other microzones with higher than average pine pollen percentages (microzones IA1 and IC2), the smaller, *P. banksiana* sub-type, increases significantly but the larger forms do not. Along with higher percentages of *P. banksiana* sub-type, these microzones also exhibit low pollen concentrations (Figure 3.5) and evidence of increased pollen preservation problems (Figure 3.6). Although these additional factors could cause pine pollen to be overrepresented, they do not explain why the response appears in only one *Pinus* sub-type.

The interpretation of *Pinus* pollen percentages from Cheyenne Bottoms presents one of the traditional dilemmas in Quaternary palynology: is a modest relative frequency of a given pollen taxon the product of a large, distant plant population, or is it representative of a more modest, local population. Pines not only produce huge quantities of pollen, but this pollen is often dispersed by wind over hundreds of kilometers (Erdtman, 1969). These factors typically result in the overrepresentation of *Pinus* pollen relative to the abundance of pine in the local vegetation (Delcourt et al., 1984; Delcourt and Delcourt, 1987).

Studies of modern pollen assemblages from the Great Plains have shown this to be especially problematic for the interpretation of grasslands pollen assemblages (Kapp, 1965; Lichti-Federovich and Ritchie, 1968; McAndrews and Wright, 1969; Holloway, 1984; Hall, 1985; MacDonald and Ritchie, 1986). Although results do vary, a threshold level of around 30% *Pinus* pollen is the minimum value typically representative of local pine populations. These studies have also documented a decrease in pine pollen percentages with distance from source. Typically, this decrease flattens out at a regional background level of around 5%. Along transects of samples in the southern and central Great Plains, this decline appears to occur over about 200 kilometers (Kapp, 1965; Hall, 1985). In the northern Great Plains this decline appears to be spread out over a considerably greater (ca. 600 km) distance (McAndrews and Wright, 1969; Holloway, 1984; MacDonald and Ritchie, 1986). McAndrews and Wright (1969:40) suggest that this greater dispersal distance in the northern Great Plains may be related to the strength of westerly air-flow across the region.

Problems resulting from the long-distance dispersal of pine pollen complicate the interpretation of the Cheyenne Bottoms record. The most conservative interpretation of the Farmdalian pine pollen record at Cheyenne Bottoms is that all pine pollen results from long-range dispersal from distant populations. Nowhere in the Cheyenne Bottoms record do pine pollen percentages approach the threshold level indicative of local populations.

Alternatively, the Farmdalian *Pinus* pollen record from Cheyenne Bottoms could represent local or extra-local populations of pine growing in nearby, protected localities (cf. Fredlund and Jaumann, 1987; Jaumann, 1991). If local or extra-local pine populations were present in the Farmdalian, they must have been very limited in size. Pine pollen from modern samples taken in open pine parklands composes over 35% of the pollen sum (Mack and Bryant, 1974; Mack et al. 1978). Although the moderate (10-20%) pine percentages in the Cheyenne Bottoms record may well represent local pine populations restricted to escarpments and other fire-protected sites, this cannot be proved. It is possible, some would argue probable, that these moderate pine pollen percentages are the product of distant pine populations, carried by strong Pleistocene wind.

***Juniperus*-type** **(juniper):**

Juniperus pollen is produced by both junipers (e.g. *J. communis*, *J. horizontalis*, *J. virginiana*) and *Thuja*-cedars (e.g. *T. occidentalis*). Even when locally present, these taxa never dominate the pollen assemblage (Kapp, 1965; Lichti-Federovich and Ritchie, 1968; McAndrews and Wright, 1969; Holloway, 1984; Hall, 1985; MacDonald and Ritchie, 1986). The low (ca. 1%) but consistent occurrence of *Juniperus*-type pollen in the Cheyenne Bottoms record is problematic (Figure 3.3). If these grains represent *Thuja*, then one would expect other wetland-adapted arboreal species to be more common than they are in the Pleistocene record. On the other hand, *Juniperus* species are upland trees and shrubs. Typically *Juniperus* has a high tolerance for drought but low tolerance for fire. It is possible that the lowered fire-disturbance regime of the Pleistocene promoted expansion of *Juniperus* populations even in more unprotected areas. Even the low percentages documented in the Cheyenne Bottoms record would represent a significant upland tree or shrub population.

Populus (aspen, poplar, cottonwood):

Populus pollen identified at Cheyenne Bottoms probably comes from three different species: *P. deltoides*, *P. balsamifera*, and *P. tremuloides*. Under ideal circumstances, the pollen of these three species can be distinguished. The differentiation of these species in the Cheyenne Bottoms record was not always possible. Most of the identifiable grains in the Holocene were *P. deltoides* (cottonwood). The trace amounts of *Populus* pollen encountered in the Holocene (less than 1%) probably comes from scattered populations of cottonwoods along the edge of the basin and along adjacent stream valleys. Most of the Pleistocene *Populus* grains appear to be *P. tremuloides* (quaking aspen), but both *P. deltoides* and *P. balsamifera* also appear to be present. Because this taxon is difficult to consistently differentiate into its component species, especially when preservation is less than pristine, the taxon is reported here by genera only.

Although the percentages of *Populus* pollen remain low (typically 1-3%) throughout the Farmdalian (Zone I; Figure 3.3), this number may represent a significant population of aspen and/or poplars. Modern pollen analog samples from aspen parklands in southern Canada typically contain from 3 to 10% *Populus*-type pollen (Lichti-Federovich, 1968; MacDonald and Ritchie, 1986). However, these analog samples are derived from smaller lakes surrounded by parklands, rather than a large marsh where extra-local pollen rain may be muted by higher local pollen accumulation rates. Although it is difficult to give precise estimates, these data suggest that aspen, perhaps as open parklands, covered some of the regional uplands during the Farmdalian.

***Betula* (birch):**

Betula pollen occurring in the Cheyenne Bottoms record could come from any of several species, including *B. papyrifera, B. glandulosa,* and *B. populifolia*. In contrast to *Populus*, *Betula* is typically abundant in modern analog samples from the southern boreal forest and adjoining aspen parklands of Canada (Lichti-Federovich, 1968; MacDonald and Ritchie, 1986). *Betula* pollen percentages from these regions typically range from 10 to 25%, even though the standing biomass of *Betula* is typically much lower than *Populus* in the same area. *Betula* typically has a much stronger local and extra-local effect than does *Populus* (Janssen, 1984). On the other hand, *Betula* pollen does not contribute strongly to the regional pollen signal. That is, *Betula* pollen is not like *Pinus* pollen; it does not disperse for long distances; therefore, *Betula* pollen will not typically show up with any degree of consistency even 20 km downwind from its source area.

At Cheyenne Bottoms, *Betula* pollen occurs in low relative frequencies (1-4%) throughout the Farmdalian portion of the section (Zone I) and is absent in the Holocene portion (Zone II) (Figure 3.3). *Betula* pollen occurs in its highest percentages in microzone IC2, at the top of the Pleistocene portion of the section. The consistent occurrence of *Betula* in low percentages does not readily match any of the defined boreal communities. This occurrence indicates that birch was probably present extra-locally in the uplands, rather than locally within the wetlands.

Quercus **(oak):**

It is not possible to distinguish individual species of *Quercus* pollen. Although this taxon is absent from the modern analog samples from western central Canada (MacDonald and Ritchie, 1986), it is important farther east in Canada, toward the deciduous forests (Lichti-Federovich and Ritchie, 1968). Oaks are highly productive and their pollen is broadly dispersed. This pollen taxon contributes significantly to the extra-local and regional components.

The percentage of *Quercus* pollen declines throughout the Farmdalian (Zone I, Figures 7.3). The highest percentages of *Quercus* pollen (ca. 5%) occur within subzone IB. Percentages decline slowly throughout the rest of the Farmdalian (Zone I). *Quercus* occurs only sporadically within the Holocene portion of the section (Zone II). Given the nature of *Quercus* pollen dispersal, all of the documented oak in the Cheyenne Bottoms core may have originated from extra-local source areas. If populations of oak did extend into the central Great Plains, they must have been small and localized.

Alnus (alder):

Alnus pollen is an important, commonly occurring taxon in the boreal forest and adjacent landscapes of Canada today (MacDonald and Ritchie, 1986). Even within the aspen parklands south of the true boreal forest, *Alnus* pollen typically comprises 5 to 10% of the total pollen sum (MacDonald and Richie, 1986). The local sources of *Alnus* pollen often yield 20 to 30% (Janssen, 1984).

Because both species of *Alnus* common to the boreal forest region, *A. rugosa* and *A. crispa*, are adapted to marshy, wet environments, it would not be surprising to recover very high percentages of *Alnus* pollen from the Pleistocene sediments of Cheyenne Bottoms; however, there is no evidence for local populations of *Alnus* at Cheyenne bottoms at any time during the late Quaternary.

The low and sporadic occurrences of *Alnus* pollen throughout the Pleistocene (Zone I) most likely originated from regionally distant source-areas (Figure 4.1). Small, localized populations of *Alnus* along the nearby Arkansas River are the probable source of these Pleistocene grains.

***Salix* (willow):**

Salix pollen is derived from numerous species of small trees or shrubs. *Salix*-type pollen grains occurring throughout the Pleistocene portion of the section (Zone I) are predominantly a tricolpate form, rather than the tricolporate form more common in the Holocene (Zone II). Species which produce this tricolpate form include: *Salix discolor, S. candida, S. interior, S. pedicellaris,* and *S. herbacea,* among many others. The typical favored habitat of these shrubby willows are mesic sites, including stream-banks, meadows, and lake shores, although some species, such as *S. herbacea,* favor more sandy, rocky sites. Modern pollen assemblages from the boreal forest and adjacent landscapes, including grasslands, contain tricolpate, *Salix*-type pollen persistently, but in variable amounts (1-15%) (MacDonald and Ritchie, 1986). The persistent occurrence of this form in the Pleistocene portion (Zone I) of the Cheyenne Bottoms record indicates that populations of these shrubby willows were locally and/or extra-locally present (Figure 4.1).

<u>*Acer negundo*</u> (boxelder):

The *Acer negundo*-type pollen identified from the Pleistocene portion of the section (Zone I) is primarily from *Acer negundo*, but as denoted by the "-type" designation, it also includes pollen grains of similar form which were not always distinguishable. The Pleistocene occurrence of boxelder at Cheyenne Bottoms is significant (Figure 4.1). *Acer negundo* (boxelder) is a small tree tolerant enough to be found both in the northeastern Great Plains and in the southern boreal forest today. *Acer negundo* is typically not a major forest component and is not a heavy pollen producer. Even when locally present, modern pollen assemblages contain only low amounts (ca. 0.5%) of this pollen type (Janssen, 1984). Its persistence throughout the Pleistocene at Cheyenne Bottoms indicates that these trees were locally present.

<u>Other AP types</u>:

Other tree pollen species identified include *Ulmus* (elm), *Juglans* (walnut), *Carya* (hickory), *Fraxinus cf. nigra* (black ash), *Carpinus*-type (including hornbeam and hophornbeam), and *Celtus* (hackberry). Most of the pollen taxa occur as isolated grains, suggesting chance deposition from very distant sources. The co-occurrence of *Fraxinus cf. nigra* and *Carpinus*-type in subzones IB1 and IB4 suggests something more than long-distance dispersal. These occurrences suggest that limited populations of both species were regionally present during the more mesic periods of the mid-Wisconsinan.

Pollen from numerous other shrub and vine species also occurs in the Pleistocene portion of Cheyenne Bottoms (Figure 4.1). These include *Elaeagnus* (silverberry), *Sheperdia canadensis* (buffaloberry), *Corylus* (hazel-nut), *Sambucus*-type (conforms with elderberry), *Cornus cf. stolonifera* (dogwood), *Morus* (mulberry), Rosaceae undiff. (the rose family), *Rhamnus* undiff. (buckthorn), *cf. Nemopanthus* (mountain-holly), and *Vitus* (grape). Most of these taxa are indicative of cooler and more mesic conditions than are present today. None of them occur in large amounts or persistently over long periods in the Cheyenne Bottoms record. Most of these probably represent taxa which occurred locally. Species differences in pollen production and dispersal and ecology make it difficult to generalize.

Cheno-Am type (Chenopods):

The Cheno-Am type includes pollen grains produced by all members of the Chenopodiaceae and Amaranthaceae families. The one exception, the only species which can readily be distinguished palynologically, is *Sarcobatus* (greasewood). In the Cheyenne Bottoms record, *Sarcobatus* occurred in only four out of the 100 samples and only as single grains. Because of its limited occurrence *Sarcobatus* has been included within the Cheno-Am type in this study (Figure 3.3).

Cheno-Am pollen producing plants are important locally at Cheyenne Bottoms and regionally, as a ruderal species. The weedy, annual habit and tolerance of saline and alkaline soils make Cheno-Am species especially important locally. Brooks and Kuhn (1987) list 13 Chenopodiaceae species and 6 Amaranthaceae species in their survey of the modern vegetation of Cheyenne Bottoms. All of these species contribute to the local Cheno-Am pollen signal. All 19 of these Cheno-Am species fill essentially the same ecological niche: salt-tolerant annuals which invade the dry lake beds during the summer months. In general, these ecological characteristics make the Cheno-Am pollen type a good indicator of regional drought and other types of community disturbance.

Cheno-Am type pollen dominates the Holocene portion of the Cheyenne Bottoms pollen record (Zone II; Figure 3.3) ranging from 35 to over 60% of the assemblage. In the Farmdalian portion of the section (Zone I), Cheno-Am type pollen typically comprises only 5 or 10%. Only in microzone IC1 is there a sustained significant rise above this relatively low, basal level. The Cheno-Am signal comprises the single largest difference between the Holocene and Farmdalian Pleistocene pollen zones at Cheyenne Bottoms.

Every modern pollen study which includes the Great Plains has shown that high Cheno-Am pollen percentages, ranging anywhere from 15 to 50%, are a distinguishing characteristic of grassland pollen signatures (Kapp, 1965; Lichti-Federovich and Ritchie, 1968; McAndrews and Wright, 1969; MacDonald and Ritchie, 1986). Although these modern data suggest that the relative frequency of this pollen taxon correlates with the regional moisture (effective precipitation) gradient (c.f. Bernado and Webb, 1977), this correlation is obscured by the highly variable nature of the signal (e.g. see the South Dakota transect in McAndrews and Wright, 1969). This local variability is probably a result of the sensitivity of this pollen taxon to local disturbance. Because of the intensity of the modern disturbance regime, which is primarily anthropogenic, it is possible that Cheno-Am type pollen percentages would have been lower prehistorically.

The major Holocene increase (Zone II), as well as the late Farmdalian rise (microzone IC1), in percentages of Cheno-Am type pollen are interpreted as local rather than regional signals. This interpretation is based on the nature of the site and the ecological role played by Cheno-Am species. At Cheyenne Bottoms, increase in Cheno-Am species is correlated with increase in exposed mudflats. Exposed mudflats increase as water levels in the basin drop. Lower water levels are equated with increased aridity.

Based on this interpretation of Cheno-Am pollen percentages, water level in the Cheyenne Bottoms basin remained more or less constant throughout most of the Farmdalian. Only during the late Farmdalian (24,000 to 25,000 yr. B.P.), did the water level begin to fall, exposing greater areas of mudflats. However, if water levels continue to decline steadily, then community successional processes would progress, resulting in a decrease in the area of Cheno-Am annuals. It is hypothesized that just this sort of areal decrease in the mudflat, Cheno-Am community is responsible for the subsequent decline of Cheno-Am pollen percentages in the upper portion of microzone IC1. This hypothesis is corroborated by the marked decline in pollen concentration which begins just at the peak of the late Farmdalian Cheno-Am signal (Figure 3.3).

The moderately lower Cheno-Am percentages in the middle portion of the Holocene (microzone IIA3) may represent a similar response. Rather than interpreting this Cheno-Am decrease as a lessening of aridity, it can be viewed instead as long-term lowering of water levels during the middle Holocene.

Artemisia **(sage and wormwood):**

Artemisia pollen is produced by about 11 native species in the Great Plains today (McGregor *et al.*, 1986). These include the large fire-tolerant, stump-sprouting shrubs (e.g. *Artemisia tridentata*), perennial herbs, and even less fire-tolerant annuals. Most are adapted to xeric, sandy or rocky upland sites, but a few are better adapted to disturbed areas. The only species occurring within the Cheyenne Bottoms today is *A. ludoviciana* (white sage). Not far from Cheyenne Bottoms, to the south and west along the sandy alluvial deposits left by the Arkansas River *A. filifolia* (sand sagebrush) becomes very common (Kuchler, 1974).

These local populations, supplemented by regional input from distant populations of other species, compose only a few percent of modern pollen assemblages from Cheyenne Bottoms. Throughout the Holocene *Artemisia* pollen makes up less than 5% of the pollen sum. The discrepancy between the Holocene and Pleistocene *Artemisia* records is second only to that seen in the Cheno-Am type curve (Figure 3.3).

Within the Pleistocene, *Artemisia* pollen is the single most common taxon, composing 25 to 30% of the pollen sum. This extremely strong Pleistocene signal from *Artemisia* is somewhat surprising. The only modern vegetation yielding similar pollen assemblages with high *Artemisia* percentages is the sagebrush steppe of the northwestern high plains (McAndrews and Wright, 1969; Barnosky et al., 1987). The sagebrush steppe community of the northwestern high plains is characterized by *Artemisia tridentata* (big sagebrush). Pollen grains of this species are today typically larger in diameter, with thicker exine, than pollen of other *Artemisia* species (Cawker, 1983). The typical *Artemisia* grains observed in the Farmdalian section of Cheyenne Bottoms do not appear to be from *A. tridentata*. Unfortunately, little work has been published on differentiation of *Artemisia* species pollen. It is not clear which specie or species of *Artemisia* are present. It is possible, but unlikely, that the Pleistocene *Artemisia* is also a local signal. Given the ecology and tolerance of the genera it is more likely representative of the upland vegetation surrounding the bottoms.

Poaceae (grass family):

Poaceae pollen grains may be derived from any of the hundreds of species of grass (comprising 76 genera) currently found within the Great Plains region (McGregor *et al.*, 1986). Even with the combined input from all of these grass species, the relative contribution of the Poaceae pollen type in modern Great Plains assemblages remains modest. Despite the domination of the modern biomass by grasses, percentages of the Poaceae type typically range only between 10 and 20% (Kapp, 1965; Lichti-Federovich and Ritchie, 1968; McAndrews and Wright, 1969; MacDonald and Ritchie, 1986). The effect of local variability, although probably significant for the Poaceae type, is not as clear as it is with Cheno-Am. Most of the dominant grasses, unlike the Cheno-Am plants, are perennial, rather than annual, weeds. Nevertheless, the effect of local variability is very strong. Percentages of Poaceae pollen in modern grassland assemblages range as high as 45% and as low as 5%.

Grass species fill many ecological roles both regionally and locally within the Cheyenne Bottoms wetlands. Brooks and Kuhn (1987) document 62 species of grasses within the Cheyenne Bottoms Wildlife Area today. Many of these species occur along roads and other recently disturbed sites; however, 12 of the 62 species act as annual invaders of alkaline flats. Higher in the landscape, perennial grasses dominate. Thus, increase in Poaceae pollen within the Cheyenne Bottoms record could conceivably result from two environmentally contradictory signals. Both changes in local conditions, such as basin drying, and regional conditions promoting grassland stability and production could cause increases in Poaceae pollen.

