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Holocene Climatic Change
in the Central United States
Inferred from Paleoecological Data

A Thesis Presented to the
Department of Geography-Geology
and the Faculty of the Graduate College
The University of Nebraska
In Partial Fulfillment of the
Requirements for the Degree
Master of Arts
University of Nebraska at Omaha

by

Raymond P. Latimer
December, 1990

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THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Masters of Arts, University of Nebraska at Omaha

Committee

Name Department

Geog-Geol

CSD-UNL

Roger Mandel

Chairman

December 13, 1990

Date

ABSTRACT

The Holocene in the central U.S. is the period of time since the retreat of the last continental ice sheets. It has been a 10,000 year period of climatic variability. In North America, Holocene climatic fluctuations have been detected in the paleoenvironmental record of the central United States. The most evident climatic fluctuation has been the mid-Holocene Climatic Optimum, or Altithermal. The Altithermal provided the warmest and driest post-glacial climatic conditions which lasted from ca. 8500-4000 years B.P.

Much research has been devoted to the climatic change initiating the Altithermal, and to the conditions which persisted during this protracted warm, dry spell. However, very little has been written about the climatic change which marked the demise of this episode at around 6000-4000 years B.P. Published paleobotanical and archeological data from the central United States provide a paleoenvironmental reconstruction from which climate change is inferred. At times the data resemble mere noise, however some trends are detectable. Decreases in arboreal pollen along with dramatic rises and falls in herb pollen, suggest warming and drying of the environment until around 5250 years B.P. Increases in arboreal pollen and steady fluctuations in herb pollen suggest the onset of more mesic conditions around 4750 years

B.P. Archeological data show a peak in margin/refugia site occupation at 5750 years B.P. Plains/prairie site occupations peak at 6250 and 4750 years B.P. These data support the changes in the environment suggested by the vegetation data. The inference is that the Altithermal ended ca. 5250-4750 years B.P. in the central United States.

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I would like to express my sincere gratitude to all of my Geography professors who have provided a most enlightening graduate education.

My deepest gratitude is extended to Roger K. Wasmer, a most excellent geographer, for his endless outpouring of knowledge, astute guidance, and unwaivering support.

I. Introduction

At first glance, the study of paleoclimate may seem esoteric. However, knowledge of past climates and their fluctuations can aid in understanding present and future episodes of climatic change (Bryson, 1983; Dort, 1983). Also, the more knowledge that can be gained about environmental responses to past climate change, the better prepared we will be to adapt to climatic fluctuations. The thesis focuses on the timing and nature of climatic change between 6000 and 4000 years Before Present (B.P.) based upon paleobotanical and archeological records from the central United States (U.S.) (Figure 1). This period of the Holocene spans the transition from the warm, dry Altithermal climatic episode to the cool, moist Sub-Boreal episode (Bryson and others, 1970).

Much research has focused on early-Holocene warming, and the environmental conditions that persisted during the protracted warm, dry Altithermal. Some of these research efforts possibly were undertaken to better understand global warming trends that are currently being hypothesized. These speculations about past and future climatic episodes rely upon models which present broad generalizations based on climate trends occurring over large periods of time. A problem thus arises from the fact that general weather systems, hence climates, have been shown through the mathematics of Lorenz and others to behave chaotically (Geike, 1987). The chaos exhibited by weather systems, and characterized by Lorenz' equations, belies the fact that climates may not behave in ways that can be accurately predicted by linear mathematics (Bryson and others, 1970). Because of this chaotic behavior of weather and climate, the knowledge of fluctuations in climate at different time scales will be beneficial to evaluate predicted global warming trends. It has also been predicted that even during climatic episodes that span thousands of years, there can exist chaotic fluctuations of climate which endure for hundreds of years (Blakeslee, 1983; Bryson, 1983; Schweger, 1987).

This thesis examines paleobotanical and archeological records from the central U.S. in order to reconstruct the environment during the period 6000 to 4000 years B.P. Climatic changes are inferred from changes in plant populations and in human settlement patterns.