The major change in Poaceae percentages occurs around the Pleistocene-Holocene unconformity. Below the unconformity, throughout the Farmdalian, Poaceae percentages average around 15%. Within the Holocene, above the unconformity, Poaceae percentages range from 5 to 10% (typically about 8%), somewhat below what would be expected according to modern analogs from the region. The lower percentages of Poaceae pollen in the Holocene are attributed, in part, to the tremendous pollen productivity of Cheno-Am type plants. The strong Cheno-Am signal, presumably from local sources, tends to mute other pollen types. Recalculation of Poaceae percentages excluding the Cheno-Am type from the sum raises the typical Holocene grass pollen percentage by about 10%.

Variations of Poaceae within the Pleistocene (Zone I) show a similar, but less pronounced, inverse correlation with Cheno-Am percentages. When Pleistocene Poaceae percentages are greater than 15% (microzones IB1 and IB4), Cheno-Am percentages are at their lowest (ca. 5%). This inverse relationship may be the result of succession. Through time, exposed lake beds which at first supported Cheno-Ams and other ruderal plants, eventually succeed first to perennial saltgrass, and eventually to full mixed-grass prairies (Brooks and Kuhn, 1987).

The relatively high percentages of Poaceae pollen which characterize both the Holocene and Pleistocene portions of the Cheyenne Bottoms record are found today only in true grassland regions. The relative strengths of local versus regional source areas for Poaceae pollen at Cheyenne Bottoms remain unknown. Increases in the Poaceae type may have resulted from greater grass productivity in the uplands, or may be solely a local phenomenon.

Cyperaceae (sedge family):

Cyperaceae pollen is produced by both wetland- and upland-adapted plants. Today within the Cheyenne Bottoms wildlife region there are 5 genera comprising 16 species (Brooks and Kukn, 1986). The Cyperaceae signal throughout the Cheyenne Bottoms record, like the Poaceae signal, is primarily locally-driven but may have an extra-local component.

Cyperaceae pollen signals in the Great Plains can be affected by local as well as upland (regional) sources. In some fossil pollen records, Cyperaceae is believed to be a local signal and is therefore removed from the primary pollen sum used to calculate percentages (e.g. Gruger, 1973; Wright et al., 1985). However, regional and continental syntheses of fossil pollen data often include Cyperaceae because of its strong correlation with grasses and grasslands (Jacobson et al., 1987; Webb et al., 1987). Studies of modern pollen assemblages not associated with lakes or wetlands have demonstrated that significant, consistent, and measurable levels of Cyperaceae pollen do occur (McAndrews and Wright, 1969). The percentages of Cyperaceae in these dry-land grassland samples, typically 5-10%, are somewhat lower than in modern lake samples (MacDonald and Ritchie, 1986), and much lower than realized in some fossil assemblages from the region.

Two of the Cheyenne Bottoms microzones (IB4 and IC2) which exhibit a significant increase in Cyperaceae pollen percentages also exhibit an increase in Poaceae (Figure 3.3). This suggests that the Cyperaceae pollen signal is responding to the same environmental variables as Poaceae. It is not clear to what extent these responses are local community responses rather than regional signals. The Farmdalian Cyperaceae as a whole conforms with the modern evidence from grasslands.

Only in the upper portions of the Holocene (microzone IA3 and IA4) does the Cyperaceae signal respond independently from Poaceae. It is suspected that this late Holocene increase may represent the introduction or expansion of one of the marshland adapted species of sedges tolerant of low water level and alkaline conditions (e.g. *Scirpus maritimus*, bulrush).

Ambrosia-type (ragweed):

Ambrosia-type pollen, typically from ragweed, is often about as abundant in grassland pollen assemblages as Poaceae. *Ambrosia*-type percentages are typically around 20 to 25% in the central and eastern Great Plains (Kapp, 1965), but only 5 to 10% elsewhere in the region

(McAndrews and Wright, 1969). Because *Ambrosia*-type producing vegetation is often ruderal, percentages of *Ambrosia* can reach much higher levels (ca. 50%) due to agricultural disturbance. In some shallow water situations, like Cheyenne Bottoms, the *Ambrosia*-type may have strong local sources and therefore be overrepresented.

At Cheyenne Bottoms *Ambrosia* is probably derived from more than one taxon and therefore may play more than one ecological role. Within the Pleistocene portion of the section (Figure 3.3, Zone I), *Ambrosia* varies from 5 to 20%. It is relatively higher throughout the lower portion of the record down to microzone IB4. Within the lower portion of the record, *Ambrosia*-type percentages fluctuate between 8 and 16%, with the highest occurrence, about 20%, in microzone IB3. Within the rest of the Farmdalian portion of the section (microzone IB4 through IC2), *Ambrosia*-type pollen remains relatively low (less than 10%). Again, in terms of the modern evidence, grasslands provide the closest modern analog to these relatively high percentages of *Ambrosia*-type pollen.

Within the Holocene (Zone II), the *Ambrosia*-type signal is clearly the inverse of the Cheno-Am type. If the *Ambrosia*-type is replacing the Cheno-Ams, presumed to be derived primarily from local populations, the *Ambrosia*-type pollen would also be locally derived. This increase in *Ambrosia* would be produced as the pioneer Cheno-Am community succeeded to perennial grasses and forbs.

Other Asteraceae types:

A more detailed accounting of the pollen taxa which are lumped into "Other Asteraceae types" on the primary pollen diagram is provided on Figure 4.2. Only two of these lesser Asteraceae pollen taxa show any obvious environmental signal: *Iva* undiff. and *Bidens*-type. *Iva* undiff. (marsh elder and sumpweed) pollen is very similar in morphology and structure to the *Ambrosia*-type (Figure 3.3). It is possible that there may be some misclassification between these two types, especially within the mid-Holocene (microzone IIA3). *Bidens*-type pollen is produced locally by *Bidens* spp. (Beggar-ticks), which are adapted to moist soils and marshy habitats, but probably includes other genera as well. Except for subzone IC, *Bidens*-type pollen occurs in low frequencies throughout the lower portion of the Farmdalian. *Bidens*-type pollen reappears in the Holocene and becomes most common towards the top of the column (microzone IIA4). Both *Iva*-type and *Bidens*-type are probably derived from local plant populations on moist and disturbed sites. Neither of these types is of any particular importance in modern pollen assemblages for the Great Plains.

Taken as a whole, the undifferentiated Asteraceae type does contribute a significant share to typical modern grasslands pollen assemblages. The level of total Other Asteraceae types at Cheyenne Bottoms, around 3 to 5%, is in keeping with observed frequencies in modern Great Plains pollen samples (McAndrews and Wright, 1969). With hundreds of species found in many diverse habitats, specific

CHEYENNE BOTTOMS, KS
Other Asteraceae types

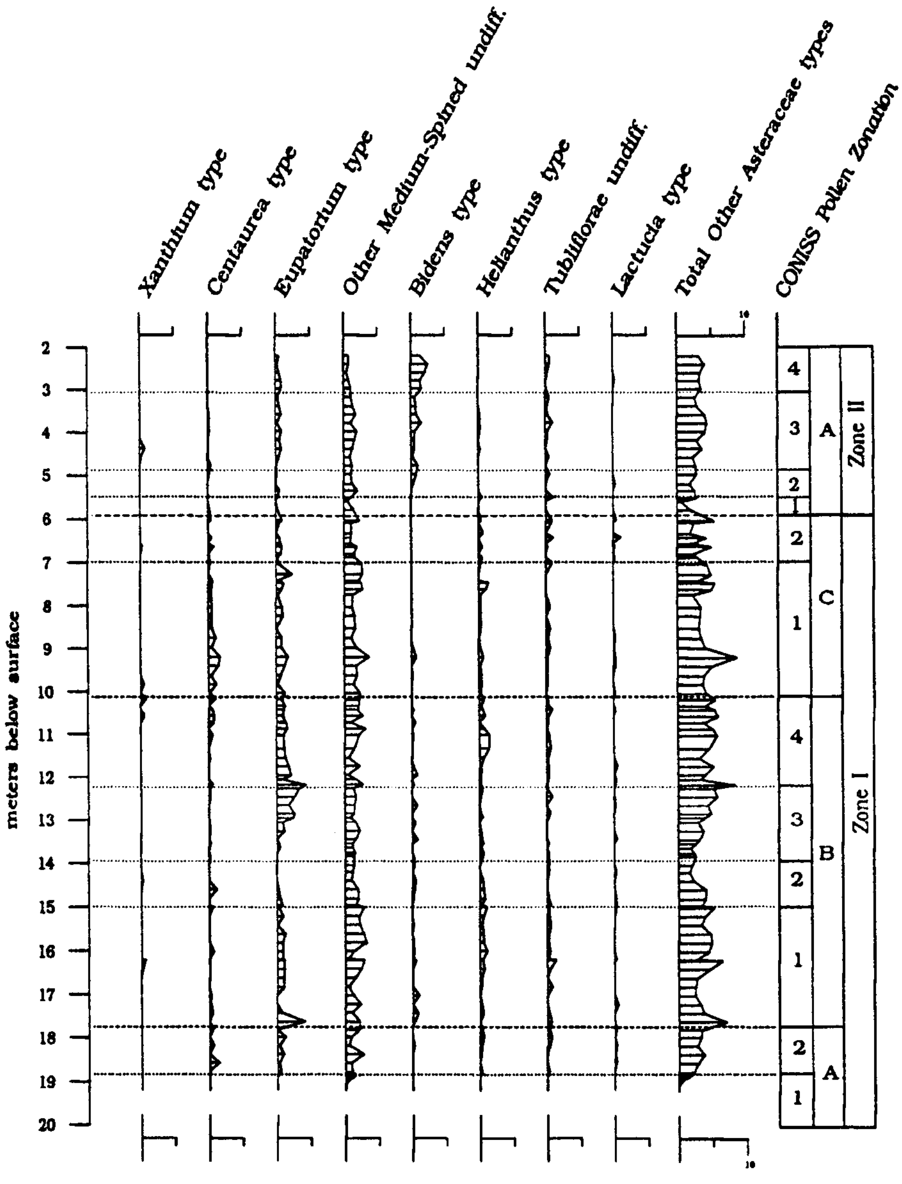


Figure 4.2: Percentages of Other Asteraceae types. CONISS pollen zones from primary pollen percentage diagram (Figure 3.3).

paleoenvironmental interpretations of the Asteraceae remain problematic.

<u>Polygonum</u> (smartweed):

Polygonum undiff.-type pollen at Cheyenne Bottoms is probably from local, within-basin populations (Figure 3.3). The differentiation of the *Polygonum* undiff. into its two distinctive types: a tricolporate *P.* cf. *cristum* type (Figure 3.3), and *P.* cf.*lapathifolium* type, a periporate form (Figure 4.3). The former of the two types accounted for almost all of pollen of that genera. Although this type occurs throughout the pollen record, it is significantly more common during the Holocene (Figure 3.3, Zone II). *Polygonum* pollen exhibits a distinctive peak in the mid-Holocene as Cheno-Am percentages drop. This may reflect a stabilization of water levels, allowing successional processes to establish a more diverse marsh vegetation.

<u>Other NAP types</u>:

The individual occurrences of pollen types within the "Other NAP types" rubric is provided on Figure 4.3. The most common pollen taxon within "Other NAP types" is the *Cassia*-type. The identification of this type remains uncertain. *Cassia*-type pollen is responsible for the higher relative frequencies shown on the Other NAP curve in the middle Holocene (Zone IIA3). The vast majority of the "Other NAP types" are relatively less frequent in the Holocene, but occur

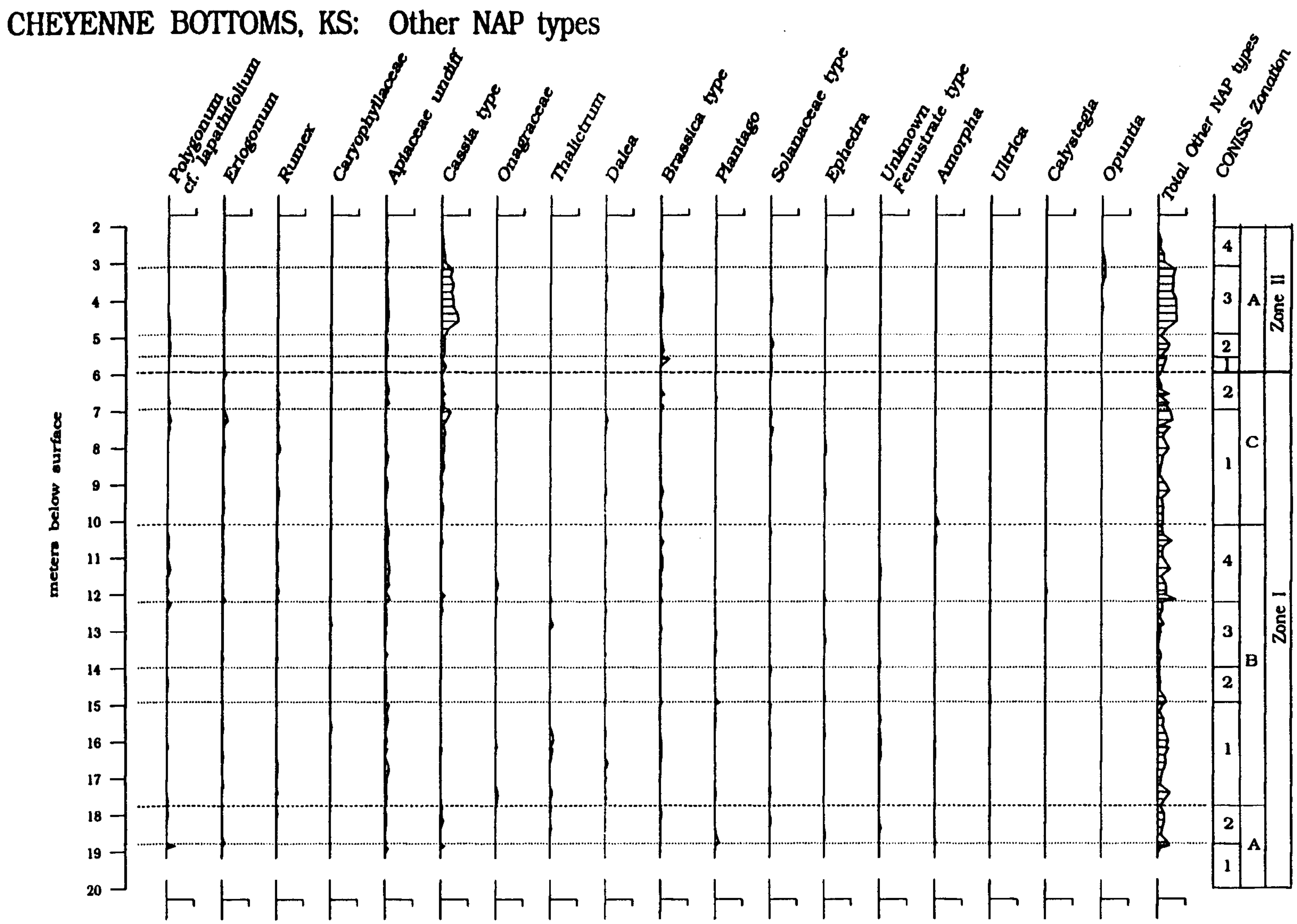


Figure 4.3: Percentages of other NAP types not shown individually on Figure 3.3. Percentage scale 2X that shown on Figure 3.3.

scattered throughout the Pleistocene. The diversity of these types is somewhat higher in microzones IB3 and IB4.

***Typha*-type (cattail):**

Typha-type pollen represents several plant species, all of which are semi-aquatic, shallow-water emergent plants. Both of the genera included within this type, *Typha* and *Sparganium*, are tolerant of fluctuating water-levels and water-quality. Of these two genera, *Typha* is by far the most common. Modern investigation has shown that, although *Typha* produces large quantities of pollen, this pollen does not travel great distance and is therefore only locally important in the pollen record. Modern peat samples taken only 50 meters from large stands of *Typha latifolia* yielded only 1 to 2% *Typha*-type pollen (Janssen, 1984). This factor accounts for the low percentages of *Typha*-type pollen, even though *Typha* historically dominated the local vegetation at the sample site.

The *Typha*-type was divided into two subtypes, *Typha latifolia* tetrads and single grains of *Typha*-type pollen (Figure 4.4). No distinctive signal was discernable in either subtype. *Typha*-type pollen occurred at 2 to 3% levels on the pre-dike surface and throughout the Holocene portion of the record (Zone II). *Typha*-type pollen reaches its peak of around 6% in the early-Holocene paleosol (microzone IIA2). Percentages of the *Typha*-type are low but more variable, ranging 0.5 to 5%, throughout the Pleistocene portion of the section (Zone I). Based on the modern analog percentages, even

CHEYENNE BOTTOMS, KS: Semi-Aquatics and Spore Types

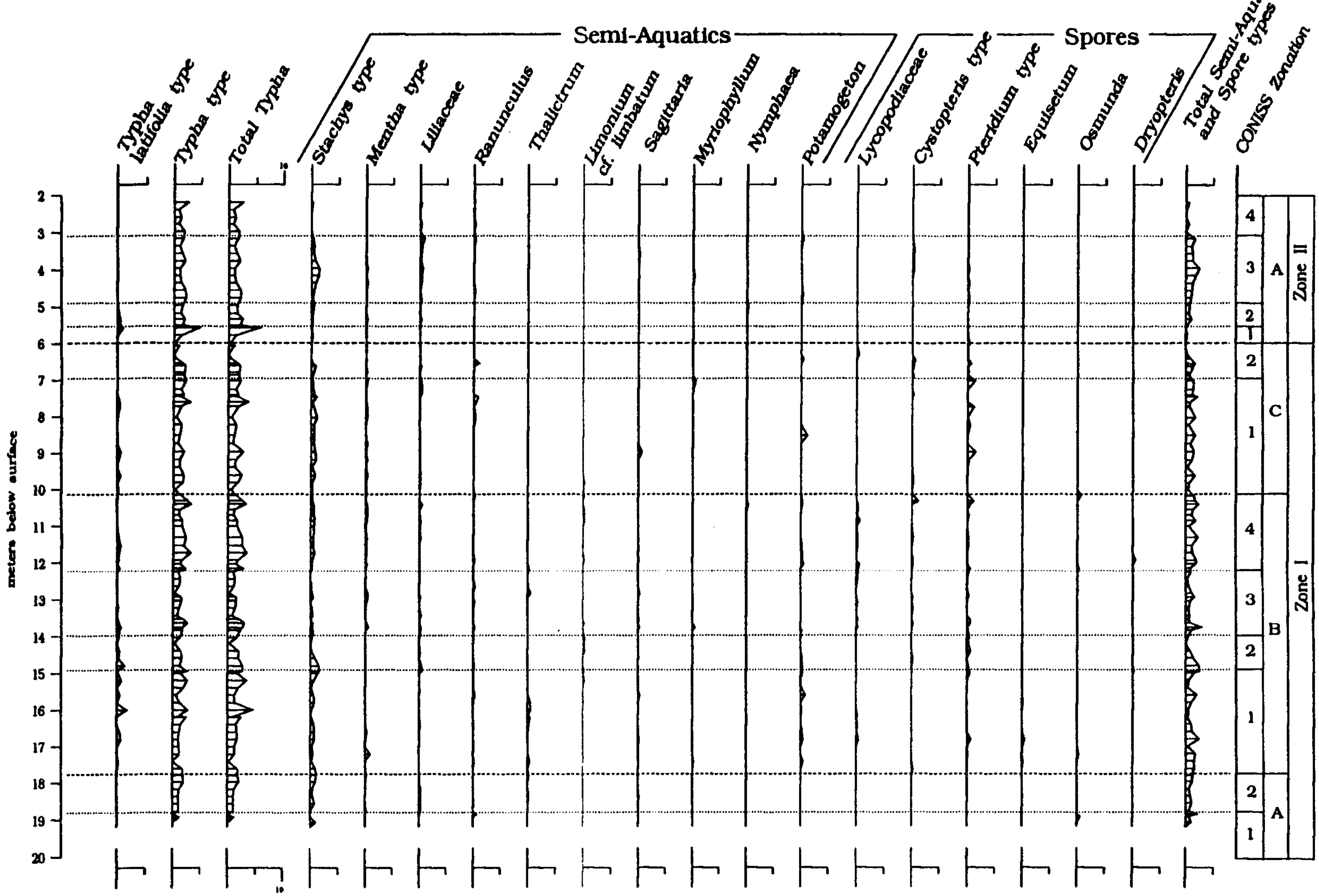


Figure 4.4: Semi-Aquatic pollen and vascular-plant spore types. Percentages 2X scale shown on Figure 3.3.

these low percentages of *Typha*-type pollen indicate that *Typha* was an important element in this shallow marsh during the late Quaternary. This suggests that Cheyenne Bottoms has remained a marshland throughout the period of time represented by the 1985 core. The possible exception to this occurs at the base of the 1985 core (microzone IA1) and just below the Pleistocene-Holocene unconformity (microzone IC2). During this period *Typha* was not as common, probably due to basin drying.

Semi-Aquatics, Ferns Spores, and Fern-Related Spore Types:

These diverse types, which are combined for simplification in the primary pollen diagram, are presented individually and within summary groups on a secondary diagram (Figure 4.4). The occurrence of these types provides some additional evidence of the water depth and quality throughout the late Quaternary history of Cheyenne Bottoms. The record of these pollen types suggests local wetland conditions have been relatively consistent throughout the period represented by the 1985 core.

One of the distinguishing features of the current wetlands community at Cheyenne Bottoms is the lack of plants which require persistent, deep water. Pollen from these floating and submerged aquatic plants is rare. Aquatic pollen taxa include *Myriophyllum*, *Nymphaea*, and *Potamogeton* (Figure 4.4). These sporadically-occurring aquatic pollen taxa are only slightly more common in the Pleistocene portion of the section (Zone I) than in the Holocene (Zone II). This suggests that even during the Farmdalian water-levels rarely, if ever, were deeper than about one meter. Pollen taxa which indicate salt-flats or playa environment (e.g. *Limonium*-type or Marsh Rosemary) are almost as common as these true aquatic taxa. The consistency of the *Typha*-type signal along with the rare and sporadic occurrence of true aquatic types indicates that Cheyenne Bottoms has been marshland, rather than a true lacustrine environment, throughout the period represented by the 1985 core.

Other Palynological Interpretations

Pollen Concentration

Changes in pollen concentration provide additional evidence by which the depositional environment and the Quaternary history of Cheyenne Bottoms can be interpreted. In interpreting pollen concentration, it is important to recognize that three factors affect concentrations: 1) the rate of sedimentation, 2) the rate of pollen production, and 3) the rate of diagenetic pollen destruction.

Concentrations in the lowermost portion of the pollen section (Zone IA) start off extremely low (less than 1000 grains per cc) but quickly rise to a level more indicative of adequate preservation (ca. 10,000 grains per cc) (Figure 3.5). The low concentration of pollen in this portion of the section is interpreted as indicative of poor pollen preservation. Based on sedimentological observations, this zone appears to represent depositional conditions before the more anaerobic, pollen-preserving marsh was well established.

It is important to note the inverse correlation between pollen concentration and *Pinus* pollen percentages in this portion of the section. The increase in the percentage of *Pinus* pollen is accounted for by its distinctive identifiable characteristics even when partially corroded (Hall, 1981). Due to this evidence of poor pollen preservation, paleoenvironmental interpretations from this microzone remain tenuous.

Throughout most of the mid-Wisconsinan portion of the section (Zone IB), pollen concentrations remain relatively stable around 10,000 grains per cc (Figure 3.5). These persistently stable high pollen concentrations suggest a period of depositional stability and good pollen preservation throughout much of the Farmdalian (Zone I). Concentrations dip only briefly below the 10,000-per-cc level in microzones IB2 and IB3. These microzones correspond with the slight rise in Cheno-Am type in Zone IB2 and the *Pinus* increase in microzone IB3. The evidence for this zone of lower pollen concentration is explained equally well by any of three alternative hypotheses: 1) dilution of the concentration by increased sedimentation, 2) decrease in pollen production, or 3) a decrease in pollen preservation.

The record of pollen concentration shows a significant decline, from more than 10,000 to around 3000 grains per cc, within subzone IC. Interestingly, the initial rise in pollen concentrations within subzone IC corresponds with the rise in Cheno-Am type pollen (microzone IC1). Local production of Cheno-Am pollen as the marsh dried out may account for this increase. The progressive lowering of pollen concentrations which occurs throughout the lower half of microzone ICa and all of ICb, may again be the result of any or all of the three factors controlling pollen concentration: 1) the dilution of the concentration by increased sedimentation, 2) decrease in pollen production, or 3) a decrease in pollen preservation. All three of these factors suggest increased aridity. The increased sediment yield by the surrounding uplands necessary for higher rates of sedimentation would be a sign of increased aridity. The lower pollen production, by both local and regional vegetation, also suggests increased aridity. Finally, a decrease in pollen preservation may also be linked with increased aridity and less persistent anaerobic depositional conditions (see discussion below).

Immediately above the Pleistocene-Holocene unconformity (microzone IIA1), within the early-Holocene silty textured sedimentary zone, pollen concentrations fall to their lowest levels. This zone contains just over 1000 grains per cc, a level considered by many palynologists as too low to allow interpretations on a quantitative basis. All of the factors outlined above may also be responsible for the low concentrations in this portion of the section. Additonal evidence on preservation suggests that the low pollen concentrations in this zone are primarily due to chemical and mechanical destruction.

Within the early Holocene paleosol, microzone IIA2, pollen concentrations increase dramatically. They jump from just above 1000 grains per cc to around 11,000 grains per cc (Figure 3.5). Throughout much of the Holocene portion of the section (Microzones IIA2 and IIA3), pollen concentrations hold steady at this level. This relatively high level of pollen concentration indicates both adequate preservation and a relatively stable rate of eolian deposition. During the late Holocene (Microzone IIA4), when there is a strong influx of Cheno-Am and Cyperaceae types, concentrations shoot up to over 100,000 grains per cc. Overall, the higher Holocene pollen concentrations are the result of greater local pollen production, primarily by Cheno-Ams, and secondarily a lower rate of sedimentation than during the Farmdalian.

Indeterminate Pollen

The occurrence of indeterminate pollen (Figure 3.6) reinforces the interpretation from pollen concentration data (Figure 3.5). The relative frequency of indeterminate pollen grains increases within zones of lower pollen concentration (microzones IA1, IB2 through IB3, and subzone IC). The middle zone of higher indeterminate pollen (microzone IB2 through IB3) differs from the others in that obscured or concealed grains account for the rise in indeterminability. In the other zones of lower concentration and higher indeterminability, degradation and breakage are more important. This suggests two different causes. Zones where taphonomic conditions include pollen degradation, breakage, and lowered concentrations are interpreted as periods of less anaerobic depositional environment (microzone IA1, and subzone IC).

Pre-Quaternary Palynomorphs

Changes in the pattern of redeposition of pre-Quaternary palynomorphs into Cheyenne Bottoms also provide evidence of changes in the depositional environment. These recycled palynomorphs are derived from the Cretaceous bedrock surrounding the basin. These pre-Quaternary forms are typically thick trileat spores which are more resistent to mechanical and chemical destruction than is contemporary fresh pollen. There are two zones of higher relative frequencies of pre-Quaternary palynomorphs (Figure 3.6). The lower zone (microzone IA1) corresponds to the basal (Sangamon?) paleosol and extremely low Quaternary pollen concentration. A second zone of relatively higher frequencies of pre-Quaternary palynomorphs occurs higher in the Pleistocene portion of the section, beginning at microzone IB4 and continuing through subzone IC. This broad zone encompasses the upper zone of lower pollen concentration, but also includes a substantial period of time prior to the lowering of concentrations. In general, this second zone of increased occurrence of pre-Quaternary fossils corresponds with the zone of higher Cheno-Am percentages. It is hypothesized that this increase resulted from erosion of upland pre-Quaternary bedrock brought on by increased aridity.

Geologic History of Cheyenne Bottoms Basin: A Summary of Interpretation

The Pre-Wisconsinan Sedimentary Unit

Although outside the thesis problem of regional vegetational reconstruction, the pre-Wisconsinan geologic history of the Cheyenne Bottoms Basin is of interest. The cause of the deep structural collapse and subsidence of the Cheyenne Bottoms basin is still unknown (Bayne, 1977). It is not clear whether the collapse was triggered by the dissolution of deeply buried salt beds, or whether the dissolution itself was the result, rather than the cause, of the basin collapse. Recently, some geologists have even considered the Cheyenne Bottoms basin as a possible impact crater (McClain, personal communication, 1990).

Whatever the cause, sedimentological evidence from the 1987 core suggests that the formation of the basin was a rather rapid geologic event. Coarse sands and gravels, indicative of high energy and rapid alluvial deposition, lie directly on the Cretaceous-Quaternary unconformity. Some of these basal gravels observed in the 1987 core samples were clasts of local sedimentary rocks, suggesting local sources for these deposits.

The pre-Wisconsinan sediments above these basal gravels appear to represent a single cycle of alluvial filling. The coarse texture at the base of this sedimentary unit suggests rapid alluvial filling of the basin. The rapid shifts from coarse to fine texture suggest that these sediments did not arrive continuously, but were episodically dumped into the basin. As sediments filled the basin, and the alluvial gradient decreased, the texture of the alluvial sediments appears to have gradually become finer. Although textural analysis was not performed on the 1987 core samples, evidence for overall fining upward throughout the unit can be seen in the natural gamma log (Figure 2.2). Observations of the 1987 core samples support this interpretation. It appears that alluvial filling of the basin gradually slowed until some equilibrium was reached. This pre-Wisconsinan cycle of alluvial sedimentation terminated in a dense clayey sedimentary unit.

The cause of this dense unit remains unknown. It is hypothesized that this dense, clay-rich horizon represents a substantial pre-Wisconsinan period of surface stability and soil development; however, core samples from this horizon do not exhibit any evidence for an organically-enriched paleo-A horizon. If this unit does represent a paleosol, then it is possible that the soil profile was truncated, or altered in some other way. Given the topographic setting, such a soil truncation may have occurred through eolian erosion. This horizon may represent a period of surface stability anywhere from thousands to hundreds of thousands of years.

The absolute chronology of the basin collapse, episode of alluvial in-filling, and subsequent period of stability documented in the lower part of the 1987 core remains poorly defined. While it seems reasonable to assume that these unconsolidated sediments are Quaternary in age, chronological control is largely lacking. The age of the sediments directly above indicates that the age of the mid-section paleosol is significantly greater than 30,000 yr. B.P., and therefore older than can be dated by radiocarbon techniques. The hypothesized period of stability and soil development within the basin appears to be correlated chronologically with the "Sangamon" portion of the upland paleosol described from the Barton County Landfill section (Feng, 1991). It is hypothesized that these upland loess deposits, analyzed by Feng (1991), postdate the formation of the Cheyenne Bottoms basin. The stratigraphic and radiocarbon evidence from both the Cheyenne Bottoms cores suggests that the basin has existed for several hundred thousand years.

Late Quaternary History of Sedimentation

The Farmdalian

The radiocarbon data indicate that a second phase of sediment influx into the Cheyenne Bottoms Basin began in the mid-Wisconsinan, perhaps 35,000 to 45,000 years ago. This period of sedimentation lasted at least until 24,000 yr. B.P., thus encompassing the entire Farmdalian stage of the Wisconsinan Stadial.

This sedimentary unit is qualitatively different from the sedimentary units which lie below and above. The Farmdalian sediments lack the major bedding that would indicate massive episodic alluvial influxes. The only sedimentary structures apparent in these silty Farmdalian sediments are thin laminae of sands and silts alternating with finer clayey silts. It is hypothesized that these laminae represent fluctuations in sedimentary input, rather than true varves. Although alluvial and colluvial transportation of sediments certainly did contribute, it is hypothesized that eolian sands and silts were more important during the deposition of this unit. Pollen and other evidence suggests that this deposition occurred in shallow-water wetlands persisting throughout the Farmdalian.

It is hypothesized that these varve-like laminae represent clastic lamination as defined by Strum (1979) and O'Sullivan (1983). Unlike classic varves, clastic laminations are deposited in shallow, isothermic water-bodies. Clastic laminations are typically created by rhythmic variations in sediment input rather than by mixing of the water column (Strum, 1979; O'Sullivan, 1983). These sedimentary structures have been observed in contemporary lacustrine sediments where rapid eolian sedimentation is occurring. The origin of these laminated sediments at Cheyenne Bottoms remains a problem for future study. It is hypothesized that the deposition of sediments throughout most of the Farmdalian was rapid. It is further hypothesized that this sedimentation was primarily eolian, trapped by the permanent, stable shallow-water wetland which occupied by floor of the basin.

Whatever the transportational mechanism, the rate of Farmdalian sedimentation at Cheyenne Bottoms was relatively rapid (Figure 3.2). The radiocarbon chronology indicated that, throughout most of the Farmdalian (subzones IA and IB), the rate of deposition was around 15 mm per year. The rate of sedimentation increases substantially during the late Farmdalian (subzone IC; 25,000 to 24,000 yr. B.P.) to around 42 mm per year.

Within this same portion of the Farmdalian (subzone IC), both pollen and sedimentary evidence indicate that the Cheyenne Bottoms wetland was undergoing a period of drying leading up to the unconformity. Increase in Cheno-Am type pollen is interpreted as a lowering of water levels leading to exposure of mudflats (Figure 3.3). The sediments throughout most of this portion of the record (microzone IC1) are significantly sandier and more oxidized in appearance (higher in iron?) than those which preceded it. Pollen concentrations also fall precipitously throughout this same period, until they are insufficient for quantitative interpretations. These lines of evidence from the late Farmdalian microzone IC1 are interpreted as representing: 1) a period of basin drying, and 2) a period of increased eolian deposition of both sands and silts.

In the uppermost pollen zone (microzone IC2), immediately below the proposed unconformity, some of these paleoenvironmental signals become reversed. The texture of microzone IC2 is significantly more clayey than microzone IC1. The color of microzone IC2 is mottled grays and oranges, rather than the dull orange observed in microzone IC1. Percentages of arboreal pollen types, especially the *Pinus banksiana*-type, show a marked increase. Pollen concentrations, however, continue to fall. These lower pollen concentrations may be a reflection of poor pollen preservation during a non-wetland period of deposition. They may also have resulted from diagenic alteration (post-depositional oxidation). A bulk radiocarbon date from the middle of this sedimentary unit yielded a date of 24,470 yr. B.P. (TX-6266). The depositional environment of this unit is not yet fully understood. Its interpretation may be related to the Woodfordian unconformity which overlies it.

The Woodfordian Unconformity

The most puzzling portion of the Cheyenne Bottoms record is the apparent unconformity that results in the absence of sediments from the Woodfordian substage of the Wisconsinan. The conclusion that there is at least one unconformity in this portion of the section is inescapable. At 5.88 meters below surface there is a sharp, not transitional, sedimentary boundary. This sharp break is reflected in all aspects of the pollen record. The radiocarbon chronology indicates that within the zone surrounding this sedimentary break either: 1) the rate of deposition slowed down to almost nothing (i.e. the surface was stable), or 2) the Woodfordian period is missing due to erosion of sediments, resulting in a nonconformity. A number of lines of evidence suggest the latter. Projection of sedimentary rates above and below the stratigraphic break indicates that more than 13,000 years, from 24,324 to 10,953 yr. B.P., are missing from the sedimentary record.

Arguing against the surface-stability hypothesis is the lack of evidence for soil development. If this hiatus really did represent a stable dry-land surface for 13,000 years then some evidence of pedogenesis should be apparent. There are no obvious indications of higher organic matter or structural indications of soil development; yet these types of evidence do occur in the Holocene portion of the section above. The only evidence which could be pedogenically related is the clayey, mottled unit (microzone IC2) which lies directly below the 5.88 mbs sedimentary break.

Also arguing against the surface stability hypothesis is the regional eolian chrono-stratigraphy. It is widely accepted that throughout the Great Plains, the Woodfordian was a period of increased eolian (loess) deposition (Fredlund *et al.*, 1985). In view of this regional loess deposition, it is difficult to account for the Woodfordian hiatus in the Cheyenne Bottoms record through non-deposition.

The second possibility is an erosional unconformity. Given the nature and topography of the basin, the only erosive agent likely to be effective is wind. Under this scenario, it is possible that early Woodfordian sediments may have been deposited at Cheyenne Bottoms but subsequently eroded later during the Woodfordian. Such erosion would not necessarily have to occur during a single episode but could have occurred repeatedly, perhaps even cyclically, during the Woodfordian. In this regard, it would make sense that the sedimentary unit underlying the erosional unconformity would be clayey, and therefore less erodable (microzone IC2).

One form of evidence which would support the nonconformity hypothesis would be the presence of a coarser eolian lag deposit resting on top of the less erodable surface. Although there is a coarsening in texture immediately above the 5.88 mbs sedimentary break (microzone IIA1), this coarsening in texture is primarily attributable to the silt-size range, rather than sand-size as would be expected of an eolian lag deposit. This does not, however, negate the nonconformity hypothesis. Given the fine texture of the sediments that were being eroded, it is conceivable that non-erodable coarse clasts simply were not present.

Neither of these hypotheses is particularly satisfying. Both working hypotheses suggest that periods of extreme aridity, drier than modern conditions, occurred during the Woodfordian. Hypotheses of an arid Woodfordian climate conflict with some interpretations of the Woodfordian conditions (Wells and Stewart, 1987). This is especially the case during the late Woodfordian period, which has been hypothesized by many to have been more mesic than today. It is not clear why at least the late-Woodfordian is not better represented in the Cheyenne Bottoms record. The conflict created by this apparent unconformity will be discussed in the concluding chapter. The creation of this unconformity remains problematic. Dating of these sediments remains problematic. Although an old-carbon bias in the radiocarbon ages is suspected, the dates should still be roughly correct. Accelerator mass spectrometry dating of macrofossils from this portion of the core may provide a more accurate radiocarbon chronology on which to base interpretations.

The Holocene Sedimentary Unit

The depositional environment of the lowermost portion of the Holocene (microzone IIA1) also remains problematic. This unit contains an abundance of aquatic mollusks, both bivalves and snails, ostracods, diatom frustules, and other fossils. The coarser (siltier) texture of this unit is most likely attributable to diatom influx. Loss-on-ignition analysis of the carbonate content of this horizon indicated that about 17% of the sediment weight was carbonate. This high carbonate content comes almost exclusively from the mollusk-shell litter and ostracods. This sedimentary unit is interpreted as representing return of standing water conditions to the Cheyenne Bottoms basin after the erosional conditions represented by the unconformity. It is not clear why pollen preservation and pollen concentrations remain so poor during this period of return to more mesic conditions.