II. Statement of Problem

The purpose of this thesis is to determine the nature of climatic change in the central U.S. between 6000 and 4000 years B.P. In order to address this question, a combination of paleobotanical and archeological data are analyzed and compared. The timing and characteristics of climatic change will be inferred from these data.

A. Origin of Problem

Many studies have focused on peculiarities in the Altithermal climatic episode. For example, Sears' (1961) pollen analysis of a core from Hackberry Lake in the Nebraska Sand Hills showed a maximum of arboreal pollen and a minimum of grass pollen at ca. 5000 years B.P. The majority of the arboreal pollen was pine, leading Sears to speculate that cooler and wetter conditions persisted in west-central Nebraska at the end of the Altithermal. He also suggested that the lake may have formed and had begun to fill sometime before 5000 years B.P. as a result of a humid climatic interval.

In a similar study, Van Zant (1979) examined the pollen assemblage in a core recovered from Lake West Okoboji, Iowa. The palynological data suggested that the water level of the lake increased around 6300 years B.P., and provided evidence for an increase in oak trees in low lying areas dating to around 5200 years B.P. The conclusion was made that a moist period was responsible for the trend in the pollen assemblage (Van Zant, 1979).

Geomorphic evidence from the Midwest supports paleobotanical data indicating a humid interval sometime between 6000 and 4000 years B.P. Knox (1983) analyzed river systems in the Tall-grass prairie and the Midwest for relationships between alluvial histories and Holocene climates. He suggested that aggradation occurred in stream valleys from 10,000 to 7500 years B.P. in response to a desiccating climate that destabilized vegetation and accelerated upland erosion. According to Knox (1983), this dry period ended around 6000 years B.P.

Other geomorphic evidence has been offered in support of a moist interval at the end of the middle Holocene. Denton and Karlen (1973) reported evidence for expansion of alpine glaciers in the St. Elias Mountains in northern North America, and in the mountains of Swedish Lapland between 5800 and 4900 years B.P. They concluded that the Holocene experienced alternating periods of worldwide glacier expansion and contraction, with expansions corresponding to cooling trends that lasted up to 900 years (Denton and Karlen, 1973).

Recent studies on dune evolution in the Nebraska Sand Hills also indicate that although a mid-Holocene climatic optimum occurred, there is evidence for moist periods within the Altithermal. Ahlbrandt and others (1983), Swinehart and Diffendal (1989), and Swinehart (1989) reported peaty and organic-rich layers in outcrops and rotary drill holes from dunes and interdunal areas. Radiocarbon ages determined on the organic material range between 13,160 and 860 years B.P. They suggested that some of the organic-rich zones correspond to an increase in moisture in that area at the end of the Altithermal.

Some studies have cautioned against making broad generalizations about the Altithermal climatic episode, and suggest that major climatic fluctuations occurred during this protracted warm, dry spell. For example, Blakeslee (1983) warned that the 100 year minimum uncertainty in radiocarbon dating techniques (Ralph and others, 1973) allows for the possibility that climate fluctuations with durations of around 300 years could go unnoticed. Bryson (1983) also cautioned that within the broad definition of a climatic episode, it would not be unlikely to find various climatic fluctuations. Finally, Benedict (1978) suggested that the Altithermal could be visualized as a two drought episode, separated by distinctive periods of increased moisture.

In summary, many studies that have focused on the Altithermal have offered only scant discussions of the end of this climatic sequence. This thesis focuses on the evidence provided by these reports about the central U.S. at the end of the Altithermal, to resolve the timing and nature of its demise.

III. Description of Study Area

A. General

The central United States is considered, for this study, to be the region of North America encompassed within 38° N and 46° N, and 91° W and 106° W (Figure 1). This study area covers a large portion of the Great Plains Province (Fenneman, 1931). Consequently, a variety of environments are present within the region. The following discussion of the modern environments of this region provides a perspective for comparing mid- and late-Holocene environments.