The rest of the Holocene sedimentary unit (microzones IIA2, IIA3, IIA4) is relatively homogenous in texture. This clay to clay-loam unit is sedimentologically distinct from the Farmdalian sediment discussed above. The Holocene sedimentary unit also lacks the laminated structures observed throughout much of the Farmdalian. Radiocarbon dating of the Holocene unit helps explain this difference. The rate of sedimentation throughout the Holocene varies from 4 mm to 7 mm per year. This is only about half of the slowest Farmdalian sedimentation rate. The slower rates of sedimentation and resulting finer-textured Holocene sediments are interpreted as signs of lower energy of transportation. This slower rate of deposition also explains, in part, the relatively high pollen concentrations observed in the Holocene. The other hypothesized explanation for the increase in Holocene pollen concentrations is the expansion of Cheno-Am dominated mud-flat plant communities on the basin floor. The Holocene depositional environment is interpreted as shallow-water ephemeral wetland, on which eolian and alluvial sediments were gradually accumulating.

Vegetative Interpretations

Inferred Farmdalian Vegetation

The oldest pollen assemblages recovered from Cheyennne Bottoms date to the Farmdalian substage. Based on comparisons of these Farmdalian pollen assemblages with modern analog pollen asseblages, the best interpretation of regional (extra-local) vegetation at Cheyenne Bottoms is grassland-steppe. The consistently high relative frequencies of *Artemisia*, Poaceae, and *Ambrosia* pollen occurring throughout the Farmdalian (Zone I) are found today only in pollen samples from grasslands and steppe communities (see discussion of individual pollen taxa above). As previously discussed, the derivation of this fossil pollen record from a large marshland does introduce some problems in making comparisons to modern analog assemblages. However, even taking into account the relative strength of the local pollen signal, and its ability to dilute the regional signal, the weakness of the AP signal at Cheyenne Bottoms indicates that regional populations of trees were very limited. Structurally, the Farmdalian vegetation mayto have been dominated by a grassland-steppe community.

One of the most important features of the Farmdalian pollen assemblages is the high relative frequency of *Artemisia*. In modern pollen assemblages, the prevalence of *Artemisia* pollen over Poaceae pollen is typically indicative of aridity (McAndrews and Wright, 1969; Mack and Bryant, 1974; Barnosky, et al., 1987). The high relative frequency of *Artemisia* pollen in the Farmdalian record from Cheyenne Bottoms indicates that one or more species of sage (*Artemisia*) were an extremely important element in the upland grassland-steppe. This vegetation does not appear to be exactly analogous to the modern sagebrush steppe of the northwestern high plains. The *Artemisia* pollen type common to the Pleistocene section does not appear to primarily be *A. tridentata* (big sagebrush). Based on the variablity in diameter, and other morphological observations, it does not appear to be a single species; however, the exact species remain unknown. Because of this taxonomic limitation, and because of potential differences in other ecological factors, which are addressed in the concluding chapter, the interpretation of the sage signal remains problematic. It is questionable whether the Farmdalian sage signal has the same climatic implications as placed on modern *Artemisia*-rich pollen assemblages.

The pollen evidence suggests that the regional vegetation, although dominated by grassland-steppe, was not totally treeless.

Most of the arboreal elements present are boreal or taiga-like in their modern distribution. The most common trees of the Pleistocene vegetation in the region, however, were not coniferous. The low percentages of both *Picea* and *Pinus* pollen could be the result solely of long-distance transportation. This is especially likely for *Pinus* which could represent forests as far away as 400 km. In the case of *Picea*, it is more likely that local populations of trees were scattered along river valleys or fire-protected escarpments. It is extremely unlikely that the pine and spruce pollen signals from the Farmdalian portion of the record represent coniferous parklands or savannas. It is more likely that these low pine and spruce pollen percentages represent small populations of conifers limited to edaphically mesic and fire-protected situations such as river valleys and escarpments.

Both junipers (*Juniperus*) and aspen or poplar (*Populus*) are potentially more important within the Farmdalian landscape than are spruce and pine. Even the relatively low percentages of these taxa occurring at Cheyenne Bottoms translate into significant populations in the uplands surrounding the basin. The distribution of these populations throughout the landscape is less certain. They were certainly along river valleys and escarpments, and to some extent may have encroached into the interfluvial uplands. The degree to which this encroachment into the upland occurred is unknown. Pollen of other associated tree and shrub taxa (i.e. *Betula, Alnus, Salix,* and *Sheperdia*), while present, does not occur at levels commensurate with that found in aspen parklands today. These data suggest that, while areas of low, shrubby parklands may have been present on the interfluvial uplands, they were not the dominant vegetation.

Inferred Holocene Vegetation

The Cheyenne Bottoms Holocene grasslands pollen record (Zone II) is markedly different from the Farmdalian grassland-steppe assemblage (Zone I). Interpretation of the vegetative differences represented by these palynological differences should first take into account the higher local pollen signal during the Holocene. Taking this local Holocene signal into account, the two most important differences between the two zones are: 1) lower *Artemisia* percentages throughout the Holocene, and 2) lower relative frequencies of arboreal pollen types. These differences suggest that the Holocene regional upland vegetation lacked the sage component which was so important during the Farmdalian. The pollen data also indicate that the Holocene vegetation also lacked the diversity of tree and shrub taxa regionally present during the Farmdalian. Of all tree and shrub pollen taxa identified, only elm (*Ulmus*) and hackberry (*Celtis*) are more common during the Holocene (Figure 3.7).

Holocene change in the upland vegetation is difficult to detect in the Cheyenne Bottoms pollen record. Zonation within the Holocene pollen record appears to be due to local, rather than regional vegetational change. Four microzones within the Holocene are defined by changes in the local pollen signal: 1) the Holocene-Pleistocene diatomaceous zone (microzone IIA1), 2) a period of Early-Holocene paleosol development (microzone IIA2), 3) the Mid-Holocene period of stability (microzone IIA3), and 4) the Late-Holocene soil development (microzone IIA4). The lowermost microzone (IIA1) does not present a coherent local or regional pollen signal. This assemblage appears to be an admixture of the two zones. Pollen concentrations within this zone are only about 1000 grains per cc, below that normally considered adequate for quantitative interpretation.

The Early-Holocene Paleosol (ca. 9,691 to 8,490 yrs. B.P.) consists of a 68-cm-thick (depth interval 5.54 to 4.86 m.b.s) zone which exhibits clear structural indications of paleosol development. The high relative frequencies of Cheno-Am type pollen in these paleosol assemblages suggest it represents a period of increased aridity and fluctuation in the water levels within the basin. Local plant communities during this early Holocene period appear to closely mirror those which occur today. The coring site itself was probably a *Typha*-marsh during this period.

In the Mid-Holocene (ca. 8490 to 4794 yrs. B.P.) portion of the Cheyenne Bottoms record, Cheno-Am pollen types, indicating exposed mud-flats, decrease significantly. Pollen samples from this portion of the core (depth interval 4.86 to 3.06 m.b.s) show increases in *Ambrosia*-type and *Polygonum*-type pollen. These data do not necessarily mean that this entire period was one of higher water-levels; they may simply indicate more stable water levels. If water levels remained stable, succession within all of the plant communities, from the salt-grass community on the marsh fringe to the open-water aquatic communities in the center of the basin, would allow these communities to become more fully developed. Such succession would have occurred at the expense of the weedy, invading Cheno-Am community.

In the upper portion of the Holocene record (depth interval 3.06 to 2.18 m.b.s), the production of Cheno-Am type pollen becomes even greater than it was during the early Holocene. During this Late-Holocene period (ca. 4,800 yrs. B.P. to present) at Cheyenne Bottoms, the water level in the basin fluctuated but deposition slowed. The lower depositional rates resulted in more intensive soil-development.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Tests of Hypotheses

Introduction

The investigations at Cheyenne Bottoms have yielded evidence of the late Cenozoic history of the Cheyenne Bottoms basin and its environs. These interpretations are based on sediment and pollen analysis from a single core, the stratigraphy of which is assumed to be representative of the central basin. The interpretations derived from these fossil data do not always conform with that which was anticipated (Chapter 1). The working hypotheses for each of the four major chronological periods (Farmdalian, Woodfordian, Woodfordian-Holocene Transition, and the Holocene) will be re-examined in chronological order from oldest to most recent.

Farmdalian

The Cheyenne Bottoms pollen data suggest that the Farmdalian vegetation was far more open and treeless than originally proposed. Pollen from Cheyenne Bottoms suggests that trees and shrubs, although far more diverse than occurred regionally during the Holocene, were really a secondary component of the overall vegetative structure. Between 30,000 and 24,000 yr. B.P. a grassland-sage steppe dominated the regional uplands surrounding the Cheyenne Bottoms basin. Because there is so little evidence for Farmdalian conditions in the central Great Plains, the interpretation derived from the Cheyenne Bottoms data does not present any significant conflicts. In fact, the Cheyenne Bottoms data are in perfect keeping with the Farmdalian pollen evidence from central Nebraska (Fredlund and Jaumann, 1987; Fredlund, 1990).

Based on modern analog comparisons, the levels of pine and spruce pollen in the Farmdalian sediments at Cheyenne Bottoms do not represent coniferous parklands. Although the low percentages of these coniferous pollen types could have resulted from long-distance transportation, it is far more likely that they represent local populations in protected edaphic situations, such as escarpments and mesic river valleys. Investigation into the possible species of pine represented showed that several species had contributed to the pine pollen record. The pine pollen record was not typically dominated by any single *Pinus* subtype. Only within one zone, dating to around 24,000 years ago, did a single *Pinus* subtype, *P. banksiana*, dominate. Pollen conforming with limber pine (*P. flexilis*) was identified, but did not dominate any of the Farmdalian pine pollen samples.

Woodfordian

One of the most important discrepancies in the Cheyenne Bottoms pollen record relates to Woodfordian conditions. It had been hypothesized that the Woodfordian, especially the later portion, would be significantly more mesic than either modern, late-Holocene, or Farmdalian conditions. The evidence from Cheyenne Bottoms suggests that this may not have been the case. It was assumed that Cheyenne Bottoms would contain a continuous sediment and pollen record which spanned the Pleistocene-Holocene boundary. Instead, the evidence indicates that quite the contrary may be true. The data indicate that the entire Woodfordian period, over 13,000 years, is missing. Although the factors responsible for this unconformity are not entirely clear, the best scenarios suggest that the Woodfordian stage in the Great Plains may have been far more arid than hypothesized.

Consistent pollen, sedimentary, and radiocarbon evidence for local conditions prior to this Woodfordian unconformity suggests that a period of basin-wide drying occurred between 25,000 and 24,000 yr. B.P. It is hypothesized that the unconformity is a continuation of this cycle of aridity, and that eolian erosion during this xeric Woodfordian period is responsible for the lack of Woodfordian sediments. This explanation is consistent with other regional geomorphic evidence (Kutzbach and Wright, 1985), but is in strong disagreement with some interpretations of the scattered biological evidence (e.g. Wells and Stewart, 1987a; 1987b).

These conflicting interpretations of Woodfordian vegetation and climate can be partially reconciled by two factors: 1) recognizing distinctive climatic differences within the Woodfordian, and 2) recognizing local landscape variability. Based on the Woodfordian land-snail record, and on the radiocarbon-dated plant fossils in the region, I have suggested that the regional climate during the

Woodfordian varied from cold xeric conditions early on (ca. 24,000 to 16,000 yrs. B.P.) to cool and more mesic conditions toward the end of the period (ca. 16,000 to 12,000 yrs B.P.). Local landscape variability is also important, in that many of the Woodfordian macro-fossil and pollen records come from atypical landscape situations (e.g. spring-fed escarpments of a major river valley). This landscape bias may have led some interpretations of the fossil record to over-estimate the regional forest cover. Nevertheless, it is clear that the late-Woodfordian landscape supported more trees than that of the Holocene.

Even during the hypothesized early Woodfordian period of aridity, it appears that some tree species did persist within major river valleys (Jaumann, 1991). It is hypothesized that these riparian tree and shrub populations spread westward, up the river valleys, and eventually onto the uplands as climatic conditions ameliorated during the course of the Woodfordian period.

There is, however, no solid regional evidence that conifers (spruce or pine) ever dominated the upland vegetation of the central Great Plains region during the late Quaternary. Instead, the data suggest that, even during the more favorable late Woodfordian climatic period, coniferous trees were probably confined to special topographic positions with favorable edaphic situations. These regional data further suggest that deciduous shrub-lands and aspen parklands interspersed with grasslands typified the vegetation of the loess-mantled uplands only during the latest portion of the Woodfordian.

Because of the Woodfordian hiatus, however, the Cheyenne Bottoms paleoenvironmental record itself does not support the Woodfordian vegetation conditions hypothesized above. The Cheyenne Bottoms unconformity could, in fact, be used as an argument that conditions remained xeric throughout the Woodfordian. The history of the Woodfordian vegetation in the central Great Plains cannot be resolved by this or any other single study.

Woodfordian-Holocene Transition

According to the radiocarbon chronology, this Woodfordian unconformity did not terminate until almost 11,000 years ago. Between about 11,000 and 9,700 yr. B.P., a 34-cm-thick sedimentary unit was deposited. The diatoms and other aquatic fossils recovered from these Woodfordian-Holocene transitional sediments suggest that a more mesic climate occurred during this period. This change is in keeping with the regional biological evidence. Unfortunately, the depositional environment of this zone was unfavorable for pollen preservation. It is not possible to reconstruct regional or local vegetation from the sparse pollen recovered from this Woodfordian-Holocene transitional sedimentary unit.

The Holocene

As anticipated, climatic changes within the Holocene period are difficult to interpret. This difficulty stems both from the taxonomic limitations of non-arboreal pollen identification and from the strength of the local plant community pollen signal during the Holocene. The Holocene portion of the Cheyenne Bottoms record is readily divisible into three periods: the early Holocene (ca. 9,700 to 8,500 yr. B.P.), the mid-Holocene (ca. 8,500 to 4,800 yr. B.P), and the late-Holocene (ca. 4,800 yr. B.P. to present). These periods, based on variation in the pollen record, are hypothesized as representing the response of local plant communities to major changes in the Holocene climate. Both the early- and late-Holocene periods contain relatively greater amounts of Cheno-Am pollen. The middle-Holocene period has lower percentages of Cheno-Am pollen. These responses may be due to higher, but less stable, water-levels during the late- and early-Holocene periods relative to lower, but more stable water-levels during the middle Holocene period.

Implications and Discussion

Fire, Climate, and Grassland

The primary objective of this research was to bring new data to bear on an old problem: the origin and history of the grasslands of the Great Plains of North America. There is a deep-seated, historical disagreement among both geographers and botanists over the origin of the Great Plains grasslands (e.g. Hay, 1878; Christy, 1892; Shimek, 1911; Clements and Weaver, 1924; Transeau, 1935; Wedel, 1941; Borchert, 1950; Wells, 1965; Axelrod, 1985). This disagreement concerns the relative importance of two variables, climate and fire, in the creation and perpetuation of grasslands. The history of the Great Plains grasslands is in some ways incidental to this processual discussion. At the heart of the disagreement is whether or not grasslands would exist without anthropogenic ignition of wildfire. It is difficult to directly test the relative importance of fire with fossil evidence, and impossible to determine if such fire was anthropogenic. Although change in regional vegetation can be inferred from the Cheyenne Bottoms fossil pollen record, the causal factors which underlie that change are not as directly testable. In general, Quaternary palynologists argue that climate is the driving force behind long-term changes in vegetation (e.g. Webb, 1986; Prentice, 1986, 1988). In the grasslands of the Great Plains, however, there is a long-standing challenge to the assumption of climatic governance (e.g. Gleason, 1922; Wells, 1965; Axelrod, 1985).

In order to put this discussion in perspective, the opposing points of view concerning the origin and perpetuation of the grasslands are presented briefly. Although there is a vast middle ground in this debate, it is rarely taken. The opinions of most researchers gravitate to one extreme or the other. At one extreme are those who argue that climate was the paramount determining factor responsible for the creation and maintenance of grasslands. In botany this point of view was most clearly set forth by Frederick Clements in the first half of this century (Pound and Clements, 1900; Clements and Weaver, 1924; Clements 1949). In geography, the banner of climatic governance over grasslands, and all natural vegetational structure, has been held highest by climatologists and other physical geographers following in the Koppen tradition (Thornthwaite, 1931; Borchert, 1950; Bryson, 1966; Bryson *et al.*, 1970).

At the other extreme are those who insist fire-disturbance is the essential factor in the creation and maintenance of grasslands. In ecology, this point of view was first put forth by Gleason (1913, 1922) as a challenge to the Clementsian paradigm. In geography and anthropology this pro-fire viewpoint became popular during the 1950s when the works of George C. Marsh (1864, 1856) underwent a period of revitalization. This 1950s neo-Marsh movement is most strongly associated with the eminent geographer Carl Sauer. Sauer clearly and directly addressed the grassland problem (Sauer, 1950). Without anthropogenic burning, in Sauer's opinion, there would be no grasslands. The botanists, geographers, and anthropologists represented on this end of the climate-fire argument insist that lightning-ignited fire alone is not enough to maintain a grassland. Without anthropogenic ignition, they argue, the frequency of the natural fires would be too low to maintain the treeless grasslands of the Great Plains region (Axelrod, 1985).

The Cheyenne Bottoms record certainly will not resolve this question. Depending on how one defines grassland, and how one interprets the fossil record, the Cheyenne Bottoms evidence can be used to support either side. Arguing for climatic governance are the pollen assemblages from the Farmdalian. These pollen data provide evidence for an open, grassland-steppe community structure prior to

24,000 years ago. The grassland-steppe community represented by this pollen assemblage would clearly be considered a grassland by many definitions (e.g. Vogl, 1974; Wright and Bailey, 1982). The 24,000 yr. B.P. date precedes currently accepted dates for the peopling of the New World (e.g. Stanford, 1982; Lewin, 1987). Thus, it can be argued that in the absence of anthropogenic ignition climate alone was able to maintain a grasslands community.

This is not to say that fire was absent. As Loren Eisely (1954:52) observed, "man, it is well to remember, is the discoverer but not the inventor of fire." There is good evidence for fire in the Cheyenne Bottoms Farmdalian sediments. Strands of burnt plant material observed throughout the Farmdalian zone indicate that fires did indeed occur. These burned plant materials have not yet been fully analyzed; however, wood charcoal is rare throughout the section. The burned fragments appear to be primarily grasses, sedges, and herbaceous plants. The lenses of partially burned grasses and sedges are assumed to be evidence of Farmdalian burning of the marshland itself. The strands of partially burned plant materials occur most frequently in sediments dating to about 25,000 years ago, around the onset of the basin drying cycle which culminated in the unconformity. While radiocarbon control of the Cheyenne Bottoms record is not yet adequate to provide an estimate of fire frequency in the Farmdalian period, it does demonstrate that fires occurred fairly regularly, even in more mesic portions of the landscape, including the Cheyenne Bottoms marsh. It is reasonable to assume from this evidence that fire also occured frequently in the uplands during the Farmdalian. It is hypothesized to have been an important shaping force in this xeric Farmdalian landscape. In the absence of people, this Farmdalian fire regime would be solely controlled by the frequency of lightning ignition, precipitation, wind, and other climate-related factors.

On the other hand, it can be argued that people were indeed present in the New World prior to 12,000 yr. B.P. It could be a mistake to totally dismiss anthropogenic ignition during the Pleistocene, even though conventional archaeological wisdom still does not accept evidence of pre-Clovis people. From this point of view, the pollen record indicating grasslands could even be used to argue for the presence of pre-Clovis people. It may be that the archaeological record will one day validate Carl Sauer's view that people have been important agents in modifying the New World landscape for several hundred thousand years (Sauer 1950:19). It is hypothesized that, if people were an active part of the Pleistocene fire regime, anthropogenic ignition was far less frequent than it was during the (prehistoric) Holocene.