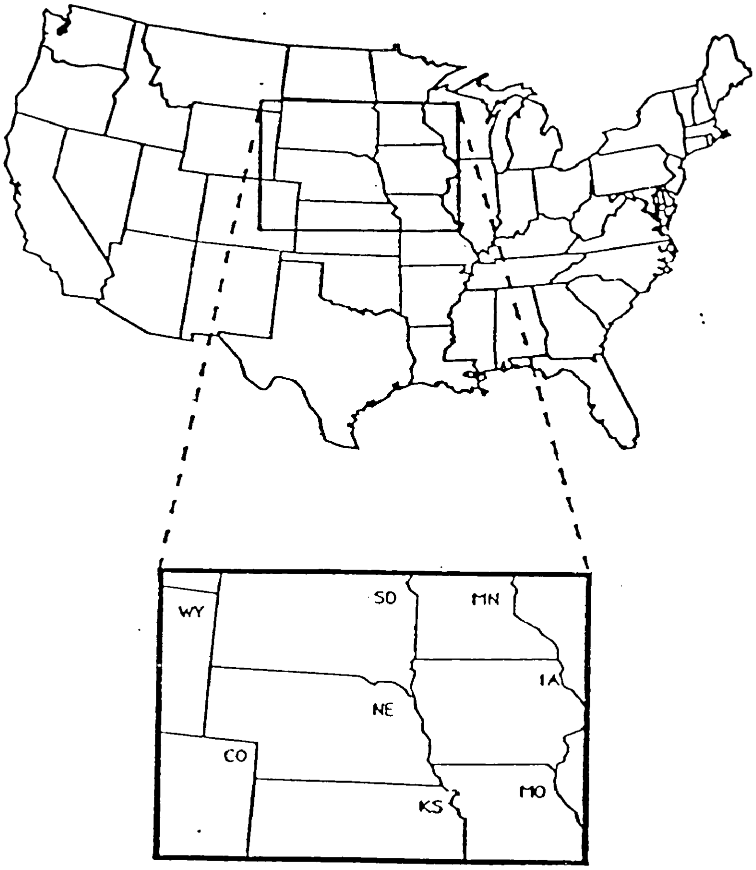


Figure 1. Map of study area

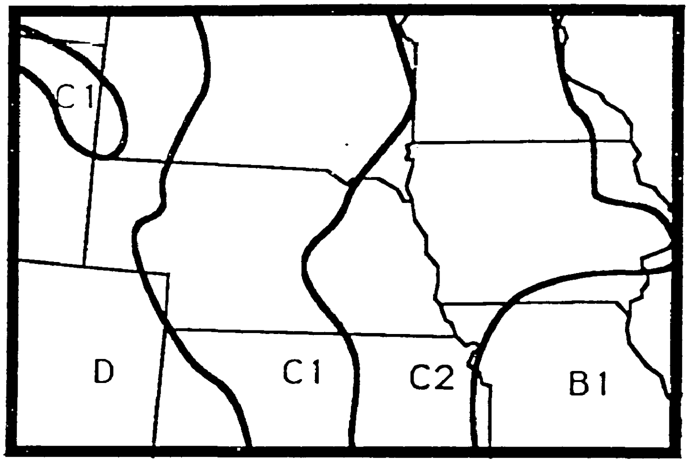
B. The Modern Environment

1. Climate and Climatic Mechanisms

The modern climate of the study area is continental, with a large annual temperature range and variability in precipitation. The central United States encompasses a broad expanse of the mid-continent, and includes four of Thornthwaite's (1948) climatic zones (Figure 2). These climatic zones range from humid (B1) in the extreme eastern and southeastern portions of the study area, to semi-arid (D) along the western boundary. The B1 and C2 (moist subhumid) climates of the eastern half of the study area are characterized by hot, humid summers and cold, dry winters. The C1 (dry subhumid) and D climates in the western half of the study area are characterized by drier summers and winters compared to the climates of the eastern half. The climate of the entire area is classified as mesothermal (Thornthwaite, 1948), with annual temperature ranges reflecting the continentality of the region. Table I presents the mean January and July temperatures from selected stations across the central United States.