Many adherents of the anthropogenic grasslands hypothesis have adopted a very stringent definition of "grassland." Sauer (1950) qualifies his use of the term as both "treeless" and "shrubless." Wells (1970a; 1970b) adopts exactly these same criteria. Axelrod (1985) also emphasizes the "treelessness" of the late Holocene Great Plains region. The Cheyenne Bottoms data clearly document a

Farmdalian vegetation which contains far more trees and shrubs than the treeless grasslands of the Holocene. This evidence for increased diversity of tree and shrub taxa suggests a different vegetation than that which occurred in the Holocene. Even though the pollen record suggests a regional grassland-steppe community structure, this Farmdalian vegetation cannot be said to be treeless or shrubless. Applying a more stringent definition of grasslands, the composition of the treeless grasslands seen by the early Euro-American explorers and settlers of the Great Plains certainly did not arise until the latter part of the Holocene when anthropogenic ignition was probably relatively common (Axelrod, 1985).

The Late-Pleistocene Vegetative Structure

The exact structure of the late-Pleistocene plant community in the central Great Plains remains somewhat ambiguous. In the interpretations of the Cheyenne Bottoms Farmdalian pollen data it has been shown that the only sets of modern analog data which quantitatively match the observed percentages of the NAP types are from grassland and sagebrush steppe communities. This grassland-steppe interpretation is the most consistent with the modern analog assemblages. It was also pointed out throughout the pollen interpretive section that the relative frequency of some of these NAP types may be due to local, marshland plant communities rather than regional (extra-local) upland communities. This potential for a stronger than normal local plant community pollen signal requires that interpretations be somewhat more flexible. In order to compensate for this uncertainty, a wider range of possible interpretations must remain open.

This range of interpretations includes both a more wooded upland community and a cold desert steppe community. Most of the tree and shrub taxa observed in the Cheyenne Bottoms pollen record are characteristic of boreal communities today. Although it cannot be shown in the Cheyenne Bottoms data, it is possible that the Woodfordian vegetation of the Great Plains also included an even more diverse complement of boreal trees and shrubs (cf. Jaumann, 1991). These woody taxa, typically occurring in low frequencies even in modern pollen assemblages, are those most likely to be affected by the influx of local marshland grass, sedge, and forb pollen. In the Cheyenne Bottoms Farmdalian assemblage, this is especially true for *Juniper*, *Populus*, *Salix*, and *Acer negundo* type pollen. These pollen taxa may represent more extensive upland tree and shrub populations than implied by the grassland-steppe label.

Far less likely is significant under-representation of the coniferous arboreal taxa spruce and pine. Both of these pollen types (*Picea* and *Pinus*) are prolific producers of pollen. Modern pollen samples taken from a large Canadian *Typha*-marsh surrounded by boreal forest show no obvious under-representation of *Picea* or *Pinus* due to local marshland pollen (Teller and Last, 1981). For a number of reasons, previously presented, the Farmdalian *Picea* and *Pinus* pollen signals probably represent local populations limited to favorable edaphic and topographic situations. It is less likely that these pollen assemblages represent either local coniferous parklands or long-distance input from extra-regional sources.

Using the same rationale, it could also be argued that over-representation of Poaceae and Cyperaceae pollen from the local marsh community may result in an over-estimation of the grassland component and an under-estimation of the significance of the upland *Artemisia* steppe community. This would be one explanation for the relatively high percentages of both Poaceae and *Artemisia* pollen throughout the Farmdalian section. The low, but relatively diverse, arboreal pollen assemblage could be argued to represent the local, within-basin plant community, rather than the upland. This scenario suggests a less diverse sagebrush steppe upland community, devoid of any deciduous trees and shrubs.

Certainly any of these interpretations of regional upland Farmdalian vegetation is possible. The grassland-steppe interpretation is best supported by the Cheyenne Bottoms data. It is parsimonious with both the regional fossil record and with our current understanding of the relationship between vegetation and assemblage composition. Included within this grassland-steppe community are significant patches of deciduous boreal species of trees and shrubs. Many of the upland boreal shrubs likely to have been included in these communities (i.e. *Elaeagnus*, *Rosa*, and *Symphoricarpos*) are insect-pollinated and even less likely to be represented in the Cheyenne Bottoms pollen record (cf. Jaumann, 1991). Conifers (spruce, and, more rarely, pine) were probably confined to fire-protected escarpments and mesic river valleys.

The hypothesized inclusion of the boreal tree and shrub taxa in this overall community is not adequately or accurately communicated by the label "grassland-steppe". A more appropriate label is that of "boreal grassland" (here using "grassland" in its less strict connotation). This term has been suggested as a descriptor for some of the "no-analog" late Pleistocene communities of the Midwest (Rhodes, 1984). "Boreal grassland" has also been applied to contemporary vegetation. Moss (1955) used the term to describe open aspen-shrub parklands in Canada. It application to the late-Pleistocene central Great Plains community seems especially appropriate given the pollen evidence discussed above.

Although patches of boreal grassland, in the sense that the term is applied here, do occur in Canada today (Moss, 1955; Maini, 1960), they are spatially restricted, and are typically considered successional. The suggested area of Pleistocene boreal grasslands is far greater. The Farmdalian evidence from Cheyenne Bottoms, as well as the regional Woodfordian pollen evidence (Fredlund and Jaumann, 1987; Jaumann, 1991), suggests that these boreal grasslands did not succeed to spruce forest.

The underlying cause for the differences between this hypothesized Wisconsinan vegetation, both Farmdalian and Woodfordian, and the modern analogs remains unclear. Both climate and the disturbance regime are possibly involved. Many researchers have postulated distinctly different, more equitable climates for the Pleistocene (e.g. Martin and Neuner, 1978; Graham and Lundelius, 1984; Martin and Martin, 1987). It is hypothesized that a more equitable climate, one with lowered climatic extremes, would have resulted in an admixture of vegetative communities which are today considered distinctive. This in itself may explain some of the floristic distinctiveness of the hypothesized Wisconsinan vegetation. It does not, however, explain the apparent lack of succession within the community toward some more wooded vegetative structure.

It is hypothesized that the differences in vegetative structure hypothesized for the Wisconsinan are better explained by differences in the disturbance regimes. It is hypothesized that the natural fire-disturbance regime would have been lowered by the equability in climate. The Farmdalian fire-disturbance regime would also have been affected by the absence or near-absence of anthropogenic ignition. Together these factors would yield a lower fire cycle than was characteristic of the Holocene Great Plains. This lowering of the fire regime would result in greater differences among the ages of disturbance patches and therefore higher diversity within the vegetative community as a whole. But, as with the equability hypothesis, this model does not explain the apparent lack of succession among the patches toward a more wooded condition. A secondary disturbance factor, the interaction of the Pleistocene herbivore community with the vegetation, has also been suggested (Axelrod, 1985; Owen-Smith, 1987). Although a combination of climatic and disturbance variables is probably responsible for this non-analog vegetative structure, little direct evidence exists concerning the nature of the Pleistocene disturbance regime or climate. Fossil evidence for Pleistocene vegetation, along with knowledge of how disturbance regimes operate, can provide the basis for deductively constructing hypotheses. It may prove difficult, if not impossible, to empirically test processual hypotheses for Great Plains Wisconsinan vegetation.

Water Levels and Climatic Inference

One indication of climate change at Cheyenne Bottoms is the evidence for fluctuation in the water level of the marshland (cf. Street-Perrott and Harrison, 1985). The broad, flat, enclosed Cheyenne Bottoms basin is in essence a large evaporation pan. Because of this topography and resulting shallow water depths, it is sensitive to change in the annual water budget. These fluctuations in water levels result in exposure of mud flats and the invasion by the annual Cheno-Am plant community. Although the exact species vary, this same type of Cheno-Am invasion occurs in the boreal and sub-boreal regions of Canada today (Dodd, 1960). It is assumed, therefore, that this type of plant community has been present throughout the late-Quaternary history of the basin. Increases in Cheno-Am type pollen in the Cheyenne Bottoms record are hypothesized to represent fluctuations in the water balance and expansion of the mud-flat plant community.

The major difference between the Farmdalian (Zone I) and the Holocene (Zone II) pollen assemblages is the level of Cheno-Am type pollen. This suggests that water levels in the basin have been far less stable, and more susceptible to episodes of drying, during the Holocene than during the Farmdalian. From around 30,000 to 25,000 yr. B.P., Cheno-Am pollen percentages remain low, suggesting little fluctuation in climatic factors relating to the water budget (Figure 3.3). This record is interpreted as representing a more stable, probably slightly more mesic climate than occurs in the region today. This hypothesized stability in the Farmdalian moisture regime may be one of the factors which underlies the qualitative differences between Holocene and Pleistocene plant communities.

Between 25,000 and 24,000 yr. B.P., the Cheno-Am pollen signal suggests that Cheyenne Bottoms began a significant, prolonged cycle of drying. The decline of Cheno-Am pollen percentages towards the unconformity does not appear to represent a return to moist conditions. Instead, this decline suggests shrinkage of the mud-flat plant community as water levels in Cheyenne Bottoms continued to fall. In other words, the transition from the Farmdalian to the Woodfordian stage was one of increasing climatic aridity. The water balance for Cheyenne Bottoms at the onset of the Woodfordian is interpreted as being significantly lower than occurs today, meaning a more arid climate. This hypothesis is supported by interpretations of the regional eolian (loess) record, and tends to validate climatic projections of global atmospheric modeling efforts (Kutzbach and

Wright, 1985; Kutzbach, 1987). This hypothesized early Woodfordian aridity does not agree with vegetation and climate reconstructions based on botanical macro-fossils and snails (Wells and Stewart, 1987a; 1987b). It is, however, consistent with other recent interpretations of the regional Woodfordian pollen evidence (Fredlund and Jaumann, 1987; Jaumann, 1990).

Because the sedimentary record for the Woodfordian itself is missing, it is not possible to offer direct evidence for changes in the moisture regime throughout the period (24,000 to 11,000 yr. B.P.). It has been hypothesized that moisture conditions would ameliorate throughout this final stage of the Pleistocene (see Chapter 1). The absence of all of the Woodfordian from the Cheyenne Bottoms record remains a puzzle. If more mesic conditions had returned, then the basin should have again begun to act as a sediment trap. It is possible that Woodfordian sediments were deposited but subsequently were eroded. Based on the radiocarbon dates and overall stratigraphy, this period of erosion would have had to occur during the late Woodfordian. This inconsistency is currently unresolvable. Because the cause of the unconformity remains unclear, the climatic implications of this break in sedimentation also remain unknown.

Conclusions

The central Great Plains includes a vast area stretching from the Rocky Mountains to the eastern forest fringes in Iowa and Missouri. This study has analyzed pollen from a single core, assumed to be representative of the Cheyenne Bottoms wetlands and of the surrounding region. No single pollen study could reflect the climatic and vegetative variability of this entire region throughout the last 30,000 or 40,000 years. The significance of the Cheyenne Bottoms pollen record is a function of its geographical centrality within the central Great Plains of North America. The data from this locality are far more likely to be representative of the region than the often-cited Muscotah Marsh in northeastern Kansas (Gruger, 1973) or the Ozark Springs localities in Missouri (King, 1973). By default, these regionally peripheral localities have become the basis for projection of hypothesized late-Pleistocene vegetation across the central Great Plains (e.g. Delcourt and Delcourt, 1981). In spite of the frustration created by the Woodfordian unconformity, the Cheyenne Bottoms pollen record will force a reevaluation of hypothesized late-Pleistocene vegetation of the region. The Farmdalian pollen record from Cheyenne Bottoms suggests a far more open, less-wooded regional vegetation than implied by many regional reviews (e.g. Axelrod, 1985). Cheyenne Bottoms provides significant new evidence germane to an array of research questions ranging from Pleistocene faunal extinctions to validation of global atmospheric circulation models.

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APPENDIX I

LIST OF BOTANICAL NAMES USED IN TEXT

A: Alphabetized list

Taxonomic Name	Common Name
Abies	fir
Acer	maple
A. negundo	box elder
Achillea millefolium	yarrow
Alnus	alder
A. rugosa	speckled alder
A. crispa	green alder
Amaranthaceae	pigweed family
Amaranthus	pigweed
Ambrosia	ragweed
Amorpha	lead plant
Andropogon scoparius	little bluestem
Andropogon gerardii	big bluestem
Apiaceae	parsley family
Apocynum cannabinum	hemp dogbane
Argemone polyanthemos	prickly poppy
Artemisia	sage
A. filifolia	sandhill sage
A. ludoviciana	white sage
A. tridentata	big sagebrush
Asteraceae	aster or sunflower family
Aster subulatus	saltmarsh aster
Betula	birch
B. papyrifera	paper birch
B. glandulosa	bog birch
B. populifolia	gray birch
Bidens	beggar-ticks
Bouteloua curtipendula	sideoats grama
Bouteloua gracilis	blue grama
Bromus tectorm	cheatgrass
Brassica	mustard
Calamovilfa longifolia	sandreed
Calystegia	bindweed
Carpinus	hophornbean
Carya	hickory
Caryophyllaceae	pink family
Cassia	senna, partridge pea
Celtis	hackberry
Centaurea	knapweed
Chenopodiaceae	goosefoot family
Chenopodium	lamb's quarter
Cyperaceae	sedge family

Cystopteris	lip fern
Dalea	prairie clover
Diploxylon	yellow-pine sub-genera
Distichlis spicta	saltgrass
Dryopteris	wood fern
Echinochloa spp.	barnyard grass
Elaeaganus	silverberry
Equisetum	horsetail
Ephedra	Mormon tea
Eriogonum	buckweat
Eupatorium	boneset
Fraxinus	ash
F. nigra	black ash
Glycerrhiza lepidota	wild licorice
Haploxylon	white-pine sub-genera
Helianthus	sunflower
Hordeum spp.	barley grass
Iva annua	sumpweed, marsh elder
Juglans	walnut
Juncus interior	inland rush
Juniperus	juniper
J. communis	eastern juniper
J. horizontalis	common juniper
J. virginiana	eastern redcedar
Kochia scoparia	kachia
Lactucia	lettuce sub-family
Larix	tamarack
Leptochlou fascicularis	sprangletop
Liliaceae	lily family
Limonium limbatum	marsh rosemary
Lycopodium	club moss
Mollugo verticillata	carpetweed
Morus	mulberry
Nemopanthus	moutain holly
Mentha	mint
Myrophyllum	water milfoil
Najas quadalupensis	naiad
Nymphaea	waterlily
Onagraceae	primrose family
Opuntia	prickly pear
Osmunds	royal fern
Ostrya	hornbean
Panicum virgatum	switchgrass

Picea	spruce
P. glacua	white spruce
P. mariana	black spruce
P. pungens	blue spruce
Pinus	pine
P. flexilis	limber pine
P. strobus	eastern white pine
P. resinosa	red pine
P. banksiana	jack pine
Plantago	plantain
Poaceae	grass family
Polygonum	knotweed, smartweed
P. cristum	knotweed
P. lapathifolium	smartweed
Populus	poplars
P. tremuloides	aspen
P. balsamifera	balsam poplar
P. deltoides	cottonwood
Potamogeton	pondweed
Pteridum	bracken fern
Quercus	oak
Ranunculus	butter cup
Rhamnus	buckthorn
Rosaceae	rose family
Rumex	dock,sorrel
Sagittaria	arrow-head
Salix	willow
S. dicolor	pussy-willow
S. candida	sage-leaved willow
S. interior	sandbar willow
S. pedicellaris	bog willow
S. herbacea	herb-like willow
Salsola iberica	Russian thistle
Sambucus	elderberry
Sarcobatus	greasewood
Scriptus	bullrush
Shepherdia	buffaloberry
Sparganium	bur-reed
Solanaceae	nightshade family
Stachys	hedge-nettle
Suaeda depressa	sea-blite
Thalictrum	meadow rue
Thuja occidentalis	northern white-cedar
Typha	cat-tail
T. angustifolia	narrow-leaved cat-tail
T. latifolia	broad-leaved cat tail
Ulmus	elm
Ultrica	nettle
Vitus	grape
Xanthium	cocklebur

B: Life-form and taxonomic list.

1. Trees, Large Shrub, and Vines (Arboreal Pollen Types)

Taxonomic Name	Common Name
Abies	fir
Picea	spruce
P. glacua	white spruce
P. mariana	black spruce
P. pungens	blue spruce
Pinus	pine
Haploxylon	white-pine sub-genera
P. flexilis	limber pine
P. strobus	eastern white pine
Diploxylon	yellow-pine sub-genera
P. resinosa	red pine
P. banksiana	jack pine
Juniperus	juniper
J. communis	eastern juniper
J. horizontalis	common juniper
J. virginiana	eastern redcedar
Larix	tamarack
Thuja occidentalis	northern white-cedar
Populus	poplars
P. tremuloides	aspen
P. balsamifera	balsam poplar
P. deltoides	cottonwood
Betula	birch
B. papyrifera	paper birch
B. glandulosa	bog birch
B. populifolia	gray birch
Quercus	oak
Alnus	alder
A. rugosa	speckled alder
A. crispa	green alder
Salix	willow
S. dicolor	pussy-willow
S. candida	sage-leaved willow
S. interior	sandbar willow
S. pedicellaris	bog willow
S. herbacea	herb-like willow
Acer	maple
A. negundo	box elder
Fraxinus	ash
F. nigra	black ash
Carya	hickory
Ulmus	elm
Juglans	walnut
Carpinus	hophornbean
Ostrya	hornbean
Celtis	hackberry
Sambucus	elderberry

Morus	mulberry
Rosaceae	rose family
Rhamnus	buckthorn
Elaeaganus	silverberry
Shepherdia	buffaloberry
Nemopanthus	moutain holly
Vitus	grape

2. Grasses, forbs, herbs (Non-Arboreal Pollen Types)

Chenopodiaceae	goosefoot family
Chenopodium	lamb's quarter
Kochia scoparia	kachia
Salsola iberica	Russian thistle
Sarcobatus	greasewood
Suaeda depressa	sea-blite
Amaranthaceae	pigweed family
Amaranthus	pigweed
Poaceae	grass family
Andropogon scoparius	little bluestem
Andropogon gerardii	big bluestem
Bouteloua curtipendula	sideoats grama
Bouteloua gracilis	blue grama
Bromus tectorm	cheatgrass
Calamovilfa longifolia	sandreed
Distichlis spicta	saltgrass
Echinochloa spp.	barnyard grass
Hordeum spp.	barley grass
Leptochlou fascicularis	sprangletop
Panicum virgatum	switchgrass
Cyperaceae	sedge family
Asteraceae	aster or sunflower family
Achillea millefolium	yarrow
Ambrosia	ragweed
Artemisia	sage
A. filifolia	sandhill sage
A. ludoviciana	white sage
A. tridentata	big sagebrush
Aster subulatus	saltmarsh aster
Iva annua	sumpweed, marsh elder
Xanthium	cocklebur
Centaurea	knapweed
Eupatorium	boneset
Bidens	beggar-ticks
Helianthus	sunflower
Lactucia	lettuce sub-family
Polygonum	knotweed, smartweed
P. cristum	knotweed
P. lapathifolium	smartweed
Eriogonum	buckweat
Rumex	dock,sorrel
Caryophyllaceae	pink family
Argemone polyanthemos	prickly poppy
Mollugo verticillata	carpetweed
Apiaceae	parsley family
Cassia	senna, partridge pea
Amorpha	lead plant
Glycerrhiza lepidota	wild licorice

Dalea	prairie clover
Onagraceae	primrose family
Apocynum cannabinum	hemp dogbane
Thalictrum	meadow rue
Brassica	mustard
Plantago	plantain
Solanaceae	nightshade family
Ephedra	Mormon tea
Ultrica	nettle
Calystegia	bindweed
Opuntia	prickly pear

3. Semi-Aquatics and Aquatics

Typha	cat-tail
T. angustifolia	narrow-leaved cat-tail
T. latifolia	broad-leaved cat tail
Sparganium	bur-reed
Juncus interior	inland rush
Scriptus	bullrush
Stachys	hedge-nettle
Mentha	mint
Liliaceae	lily family
Ranunculus	butter cup
Limonium limbatum	marsh rosemary
Sagittaria	arrow-head
Myrophyllum	water milfoil
Nymphaea	waterlily
Najas quadalupensis	naiad
Potamogeton	pondweed

4. Ferns and their allies.

Lycopodium	club moss
Cystopteris	lip fern
Pteridum	bracken fern
Equisetum	horsetail
Osmunds	royal fern
Dryopteris	wood fern

APPENDIX II

Cheyenne Bottoms Sediment Analysis Data

Key to letter codes used in sediment data table:

Depth	Meters below surface of dike.
A	Soluble salts in milli-mhos
B	Orgamic Matter in percent dry wt.
C	Carbonate in percent dry wt.
D	Sands in percent dry wt. after LOI
E	Coarse Silts in percent dry wt. after LOI
F	Medium Silts in percent dry wt. after LOI
G	Fine Silts in percent dry wt. after LOI
H	Clays in percent dry wt. after LOI

Sediment Analysis Data:

Depth	A	B	C	D	E	F	G	H
2.18	3.50	8.97	1.15	9.14	6.69	13.38	20.07	50.72
2.38	3.33	7.15	1.65	4.62	4.40	7.69	17.58	65.71
2.58	5.25	6.65	1.87	4.60	4.38	8.76	17.53	64.72
2.76	2.40	5.83	1.96	6.74	2.17	8.70	17.39	65.00
2.96	1.98	5.18	2.80	4.57	4.36	8.71	19.60	62.75
3.16	2.02	5.27	4.77	11.36	3.34	7.80	15.60	61.90
3.36	1.83	4.29	2.23	6.65	4.29	15.01	17.15	56.90
3.56	2.75	4.11	1.43	6.58	4.24	13.79	16.97	58.42
3.76	4.18	4.95	1.78	6.66	4.30	6.45	3.22	79.37
3.96	4.42	5.11	2.34	6.71	4.33	4.33	10.83	73.80
4.16	2.97	5.46	1.33	7.05	4.30	6.45	15.05	67.16
4.36	3.03	4.59	2.35	4.91	2.15	6.46	19.38	67.10
4.56	3.27	4.74	2.06	4.90	2.15	6.45	17.20	69.30
4.76	3.60	4.08	1.30	4.83	2.12	8.47	21.17	63.41
4.96	3.65	4.27	2.21	2.74	6.43	8.57	20.35	61.91
5.18	3.88	4.59	1.87	7.03	4.28	8.57	19.28	60.85
5.34	3.41	4.48	1.49	4.86	4.26	10.65	19.17	61.05
5.50	3.52	3.64	10.93	7.69	7.04	9.38	37.53	38.36
5.58	3.46	3.43	17.40	8.30	7.59	15.19	43.03	25.89
5.78	4.32	3.32	17.38	8.29	7.58	15.16	45.49	23.48
6.02	3.48	3.37	7.88	5.27	6.93	11.55	26.56	49.70
6.07	3.68	3.98	7.52	7.60	8.11	11.58	24.32	48.39
6.32	4.41	4.09	8.19	5.33	7.01	11.69	24.54	51.42
6.42	4.04	3.64	8.10	7.62	11.62	11.62	25.55	43.60
6.55	3.91	3.71	7.21	7.55	6.90	13.81	24.16	47.59
6.62	3.33	4.20	6.27	12.09	6.87	6.87	29.76	44.42
6.79	3.42	4.05	5.30	16.45	4.52	5.65	25.99	47.38
6.87	3.32	3.81	6.31	17.74	5.70	6.84	25.08	44.65
7.02	3.68	4.29	6.75	12.16	2.30	8.06	27.65	49.82
7.26	3.71	3.26	3.69	35.82	8.80	5.50	15.40	34.47
7.41	4.06	4.41	4.94	30.89	6.62	2.21	18.75	41.54
7.46	4.02	4.07	5.59	27.67	4.43	3.32	19.92	44.66
7.61	4.53	4.25	5.74	24.44	6.67	4.44	22.22	42.23
7.73	5.00	3.91	6.48	26.78	6.70	4.46	16.74	45.31
8.03	3.78	4.86	6.26	27.00	5.63	4.50	20.25	42.62
8.23	3.51	4.22	4.76	29.66	8.79	6.59	18.68	36.28
8.52	4.19	3.95	5.51	29.82	6.63	5.52	16.57	41.46
8.75	3.78	4.42	6.64	19.11	3.37	6.75	23.61	47.15
8.97	4.80	5.71	5.03	8.96	2.24	8.96	26.89	52.94
9.19	3.36	5.63	6.16	9.07	4.53	9.07	22.67	54.65
9.39	4.12	5.44	7.59	8.10	4.88	7.32	24.40	55.30
9.62	4.18	4.55	6.19	20.93	5.93	8.31	17.80	47.02
9.82	4.50	4.43	6.76	13.89	4.77	7.16	22.67	51.51
10.02	4.52	5.06	7.53	14.13	3.64	6.07	20.63	55.54
10.17	4.71	5.57	5.64	9.12	4.77	7.16	25.07	53.88
10.32	4.00	5.50	7.13	4.42	2.43	7.28	23.07	62.80
10.41	3.98	12.24	6.22	8.67	2.61	6.53	27.44	54.75
10.56	3.65	4.69	5.36	6.64	2.35	14.13	27.07	49.81
10.71	3.61	4.55	6.95	6.75	9.58	15.57	25.15	42.95
10.86	3.50	3.44	5.57	11.21	11.63	18.61	22.10	36.46
11.01	1.91	3.80	7.90	6.80	6.80	11.33	26.05	49.04
11.32	3.63	3.07	7.62	5.60	6.72	12.32	32.47	42.90
11.54	2.95	2.96	7.25	8.91	11.14	17.82	25.61	36.52
11.74	3.38	3.05	7.34	8.93	4.46	15.62	23.43	47.55
11.94	3.80	3.47	8.02	10.17	6.78	14.69	28.24	40.12
12.04	2.83	4.96	7.04	9.09	6.82	15.91	21.59	46.59
12.16	3.30	2.50	5.72	15.25	2.18	22.88	29.42	30.26

Sediment Analysis Data (continued)

Depth	A	B	C	D	E	F	G	H
12.25	4.11	3.49	7.32	13.45	13.45	14.58	23.55	34.97
12.45	3.91	3.46	6.80	13.37	14.49	17.83	21.17	33.14
12.64	3.72	5.08	9.18	4.67	7.00	4.67	25.66	58.01
12.84	5.80	4.78	7.08	12.24	4.31	4.31	22.63	56.50
12.94	4.27	3.93	6.46	7.81	4.24	12.73	25.47	49.75
13.04	2.45	4.49	7.04	8.98	8.59	19.33	20.41	42.69
13.24	5.30	3.55	7.32	5.72	6.40	12.80	28.79	46.30
13.44	3.33	4.79	7.95	8.01	8.71	10.88	23.94	48.46
13.54	5.30	5.90	7.17	5.85	6.55	10.92	17.47	59.20
13.64	4.28	4.74	7.87	8.00	6.52	10.87	23.90	50.71
13.76	4.22	4.99	9.58	7.06	5.55	11.10	24.42	51.86
13.84	2.80	3.29	6.74	7.78	6.34	6.34	23.25	56.28
14.04	3.50	2.65	5.69	13.87	10.38	10.38	22.84	42.51
14.20	1.55	4.51	7.12	3.71	6.80	11.33	24.92	53.25
14.40	3.40	4.65	6.96	5.98	6.79	11.32	24.91	50.99
14.60	2.63	3.96	6.25	10.34	11.15	17.83	22.29	38.38
14.80	2.95	4.10	6.54	10.39	11.20	11.20	24.64	42.56
14.95	2.99	4.03	6.93	8.18	6.74	12.37	22.48	50.22
15.00	2.81	3.68	6.68	5.90	11.17	11.17	26.80	44.97
15.20	3.24	3.60	6.93	14.86	8.95	6.71	22.37	47.11
15.40	3.19	3.46	7.72	8.20	9.02	13.52	19.16	50.10
15.60	2.95	3.41	7.62	1.44	6.75	9.00	29.25	53.56
15.80	2.97	3.47	9.05	3.75	4.58	9.15	25.17	57.34
16.00	3.90	4.08	8.15	5.26	4.46	11.14	22.28	56.87
16.18	4.60	3.61	8.48	7.47	4.45	11.12	22.24	54.71
16.20	2.88	4.04	7.77	5.23	4.44	11.09	24.39	54.85
16.40	4.89	3.65	9.21	9.78	8.97	8.97	24.68	47.59
16.61	5.70	4.17	8.40	7.51	4.47	11.18	24.60	52.23
16.81	6.00	4.37	7.46	7.45	6.65	13.31	23.29	49.30
17.01	5.80	4.00	8.42	7.50	6.70	11.16	27.91	46.73
17.21	5.80	4.35	9.49	7.62	4.54	11.34	31.76	44.74
17.41	6.20	4.50	8.84	7.58	6.77	9.02	25.94	50.69
17.61	4.99	4.07	7.63	11.87	11.07	15.50	23.26	38.30
17.79	3.93	4.74	6.50	9.61	6.61	11.02	26.44	46.32
17.97	2.70	3.26	6.92	16.03	8.71	15.25	25.05	34.96
18.17	2.93	4.08	7.66	16.31	4.43	8.86	24.38	46.02
18.36	2.89	3.68	7.36	20.58	4.40	8.79	23.09	43.14
18.56	2.78	3.68	7.20	18.35	6.58	7.68	19.75	47.63
18.76	2.77	3.64	6.44	22.54	6.53	13.05	23.93	33.94
18.86	3.42	4.35	5.59	20.34	4.35	8.69	24.98	41.64
18.92	2.23	4.75	6.39	7.40	4.40	6.60	25.31	56.28
19.07	2.38	3.35	6.86	13.86	6.54	13.07	29.42	37.11
19.19	3.15	3.58	7.03	11.73	4.38	10.94	26.26	46.69

APPENDIX III

CHEYENNE BOTTOMS POLLEN COUNTS

Arboreal Pollen types

Letter codes for Arboreal Pollen (AP) types:

Depth	Meters Below Surface (m.b.s)
A	Picea
B	Pinus other (Lg.)
C	Pinus banksiana type
D	Juniperus type
E	Populus
F	Betula
G	Quercus
H	Abies
I	Larix
J	Alnus
K	Salix
L	Acer negundo type
M	Fraxinus cf. nigra
N	Carya
O	Corylus
P	Ulmus
Q	Juglans
R	Carpinus type
S	Celtis
T	Sambucus type
U	Cornus cf. stolonifera
V	Morus type
W	Rosaceae undiff.
X	Rhamnus
Y	Elaeaganus
Z	Shepherdia
AA	cf. nemopanthus
BB	Vitus

AP Counts:

Depth	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2.18	0	4	4	0	2	0	2	0	0	0	0	0	0	0	0	1
2.38	0	5	4	0	2	0	1	0	0	0	0	0	0	0	0	0
2.58	0	2	3	0	1	0	2	0	0	0	0	0	0	0	0	1
2.76	0	2	3	1	1	0	1	0	0	0	0	0	0	0	0	1
2.96	0	2	2	0	0	0	1	0	0	0	0	0	0	0	0	1
3.16	0	3	2	1	0	0	3	0	0	0	0	0	0	0	0	0
3.36	0	6	7	0	1	0	3	0	0	0	0	0	0	0	0	1
3.56	0	4	5	1	1	0	3	0	0	0	0	0	0	0	0	0
3.76	1	5	4	2	1	0	3	0	0	0	0	0	0	0	0	1
3.96	0	3	3	1	2	0	4	0	0	0	1	1	0	0	0	2
4.16	0	2	3	1	1	0	3	0	0	0	1	1	0	0	0	1
4.36	0	7	4	0	1	0	3	0	0	0	0	0	0	0	0	0
4.56	0	7	7	1	1	0	2	0	0	0	0	1	0	0	0	0
4.76	0	3	2	0	2	0	2	0	0	0	0	2	0	0	0	2
4.96	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5.18	0	4	2	0	0	0	1	0	0	0	0	0	0	0	0	0
5.34	0	3	1	1	1	0	0	0	0	1	0	0	0	0	0	0
5.50	0	6	4	2	0	0	2	0	0	0	0	0	0	0	0	1
5.58	0	4	2	4	2	1	2	0	0	0	0	0	0	0	0	0
5.78	1	11	25	3	3	4	3	0	0	4	2	0	0	1	1	0
6.02	5	8	48	3	3	7	3	0	0	1	1	0	0	0	1	0
6.07	8	19	78	3	7	8	2	0	0	2	3	1	0	0	1	0
6.32	12	15	37	4	5	10	2	0	0	0	1	0	0	1	0	0
6.42	9	1	22	3	4	6	1	0	0	0	2	1	0	0	0	0
6.55	7	9	43	3	5	7	5	0	0	1	2	0	0	0	2	0
6.62	8	6	38	5	8	12	8	0	0	1	2	3	1	0	2	0
6.79	6	15	53	4	6	8	1	0	0	2	1	1	0	0	0	0
6.87	12	14	52	2	9	11	4	0	0	4	4	1	1	0	1	2
7.02	1	5	10	2	4	3	2	0	0	2	1	0	0	0	0	0
7.26	1	3	3	2	1	2	1	0	0	2	2	0	0	0	0	0
7.41	4	5	8	1	5	6	5	0	0	0	0	0	0	0	0	0
7.46	4	4	10	2	4	4	7	0	0	0	2	2	0	0	0	0
7.61	4	13	23	3	5	6	4	0	0	5	1	1	0	0	0	0
7.73	8	9	26	3	3	7	7	0	0	1	1	3	0	0	0	1
8.03	3	6	12	2	1	2	6	0	0	0	2	2	0	0	0	0
8.23	4	10	15	2	2	2	4	0	0	1	1	1	0	0	0	0
8.52	3	6	16	2	5	3	4	0	0	4	2	2	0	0	0	0
8.75	4	5	8	4	5	2	3	0	0	0	2	0	0	0	0	0
8.97	5	12	22	5	9	8	11	0	0	0	2	4	2	0	0	0
9.19	6	11	23	4	9	2	14	0	0	0	1	2	0	0	0	1
9.39	3	8	23	4	7	3	4	0	0	0	3	0	0	0	0	0
9.62	5	10	16	3	8	7	7	0	0	0	0	1	1	0	0	0
9.82	5	11	19	3	10	8	5	0	0	1	0	1	0	0	1	0
10.02	3	9	13	4	5	3	5	0	0	0	2	2	0	0	0	0
10.17	4	13	15	4	12	8	8	0	0	2	1	2	1	0	0	0
10.32	2	18	17	8	8	5	6	0	0	1	3	1	1	0	0	0
10.41	2	19	14	5	13	1	14	0	0	1	3	0	2	0	0	0
10.56	3	13	8	4	8	7	12	0	0	1	2	2	0	0	1	0
10.71	3	13	13	6	9	4	5	0	0	1	1	2	0	0	1	0
10.86	3	19	15	2	9	4	10	0	0	2	4	2	2	0	0	0
11.01	6	21	20	5	12	7	12	0	0	0	2	3	1	0	1	1
11.32	4	19	18	2	9	5	16	0	0	1	4	5	1	0	0	0
11.54	7	32	18	4	14	7	14	0	0	1	5	3	1	0	1	0
11.74	6	23	18	4	12	9	11	0	0	1	1	5	2	0	0	0
11.94	2	15	8	6	15	6	15	0	0	4	2	2	0	0	0	1
12.04	3	14	11	5	11	5	13	0	0	2	3	3	1	0	0	0
12.16	19	34	7	3	8	7	6	0	0	0	1	1	0	0	0	0

AP Counts (continued)

Depth	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
12.25	7	20	7	3	3	3	8	0	0	0	3	2	0	0	0	0
12.45	9	41	23	5	9	2	12	0	0	1	1	5	0	0	0	0
12.64	7	15	15	4	8	6	11	0	0	1	2	4	0	0	0	0
12.84	12	26	20	3	5	2	10	0	0	0	1	2	0	0	0	0
12.94	14	21	20	5	10	4	18	0	0	2	3	2	0	0	0	0
13.04	11	31	32	3	8	4	17	0	0	0	2	1	0	0	0	0
13.24	5	20	29	3	7	4	13	0	0	0	2	2	0	0	0	0
13.44	10	17	22	2	6	4	15	0	0	0	2	2	0	2	0	0
13.54	11	30	34	3	9	8	15	0	0	1	2	4	0	0	0	0
13.64	15	33	44	5	15	5	22	0	0	0	4	5	0	0	0	0
13.76	11	45	41	2	4	4	19	0	0	0	2	2	0	0	0	1
13.84	21	42	35	5	6	3	9	0	0	1	2	0	0	0	0	0
14.04	5	18	13	3	5	3	8	0	0	0	1	1	0	0	0	0
14.20	4	12	20	4	6	4	10	0	0	0	1	5	0	0	0	0
14.40	8	24	21	4	10	4	15	0	0	2	4	3	0	0	0	0
14.60	6	17	29	2	3	1	11	0	0	0	2	2	0	1	0	0
14.80	4	23	19	4	12	2	10	0	0	2	4	2	0	1	0	1
14.95	5	19	30	3	7	4	20	0	0	0	2	2	0	0	0	0
15.00	2	10	36	4	4	1	11	0	0	0	0	4	1	0	0	0
15.20	3	18	18	4	7	2	15	0	0	0	2	2	0	0	0	0
15.40	2	22	24	3	8	3	16	0	1	0	2	3	0	0	0	1
15.60	2	10	13	3	6	5	7	0	0	0	2	1	1	0	1	0
15.80	3	16	24	3	9	5	12	0	0	1	6	4	2	0	0	0
16.00	3	27	17	5	9	4	16	0	0	0	2	3	2	0	0	0
16.18	4	25	33	4	10	2	17	0	0	8	2	3	0	1	1	0
16.20	4	16	19	3	11	5	10	1	0	0	6	4	1	0	0	0
16.40	4	20	42	3	10	7	14	1	1	2	6	5	0	0	0	0
16.61	5	18	18	3	7	2	9	1	1	0	1	4	2	0	0	1
16.81	3	24	25	8	7	4	28	0	0	0	0	3	0	0	0	0
17.01	1	11	25	5	11	4	15	0	0	0	2	5	2	0	0	0
17.21	2	34	48	2	9	3	18	0	0	3	1	8	0	0	0	0
17.41	8	26	53	4	6	2	19	0	0	2	1	2	0	0	1	0
17.61	9	10	24	2	4	4	9	0	0	2	1	0	0	0	0	0
17.79	1	14	22	3	7	1	10	0	0	2	2	2	0	0	0	0
17.97	6	20	37	4	5	0	8	0	0	0	0	0	0	0	0	0
18.17	3	8	26	2	4	4	3	0	0	3	0	1	0	0	0	0
18.36	3	7	24	4	5	4	1	0	0	0	1	1	1	0	0	0
18.56	1	10	28	6	3	1	1	0	0	1	2	0	0	0	0	0
18.76	2	22	42	1	5	4	5	0	0	0	1	0	0	0	0	0
18.86	1	4	13	2	2	0	0	0	0	0	0	0	0	0	0	0
18.92	1	18	23	3	2	0	2	0	0	0	1	0	0	0	0	0
19.07	1	7	13	2	0	0	0	0	0	0	1	0	0	0	0	0
19.19	0	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0

AP Counts (continued):

Depth	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
2.18	1	0	0	0	0	0	0	0	0	0	0	0
2.38	0	0	0	0	0	0	0	0	0	0	0	0
2.58	0	0	0	0	0	0	0	0	0	0	0	0
2.76	0	0	0	0	0	0	0	0	0	0	0	0
2.96	0	0	0	0	0	0	0	0	0	0	0	0
3.16	0	0	1	0	1	0	1	0	0	0	0	0
3.36	0	0	0	0	0	0	0	0	0	0	0	0
3.56	0	0	0	0	0	0	0	0	0	0	0	1
3.76	0	0	0	0	0	0	0	0	0	0	0	0
3.96	0	0	0	0	0	0	0	0	0	0	0	0
4.16	0	0	0	0	0	0	0	0	0	0	0	0
4.36	0	0	0	0	0	0	0	0	0	0	0	0
4.56	0	0	0	0	0	0	0	0	0	0	0	0
4.76	0	0	0	0	0	0	0	0	0	0	0	0
4.96	0	0	0	0	0	0	0	0	0	0	0	0
5.18	0	0	0	0	0	0	0	0	0	0	0	0
5.34	0	0	0	0	0	0	0	0	0	0	0	0
5.50	0	0	0	0	0	0	0	0	0	0	0	0
5.58	0	0	0	0	0	0	0	0	0	0	0	0
5.78	0	1	0	0	0	0	0	0	0	0	0	0
6.02	0	0	0	0	0	0	0	0	0	0	0	0
6.07	0	0	0	0	0	0	0	0	0	0	0	0
6.32	0	0	0	0	0	0	0	0	0	0	0	0
6.42	0	0	0	0	0	0	0	0	0	0	0	0
6.55	1	0	0	0	0	0	0	0	0	1	0	0
6.62	0	1	1	0	1	0	1	0	0	0	0	0
6.79	0	1	0	0	0	0	0	0	1	0	0	0
6.87	0	0	0	0	0	0	0	0	0	0	0	0
7.02	0	1	0	0	0	0	0	0	0	0	0	0
7.26	0	0	0	0	0	0	0	0	0	0	0	0
7.41	0	0	0	0	0	0	0	0	0	0	0	0
7.46	0	0	0	0	0	0	0	0	0	0	0	0
7.61	0	0	0	0	0	0	0	0	0	0	0	0
7.73	0	1	0	0	0	0	0	0	1	0	0	0
8.03	0	0	0	1	0	1	0	1	0	0	0	0
8.23	0	0	0	1	0	1	0	1	0	0	0	0
8.52	0	1	0	0	0	0	0	0	0	0	0	0
8.75	0	0	0	0	0	0	0	0	0	0	0	0
8.97	0	0	0	0	0	0	0	0	0	0	0	0
9.19	0	0	0	0	0	0	0	0	0	0	0	0
9.39	0	0	0	0	0	0	0	0	0	0	0	0
9.62	0	0	0	1	0	1	0	1	0	1	0	0
9.82	1	0	0	0	0	0	0	0	0	0	0	0
10.02	0	1	0	0	0	0	0	0	0	0	0	0
10.17	0	1	0	0	0	0	0	0	0	0	0	0
10.32	0	0	1	0	1	0	1	0	0	0	0	0
10.41	0	1	2	0	2	0	2	0	0	0	0	0
10.56	0	0	1	0	1	0	1	0	0	0	0	0
10.71	0	1	0	0	0	0	0	0	0	0	0	0
10.86	0	0	0	0	0	0	0	0	0	0	0	0
11.01	0	0	0	0	0	0	0	0	0	0	0	0
11.32	0	1	0	0	0	0	0	0	0	0	0	0
11.54	0	1	0	0	0	0	0	0	0	0	0	0
11.74	0	1	0	0	0	0	0	0	0	0	0	1
11.94	0	2	0	0	0	0	0	0	0	1	1	0
12.04	0	1	0	0	0	0	0	0	0	0	0	0
12.16	0	0	0	0	0	0	0	0	0	0	0	0

AP Counts (continued):

Depth	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
12.25	0	0	0	0	0	0	0	0	0	0	0	0
12.45	0	0	0	0	0	0	0	0	0	0	0	0
12.64	0	0	0	0	0	0	0	0	0	0	0	0
12.84	0	0	0	0	0	0	0	0	0	0	0	0
12.94	0	0	0	0	0	0	0	0	0	0	0	0
13.04	0	0	0	0	0	0	0	0	0	0	0	0
13.24	0	0	0	0	0	0	0	0	0	0	0	0
13.44	0	0	0	0	0	0	0	0	0	0	0	0
13.54	0	0	0	0	0	0	0	0	0	0	0	0
13.64	0	0	0	0	0	0	0	0	0	1	0	0
13.76	0	0	0	0	0	0	0	0	0	0	0	0
13.84	0	0	0	0	0	0	0	0	0	0	0	0
14.04	0	0	0	0	0	0	0	0	0	0	0	0
14.20	0	0	0	0	0	0	0	0	0	0	0	0
14.40	0	0	0	0	0	0	0	0	0	0	0	0
14.60	0	0	0	0	0	0	0	0	0	0	0	0
14.80	0	0	2	0	2	0	2	0	0	0	0	0
14.95	0	1	0	0	0	0	0	0	0	0	0	0
15.00	0	0	1	0	1	0	1	0	0	0	0	0
15.20	0	0	0	0	0	0	0	0	0	0	0	0
15.40	0	0	0	0	0	0	0	0	0	0	0	0
15.60	0	0	0	0	0	0	0	0	0	0	0	0
15.80	0	1	0	0	0	0	0	0	0	0	0	0
16.00	0	2	0	0	0	0	0	0	0	0	0	0
16.18	0	1	1	1	1	1	1	1	0	0	0	0
16.20	1	2	0	0	0	0	0	0	0	0	0	0
16.40	0	0	0	0	0	0	0	0	0	0	0	0
16.61	0	0	0	0	0	0	0	0	0	0	0	0
16.81	0	2	1	0	1	0	1	0	0	0	0	0
17.01	0	0	0	0	0	0	0	0	0	0	0	0
17.21	0	1	0	0	0	0	0	0	0	0	0	0
17.41	0	0	0	0	0	0	0	0	0	0	0	0
17.61	0	0	0	0	0	0	0	0	1	1	0	0
17.79	0	0	0	0	0	0	0	0	0	0	0	0
17.97	0	0	0	0	0	0	0	0	0	0	0	0
18.17	0	0	0	0	0	0	0	0	0	0	0	0
18.36	0	0	0	0	0	0	0	0	0	0	0	0
18.56	0	0	0	0	0	0	0	0	0	1	0	0
18.76	0	0	1	1	1	1	1	1	0	0	0	0
18.86	0	0	0	1	0	1	0	1	0	0	0	0
18.92	0	0	0	0	0	0	0	0	0	0	0	0
19.07	0	0	0	0	0	0	0	0	0	0	0	0
19.19	0	0	0	0	0	0	0	0	0	0	0	0

Non-Arboreal Pollen types

Letter codes for Non-Arboreal Pollen (NAP) types:

Depth	Meters Below Surface
A	Cheno-Am type
B	Artemisia
C	Poaceae
D	Cyperaceae
E	Ambrosia type
F	Iva type
G	Xanthium type
H	Centaurea type
I	Eupatorium type
J	Other Medium-Spined undiff.
K	Bidens type
L	Helianthus type
M	Tubliflorae undiff.
N	Lactucia type
O	Polygonum cf. cristum
P	Polygonum cf. lapathifolium
Q	Eriogonum
R	Rumex
S	Caryophyllaceae
T	Apiaceae undiff.
U	Cassia type
V	Onagraceae
W	Thalictrum
X	Dalea
Y	Brassica
Z	Plantago
AA	Solanaceae type
BB	Ephedra
CC	Unknown Fenustrate type
DD	Amorpha
EE	Ultrica
FF	Calystegia
GG	Opuntia
HH	Typha latifolia type
II	Typha type other
JJ	Stachys type
KK	Mentha type
LL	Liliaceae
MM	Ranunculus
NN	Thalictrum
OO	Limonium cf limbatum
PP	Sagittaria
QQ	Myriophyllum
RR	Nymphaea
SS	Potamogeton
TT	Lycopodiaceae
UU	Cystopteris type
VV	Pteridium type
WW	Equisetum
XX	Osmunda type
YY	Dryopteris type

NAP Counts:

Depth	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2.18	226	4	18	53	29	4	0	0	2	3	5	0	2	0
2.38	234	7	9	40	35	4	0	0	1	3	9	0	2	0
2.58	228	6	16	53	38	5	0	0	2	2	8	0	1	0
2.76	234	5	21	36	30	5	0	0	3	3	5	0	0	1
2.96	215	7	28	44	34	3	0	0	3	4	6	0	0	0
3.16	154	9	37	32	57	6	0	0	1	4	2	0	2	0
3.36	146	13	35	22	79	7	0	0	2	5	3	0	1	0
3.56	161	11	29	20	70	9	0	1	3	7	3	1	1	0
3.76	127	14	28	24	99	9	0	1	1	4	6	1	4	0
3.96	144	8	32	9	83	7	0	1	3	7	2	1	1	0
4.16	163	12	32	19	81	10	0	0	2	6	2	0	1	0
4.36	151	20	27	17	90	8	3	0	3	5	2	1	0	0
4.56	169	13	36	15	99	23	1	0	2	4	1	0	2	0
4.76	172	14	37	24	76	10	0	2	0	5	4	0	0	0
4.96	210	20	17	8	88	5	0	1	1	4	3	0	2	0
5.18	179	12	33	7	48	11	0	0	0	4	1	0	0	1
5.34	181	15	28	9	59	11	0	0	2	7	0	0	0	0
5.50	231	13	30	12	52	12	0	0	1	4	0	2	4	0
5.58	72	27	31	5	26	1	0	0	0	1	0	0	0	0
5.78	106	57	48	2	50	1	0	1	1	5	0	0	0	0
6.02	14	59	29	9	18	2	0	1	2	5	0	1	2	1
6.07	24	99	65	15	25	1	0	0	2	4	0	0	3	0
6.32	28	67	44	16	23	0	0	0	0	3	0	2	0	0
6.42	24	48	27	8	20	3	0	1	1	2	0	0	2	2
6.55	22	68	58	12	18	2	0	0	2	3	0	1	0	0
6.62	31	64	89	22	31	3	1	3	3	7	0	2	1	1
6.79	59	100	49	31	31	2	0	0	3	6	0	0	0	0
6.87	38	77	63	24	24	3	0	1	1	6	0	2	0	1
7.02	52	78	61	40	41	4	0	1	1	9	0	1	3	0
7.26	54	70	25	8	21	1	0	0	5	6	0	0	0	0
7.41	89	79	42	14	51	1	0	2	1	7	0	0	0	0
7.46	84	89	41	18	41	3	0	2	4	9	0	5	0	0
7.61	84	79	44	15	48	3	0	2	3	10	0	4	0	0
7.73	98	98	49	19	43	1	0	2	1	5	0	1	0	0
8.03	99	105	45	7	19	1	0	2	3	4	0	1	2	0
8.23	105	99	54	15	44	1	0	2	4	6	0	1	0	0
8.52	96	87	48	13	36	0	0	2	0	6	0	1	2	0
8.75	110	125	36	14	26	2	0	4	3	4	0	0	1	1
8.97	76	77	54	30	31	2	0	2	3	7	1	1	2	0
9.19	81	87	65	20	42	3	0	7	7	15	3	3	1	1
9.39	117	86	50	21	46	4	0	6	5	7	0	1	1	1
9.62	96	123	81	24	35	4	0	2	3	9	1	2	1	0
9.82	98	97	91	29	41	2	2	5	1	6	0	2	1	0
10.02	83	123	55	15	44	2	0	1	5	9	0	1	0	1
10.17	29	102	93	38	45	3	3	4	3	9	0	3	1	0
10.32	30	88	54	26	27	3	0	0	4	7	0	1	1	0
10.41	33	79	62	35	34	5	0	2	4	7	1	2	3	1
10.56	21	108	68	23	29	2	2	3	3	9	0	3	1	0
10.71	17	131	67	34	27	6	0	3	5	3	2	0	1	0
10.86	20	129	69	47	28	1	0	0	6	12	0	3	0	0
11.01	14	142	110	51	32	1	0	3	5	10	1	7	2	0
11.32	18	77	64	39	22	2	0	0	4	5	0	5	2	0
11.54	21	138	85	37	35	3	0	1	6	3	0	3	1	0
11.74	13	98	81	36	32	1	0	0	7	9	1	1	1	2
11.94	16	86	82	42	32	5	0	0	8	2	3	1	1	0
12.04	15	102	67	28	45	3	0	0	3	6	0	1	1	1
12.16	14	68	54	31	34	2	0	2	14	9	1	1	0	1

NAP Counts (continued)

Depth	A	B	C	D	E	F	G	H	I	J	K	L	M	N
12.25	26	119	65	24	78	2	0	1	13	5	0	2	0	0
12.45	17	57	59	24	51	4	0	1	9	6	0	1	3	0
12.64	20	93	55	17	68	1	0	0	6	5	3	0	0	1
12.84	22	84	40	12	79	4	0	0	9	5	0	1	2	0
12.94	22	76	46	22	78	4	0	0	9	3	0	2	1	0
13.04	16	101	50	13	66	2	0	0	3	6	2	0	0	0
13.24	25	94	65	10	67	3	0	1	4	8	0	1	0	0
13.44	22	47	29	13	45	3	0	0	0	4	2	1	0	1
13.54	24	53	57	22	56	2	0	1	1	4	0	2	1	0
13.64	48	91	55	24	44	2	0	0	2	5	0	1	0	0
13.76	16	59	59	15	28	2	0	0	0	5	0	2	1	0
13.84	58	98	35	14	31	3	0	1	0	5	1	2	1	0
14.04	43	103	31	9	44	3	0	0	0	4	1	0	1	0
14.20	36	137	30	8	70	7	0	0	0	4	0	0	1	1
14.40	26	114	42	14	71	6	1	0	0	4	2	2	0	0
14.60	39	123	46	13	41	2	0	4	1	7	1	2	0	0
14.80	34	118	50	28	39	4	0	0	2	8	1	3	1	1
14.95	15	100	69	17	40	8	0	0	3	6	0	1	2	1
15.00	16	107	74	15	48	4	0	2	1	10	0	4	1	1
15.20	12	85	72	21	42	6	0	0	3	7	0	2	1	0
15.40	29	128	125	20	87	3	0	0	0	11	1	2	3	0
15.60	13	103	73	15	50	2	0	0	4	9	0	2	1	0
15.80	13	113	92	16	35	2	0	0	3	12	1	2	1	0
16.00	23	114	109	21	59	2	0	3	4	6	1	5	2	0
16.18	23	112	71	22	33	4	0	0	3	2	1	2	1	1
16.20	15	142	73	13	34	2	2	0	4	11	2	2	5	0
16.40	15	176	80	17	35	1	1	0	5	11	0	3	2	0
16.61	26	112	44	8	41	3	0	0	3	5	0	1	0	0
16.81	24	104	61	24	46	3	0	0	4	2	0	1	3	0
17.01	15	80	49	10	72	2	0	1	0	4	3	0	0	0
17.21	50	79	49	10	50	2	0	1	0	9	0	1	0	2
17.41	12	110	58	22	43	6	0	2	3	4	3	2	1	0
17.61	28	101	26	11	48	5	0	0	13	7	1	0	2	0
17.79	33	140	70	10	32	3	0	2	0	8	0	1	1	1
17.97	41	119	39	10	20	4	0	0	4	3	0	2	2	0
18.17	24	153	38	10	34	1	0	2	1	2	1	1	1	1
18.36	58	203	47	8	53	2	0	0	4	12	0	1	0	0
18.56	53	159	26	5	36	4	0	5	1	3	0	0	0	1
18.76	37	115	37	10	58	2	0	0	2	4	0	1	1	0
18.86	13	50	35	3	9	0	0	0	0	2	0	0	0	0
18.92	10	47	35	8	10	0	0	0	0	1	0	0	0	0
19.07	5	41	14	1	11	1	0	0	0	0	0	0	0	0
19.19	1	8	4	2	2	0	0	0	0	0	0	0	0	0

NAP Counts (continued):

Depth	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC
2.18	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.38	11	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2.58	7	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2.76	9	0	0	0	0	0	2	0	0	0	1	0	0	0	0
2.96	8	0	0	0	0	0	2	0	0	0	0	0	0	0	0
3.16	16	0	0	0	0	1	7	0	0	0	0	0	0	1	0
3.36	25	0	1	0	0	0	6	0	0	1	0	0	0	0	0
3.56	38	0	1	0	0	1	9	0	0	0	0	0	0	0	0
3.76	30	0	1	0	0	1	7	0	0	0	1	0	0	0	0
3.96	19	0	1	0	0	1	8	0	0	0	1	0	1	0	0
4.16	17	0	1	0	0	1	8	0	0	1	1	0	0	0	0
4.36	16	0	0	0	0	2	11	0	0	0	0	0	0	0	0
4.56	18	1	0	0	0	1	13	0	0	0	0	0	0	0	0
4.76	23	1	0	0	0	1	5	0	0	0	0	0	0	0	0
4.96	9	0	0	0	0	0	2	0	0	0	0	0	0	0	0
5.18	9	1	0	0	0	1	2	0	0	0	1	0	2	0	0
5.34	10	1	0	0	0	1	2	0	0	0	2	0	0	0	0
5.50	12	0	0	0	0	0	2	0	0	0	0	0	1	0	0
5.58	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
5.78	2	0	0	0	0	0	3	0	0	0	0	0	1	0	0
6.02	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.32	3	0	0	0	0	1	1	0	0	0	0	0	0	0	0
6.42	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6.55	3	0	0	1	0	1	2	0	0	0	2	0	0	0	0
6.62	4	0	1	0	0	0	0	0	0	0	0	1	0	0	0
6.79	8	1	0	2	0	3	2	0	0	0	0	0	0	0	0
6.87	6	0	0	1	0	0	1	1	0	0	2	0	0	0	0
7.02	5	0	1	0	0	0	6	0	0	0	0	0	1	0	0
7.26	5	1	2	0	0	0	2	0	0	1	0	0	0	0	0
7.41	5	0	0	1	0	0	1	0	0	0	0	0	0	0	0
7.46	9	1	0	1	0	0	2	0	0	1	0	0	2	0	0
7.61	4	0	0	0	0	0	3	0	0	0	0	0	1	0	0
7.73	4	0	0	0	0	1	2	0	0	0	0	0	0	0	0
8.03	8	0	1	2	0	0	2	0	0	0	0	0	0	1	0
8.23	5	0	0	0	0	2	1	0	0	0	0	0	1	0	0
8.52	5	0	0	0	0	0	2	0	0	0	0	0	0	0	0
8.75	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.97	5	0	0	0	0	2	1	0	0	0	0	0	0	0	0
9.19	3	0	1	2	0	1	0	0	0	1	2	0	0	1	0
9.39	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9.62	8	0	1	0	0	0	2	0	0	0	0	0	0	0	0
9.82	8	0	0	0	0	1	1	0	0	0	2	0	0	0	0
10.02	10	0	0	0	0	1	0	0	0	0	0	0	0	0	0
10.17	3	0	1	0	0	2	0	0	0	0	0	0	0	0	0
10.32	1	0	0	0	0	2	0	0	0	0	0	0	1	0	0
10.41	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
10.56	2	1	0	1	0	2	1	0	0	1	2	0	0	0	0
10.71	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0
10.86	4	0	1	0	0	2	0	0	0	0	0	0	0	0	0
11.01	3	0	0	0	0	2	0	0	0	0	2	0	0	0	0
11.32	4	2	0	1	0	3	0	0	0	0	1	0	0	0	1
11.54	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1
11.74	3	0	0	0	0	3	0	2	0	0	1	0	0	0	0
11.94	0	1	1	2	0	0	0	0	0	1	0	0	0	0	0
12.04	5	0	0	0	0	2	3	0	0	0	0	0	0	0	0
12.16	4	0	2	1	0	3	0	1	1	0	1	0	0	1	1

NAP Counts (continued)

Depth	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC
12.25	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
12.45	3	0	0	0	0	1	1	0	0	1	0	0	0	0	0
12.64	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12.84	2	0	0	0	1	1	0	0	2	0	0	0	0	0	0
12.94	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13.04	3	0	0	0	0	1	0	0	0	0	0	1	0	0	0
13.24	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0
13.44	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.54	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0
13.64	2	0	0	0	0	2	0	0	0	1	0	0	0	0	0
13.76	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0
13.84	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1
14.04	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
14.20	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14.40	6	1	0	0	0	1	0	0	0	0	0	0	0	0	0
14.60	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14.80	3	0	0	0	0	1	0	0	0	1	0	0	0	1	1
14.95	1	0	0	0	0	0	0	0	0	1	1	3	0	0	0
15.00	1	0	0	0	0	3	0	0	0	0	0	0	1	0	0
15.20	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
15.40	1	0	0	0	0	3	0	0	0	0	0	1	0	0	2
15.60	2	0	1	0	1	1	0	0	0	0	0	0	0	0	0
15.80	2	0	0	0	0	0	0	0	2	1	0	0	1	1	1
16.00	2	0	0	0	0	2	0	0	3	0	1	0	0	0	2
16.18	1	1	0	0	1	0	0	1	0	0	1	0	1	0	1
16.20	2	0	0	0	0	2	1	0	2	0	1	0	0	0	1
16.40	0	0	1	0	0	0	0	0	1	0	1	0	0	0	2
16.61	5	0	0	1	0	2	0	0	0	2	0	0	0	0	0
16.81	4	0	0	1	0	3	0	0	0	0	0	0	0	0	0
17.01	3	0	0	0	0	1	0	0	0	1	0	0	0	0	0
17.21	4	0	1	0	0	1	0	0	0	0	0	0	0	0	0
17.41	2	0	0	1	0	1	0	2	2	1	0	1	1	0	0
17.61	5	1	0	0	0	1	0	1	0	1	0	0	0	0	0
17.79	5	0	0	0	0	0	1	0	1	0	0	0	0	0	0
17.97	3	1	0	1	0	1	0	0	0	0	1	0	0	0	0
18.17	2	0	0	0	0	1	2	0	0	0	0	0	1	0	0
18.36	8	0	0	0	0	1	0	0	1	0	0	0	0	0	2
18.56	7	0	0	0	0	0	0	0	0	0	0	1	0	1	0
18.76	6	0	2	0	0	1	0	0	0	0	0	3	0	0	0
18.86	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0
18.92	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
19.07	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NAP Counts (continued):

Depth	DD	EE	FF	GG	HH	II	JJ	KK	LL	MM	NN	OO	PP	QQ	RR	SS
2.18	0	0	0	0	0	10	1	0	1	0	0	0	0	0	0	0
2.38	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
2.58	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
2.76	0	0	0	1	0	3	0	0	1	1	0	0	0	0	0	0
2.96	0	0	0	2	0	7	0	0	0	0	0	0	0	0	0	0
3.16	0	0	0	2	0	6	1	0	3	1	0	0	0	0	0	1
3.36	0	0	0	2	0	4	2	0	1	0	0	0	0	0	0	0
3.56	0	0	0	0	0	6	2	0	1	0	0	0	1	0	0	0
3.76	0	0	0	0	0	8	3	0	1	0	0	0	0	0	0	0
3.96	0	0	0	0	0	4	5	1	2	0	0	0	0	0	0	0
4.16	0	0	0	1	0	4	5	0	1	0	0	0	0	1	0	0
4.36	0	0	0	0	0	5	3	1	1	0	0	0	0	0	0	0
4.56	0	0	0	0	0	9	2	0	0	1	0	0	0	0	0	1
4.76	0	0	0	0	0	9	1	0	1	0	0	0	0	0	0	1
4.96	0	0	0	0	0	6	2	0	0	0	0	0	0	0	1	0
5.18	0	0	0	0	1	4	1	0	0	0	0	0	0	0	0	0
5.34	0	0	0	0	2	7	1	1	1	0	0	0	0	0	0	0
5.50	0	0	0	0	2	6	1	0	0	0	0	0	0	0	0	0
5.58	0	0	0	0	2	9	0	0	0	0	0	0	0	0	0	0
5.78	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0
6.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.07	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
6.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.42	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
6.55	0	0	0	0	0	5	1	0	0	3	0	0	0	0	0	0
6.62	0	0	0	0	0	8	3	0	1	0	0	0	0	0	0	0
6.79	0	0	0	0	0	8	2	1	0	0	0	0	0	0	0	0
6.87	0	0	0	0	0	7	1	0	0	0	0	0	0	0	0	0
7.02	0	0	0	0	0	8	1	1	1	0	0	0	0	2	0	0
7.26	0	0	0	0	0	3	1	0	1	0	0	0	0	0	0	0
7.41	0	0	0	0	0	6	2	0	1	0	0	0	0	0	0	0
7.46	0	0	0	0	1	5	4	0	0	3	0	0	0	0	0	0
7.61	0	0	0	0	2	12	1	0	0	2	0	0	0	0	0	0
7.73	0	0	0	0	2	6	2	1	0	0	0	0	0	0	0	0
8.03	0	0	0	0	0	2	4	1	0	1	0	0	0	0	0	0
8.23	0	0	0	0	0	6	2	0	0	0	0	0	0	0	0	0
8.52	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	4
8.75	0	0	0	0	0	3	2	1	0	0	0	0	0	0	0	0
8.97	0	0	0	0	3	8	3	0	0	0	0	0	3	0	0	0
9.19	0	0	0	0	1	5	4	1	0	0	0	0	0	0	0	0
9.39	1	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0
9.62	0	0	0	0	3	9	4	2	1	0	0	0	0	0	0	0
9.82	0	0	0	0	0	8	1	0	1	0	0	1	0	0	0	0
10.02	3	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
10.17	0	0	0	0	0	6	1	0	0	1	0	1	0	0	0	0
10.32	0	0	0	0	0	9	1	0	0	0	0	0	0	0	0	1
10.41	1	0	0	0	0	12	2	1	2	0	0	0	0	0	1	1
10.56	1	0	0	0	0	4	2	1	0	0	0	1	0	0	0	0
10.71	0	0	0	0	0	4	2	1	0	0	0	1	0	0	0	0
10.86	0	0	0	0	0	7	3	1	1	0	0	1	0	0	0	0
11.01	0	0	0	0	0	8	3	0	0	0	0	0	0	0	0	0
11.32	0	0	0	0	1	8	2	1	1	0	0	0	0	0	0	0
11.54	0	0	0	0	3	9	2	1	0	0	0	0	0	0	0	1
11.74	0	0	0	0	1	13	3	1	0	0	0	0	0	0	0	1
11.94	0	0	1	0	1	6	1	0	0	1	0	1	1	0	0	1
12.04	0	0	0	0	0	5	1	1	0	0	0	0	0	0	0	2
12.16	0	0	0	0	2	8	1	0	0	0	1	0	0	0	0	0

NAP Counts (continued):

Depth	DD	EE	FF	GG	HH	II	JJ	KK	LL	MM	NN	OO	PP	QQ	RR	SS
12.25	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
12.45	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
12.64	0	0	0	0	0	4	1	0	0	1	0	0	0	0	0	0
12.84	0	0	0	0	0	1	1	2	0	0	2	0	1	0	0	0
12.94	0	0	0	0	0	6	2	2	1	0	0	0	0	0	0	0
13.04	0	0	0	0	0	6	0	1	0	1	0	0	0	0	0	0
13.24	0	0	0	0	1	4	1	0	0	0	0	0	0	0	0	0
13.44	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0
13.54	0	0	0	0	1	7	0	0	0	0	0	0	1	0	0	0
13.64	0	0	0	0	2	12	2	1	0	0	0	1	0	0	0	0
13.76	0	0	0	0	3	6	1	2	1	1	0	0	1	2	0	0
13.84	0	0	0	0	2	7	2	0	1	0	0	0	0	0	0	1
14.04	0	0	0	0	1	4	1	0	0	0	0	1	0	0	0	0
14.20	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
14.40	0	0	0	0	2	6	1	0	1	0	0	1	0	0	0	0
14.60	0	0	0	0	1	6	3	0	0	0	0	0	0	0	0	1
14.80	0	1	0	0	6	5	6	0	2	1	0	0	0	0	0	1
14.95	0	1	0	0	0	10	6	0	2	0	0	1	0	0	0	1
15.00	0	0	0	0	1	5	5	0	0	0	0	0	0	0	0	1
15.20	0	0	0	0	3	9	2	0	0	0	0	1	0	0	0	0
15.40	0	0	0	0	0	10	1	0	0	0	0	0	0	0	0	1
15.60	0	0	0	0	2	2	2	0	0	1	0	0	1	0	0	3
15.80	0	0	0	0	0	5	3	0	0	0	2	0	0	0	0	0
16.00	1	0	0	0	9	13	1	0	0	0	3	0	0	0	0	1
16.18	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
16.20	1	0	0	0	0	10	1	0	0	0	2	0	0	0	0	0
16.40	1	0	0	0	0	7	3	0	1	0	1	0	0	0	0	0
16.61	0	0	0	0	2	4	2	1	0	0	0	0	0	0	0	1
16.81	0	0	0	0	3	4	3	0	0	0	0	0	1	0	0	2
17.01	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0
17.21	0	0	0	0	0	5	2	4	0	0	0	0	0	0	0	0
17.41	0	0	0	0	1	0	1	0	0	1	2	0	0	1	0	2
17.61	0	0	0	0	0	6	3	0	0	0	0	0	0	0	0	0
17.79	0	0	0	0	0	7	4	1	0	0	1	0	0	0	0	0
17.97	0	0	0	0	0	7	3	0	0	0	0	0	0	0	0	0
18.17	0	0	0	0	0	4	1	0	1	0	0	0	0	0	0	0
18.36	0	0	0	0	0	5	2	0	1	0	1	0	1	0	0	0
18.56	0	0	0	0	0	4	3	0	1	0	0	0	0	0	0	0
18.76	1	0	0	0	0	4	0	1	1	0	0	0	0	0	0	0
18.86	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
18.92	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
19.07	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
19.19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

NAP Counts (continued)

Depth	TT	UU	VV	WW	XX	YY
2.18	0	0	0	0	0	0
2.38	0	0	0	0	0	0
2.58	0	0	0	0	0	0
2.76	0	0	0	0	0	0
2.96	0	0	0	0	0	0
3.16	0	0	0	0	0	0
3.36	0	1	0	0	0	0
3.56	0	1	0	0	0	0
3.76	0	1	0	0	0	0
3.96	0	1	1	0	0	0
4.16	0	0	0	0	0	0
4.36	0	0	1	0	0	0
4.56	0	0	0	0	0	0
4.76	0	0	1	0	0	0
4.96	0	0	0	0	0	0
5.18	0	0	0	0	0	0
5.34	0	0	0	0	0	0
5.50	0	0	0	0	0	0
5.58	0	0	0	0	0	0
5.78	0	0	0	0	0	0
6.02	0	0	1	0	0	0
6.07	0	0	0	0	0	0
6.32	1	0	0	0	0	0
6.42	0	1	0	0	0	0
6.55	0	1	2	0	0	0
6.62	0	1	0	0	0	0
6.79	0	0	1	0	0	0
6.87	0	1	0	0	0	0
7.02	0	0	5	0	0	0
7.26	0	0	0	0	0	0
7.41	0	1	0	0	0	0
7.46	0	0	0	0	0	0
7.61	0	0	0	0	0	0
7.73	0	0	5	0	0	0
8.03	0	0	0	0	0	0
8.23	0	0	2	0	0	0
8.52	0	0	0	0	0	0
8.75	0	0	0	0	0	0
8.97	0	0	6	0	0	0
9.19	0	0	1	0	0	0
9.39	0	0	0	0	0	0
9.62	0	1	0	0	0	0
9.82	0	1	0	0	0	0
10.02	0	0	0	0	0	0
10.17	0	1	1	0	3	0
10.32	0	4	4	0	0	0
10.41	1	0	2	0	0	0
10.56	1	0	0	0	0	0
10.71	0	0	1	0	0	0
10.86	3	0	0	0	0	0
11.01	0	0	0	0	0	0
11.32	1	1	1	0	0	
11.54	1	0	1	0	0	0
11.74	0	0	0	0	0	0
11.94	0	1	0	0	0	2
12.04	2	1	0	0	0	0
12.16	1	0	2	0	1	0

NAP Counts (continued):

Depth	TT	UU	VV	WW	XX	YY
12.25	1	0	1	0	0	0
12.45	1	0	0	0	0	0
12.64	0	0	0	0	0	0
12.84	0	0	1	0	0	0
12.94	0	1	1	0	0	0
13.04	1	0	0	0	0	0
13.24	0	1	0	0	0	0
13.44	0	0	0	0	0	0
13.54	1	0	2	0	0	0
13.64	0	1	3	0	0	0
13.76	1	0	0	0	0	0
13.84	0	0	1	0	0	0
14.04	0	0	1	0	0	0
14.20	0	0	1	0	0	0
14.40	0	0	3	0	0	0
14.60	0	1	0	0	0	0
14.80	0	0	1	0	0	0
14.95	0	0	2	0	0	1
15.00	0	0	2	0	0	0
15.20	0	0	0	0	0	0
15.40	0	0	0	0	0	0
15.60	0	0	0	0	0	0
15.80	0	0	0	1	0	0
16.00	0	0	0	0	0	0
16.18	1	0	0	0	0	0
16.20	0	0	0	0	0	0
16.40	1	0	0	0	0	0
16.61	0	0	0	0	0	0
16.81	2	0	3	2	0	0
17.01	0	0	0	0	0	0
17.21	0	0	1	0	1	0
17.41	0	0	0	1	0	0
17.61	0	1	0	0	0	0
17.79	0	0	0	0	0	0
17.97	0	0	0	0	0	0
18.17	0	0	0	0	0	0
18.36	0	0	0	0	0	0
18.56	0	0	0	0	0	0
18.76	0	0	0	0	0	0
18.86	0	0	0	0	0	0
18.92	0	0	0	0	1	0
19.07	0	0	0	0	0	0
19.19	0	0	0	0	0	0

Indeterminate Pollen Classes,

Pre-Quaternary Forms

and Marker Grains

Letter codes for pollen types:

Depth	Meters Below Surface (m.b.s)
A	Degraded/Corroded Grains
B	Broken/Fragmented Grains
C	Folded/Collapsed Grains
D	Obscured/Concealed Grains
E	Pre-Quaternary Palynomorphs
F	Lycopodium Marker Grains

Note: Two (2) *Lycopodium* tablets were added to each 4 cc pollen sample. Each *Lycopodium* tablet contained 56,335 +/- 1850 grains.

Pollen Counts: Pollen preseravation, pre-Quaternary Palynomorphs, Marker Grains

Depth	A	B	C	D	E	F
2.18	2	6	7	0	0	16
2.38	4	4	9	2	1	16
2.58	4	6	16	1	1	12
2.76	6	3	12	0	0	6
2.96	7	6	11	0	2	35
3.16	7	6	13	1	0	85
3.36	10	12	12	0	1	99
3.56	8	6	9	0	0	197
3.76	10	6	10	3	0	148
3.96	11	11	9	0	0	191
4.16	12	9	8	0	0	246
4.36	7	5	4	1	2	176
4.56	8	6	8	0	0	238
4.76	10	7	6	0	0	178
4.96	9	5	5	0	1	176
5.18	9	5	6	1	0	140
5.34	9	8	6	3	1	119
5.50	29	7	8	2	2	75
5.58	25	13	10	2	11	864
5.78	15	7	3	2	16	1030
6.02	10	11	7	5	8	287
6.07	7	7	5	3	7	539
6.32	12	10	12	5	20	483
6.42	10	12	10	4	8	335
6.55	12	9	8	2	18	399
6.62	9	24	11	3	7	370
6.79	17	9	6	3	8	228
6.87	15	6	4	2	30	490
7.02	13	21	5	0	15	182
7.26	20	22	5	2	19	226
7.41	15	12	5	8	25	362
7.46	15	11	6	5	15	212
7.61	8	7	5	4	12	288
7.73	12	9	6	9	18	209
8.03	8	8	5	1	3	156
8.23	6	11	5	3	7	235
8.52	7	10	6	5	11	241
8.75	6	14	9	2	7	89
8.97	2	15	8	3	11	129
9.19	3	14	13	5	12	92
9.39	4	12	9	8	8	101
9.62	4	14	8	2	20	160
9.82	1	16	7	0	21	117
10.02	3	10	8	4	6	117
10.17	1	17	8	2	18	141
10.32	7	24	8	6	26	181
10.41	4	20	6	2	17	99
10.56	1	13	8	4	25	211
10.71	1	21	9	2	5	134
10.86	1	5	6	0	4	165
11.01	0	10	6	3	7	148
11.32	2	8	7	2	6	81
11.54	0	8	7	2	4	116
11.74	1	18	4	2	11	144
11.94	3	17	14	1	9	88
12.04	2	11	5	5	4	131

Other Palynomorph Counts (continued):

Depth	A	B	C	D	E	F
12.16	1	10	6	11	1	138
12.25	4	8	8	19	1	188
12.45	2	13	9	10	3	222
12.64	0	10	9	16	3	177
12.84	2	17	4	17	2	237
12.94	8	10	8	11	8	230
13.04	1	10	4	19	8	313
13.24	3	10	5	16	2	191
13.44	8	8	3	21	2	165
13.54	0	6	4	16	2	111
13.64	2	21	5	30	5	251
13.76	1	7	10	8	2	95
13.84	3	10	5	15	4	306
14.04	2	10	3	16	1	293
14.20	1	12	4	20	5	298
14.40	4	12	6	29	4	273
14.60	1	9	4	14	0	108
14.80	1	14	5	4	1	153
14.95	1	15	5	4	3	67
15.00	0	10	4	2	3	79
15.20	1	6	1	3	0	72
15.40	0	10	8	3	2	95
15.60	0	5	3	2	0	85
15.80	0	7	5	3	1	132
16.00	2	12	4	2	1	148
16.18	1	7	4	3	1	66
16.20	0	13	3	6	2	164
16.40	1	8	2	6	1	103
16.61	7	6	2	11	2	156
16.81	3	4	6	5	2	113
17.01	10	6	4	8	2	130
17.21	5	5	7	19	8	116
17.41	1	10	1	6	3	67
17.61	2	6	3	15	3	77
17.79	3	8	4	4	3	80
17.97	4	10	6	9	1	95
18.17	4	8	4	6	5	102
18.36	6	13	5	3	6	164
18.56	12	8	9	12	6	360
18.76	5	9	6	11	4	754
18.86	4	7	3	4	5	800
18.92	11	10	4	0	3	1065
19.07	8	6	3	2	4	664
19.19	3	2	0	4	2	315