Mean annual precipitation decreases from east to west across the study area (Figure 3). Some locales in the extreme southeastern corner of the region receive up to 40 inches (100 cm) of precipitation annually. Mean annual precipitation steadily declines westward, with 10-20 inches

(25-50 cm) received in the extreme western Plains. Table I presents the average annual precipitation from selected stations across the central United States.



D=semiarid C1=dry subhumid C2=moist subhumid B1=humid

Figure 2. Climatic zones in the study area (after Thornthwaite, 1948)

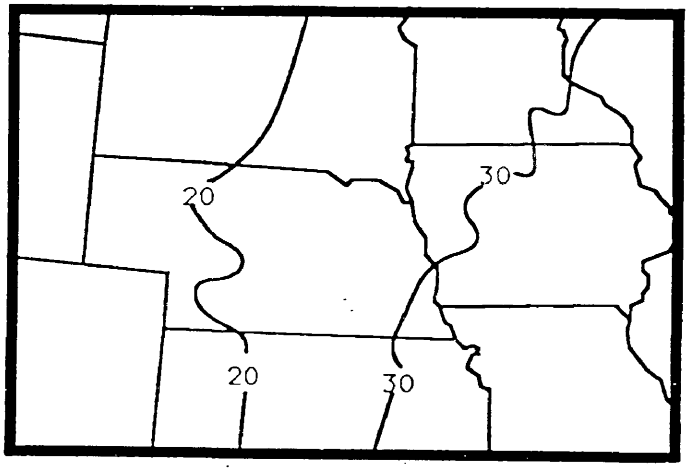


Figure 3. Precipitation zones of the study area in inches/year (after Wernstedt, 1972)

Table I. Average January and July temperatures and annual precipitation from selected central U.S. stations. (Wernstedt, 1972)

Station	**Mean Temps. ($^\circ$F)** **Jan.**	 **July**	**Mean Annual Precip. (in.)**	**# years of record**
Booneville,MO	27.8	78.6	39.1	23
Davenport,IA	17.6	73.9	33.1	89
Topeka, KS	28.6	76.6	33.0	14
Lincoln,NE	26.4	73.8	27.5	30
Minneapolis,MN	11.9	72.6	25.2	22
Sioux Falls,SD	11.9	72.6	24.5	15
Hays, KS	29.7	79.5	22.9	93
NorthPlatte,NE	25.5	76.2	18.4	86
Cheyenne, WY	27.1	68.1	15.2	25
Limon, CO	21.7	65.3	14.8	51
Denver, CO	14.2	54.9	13.8	89

The study area lies in the zone of the prevailing westerlies. Maritime polar (mP) and continental polar (cP) air masses that flow into the region in late spring and early summer, usually converge with moist maritime tropical (mT) air flowing northward from the Gulf of Mexico. Cyclonic frontal storms associated with the convergence of these invading air masses are largely responsible for the short-term (daily-weekly) changes that affect the weather (Mandel, 1987). The weather patterns for the tall grass prairies in the eastern half of the study area have been described by Borchert (1950) as follows:

1. low winter rainfall and snowfall;

2. occasional major summer droughts with a tendency for major summer droughts to occur synchronously within the region; and
3. a continental source and trajectory of the mean airstream which blankets the region during the dry periods.

The climate of the short grass prairies in the western half of the central United States has been described as the most variable climate in North America (Frison, 1978). This region is located in the rain shadow of the Rocky Mountains. Cool, moist Pacific air that loses much of its moisture on the windward side of the Rockies, is drastically warmed as it descends the eastern slopes, dessicating the plains in the western portion of the study area. This dry, mild, Pacific air dominates the short grass prairie during both the summer and winter, resulting in low annual precipitation (Mandel, 1987).

2. Vegetation

The central United States is located in the grassland region of North America, variously referred to as the Great Plains, Prairie and Plains, or Interior Grasslands (Mandel, 1987). This region is biogeographically complex; the composition and overall appearance of the vegetation changes dramatically across the study area. A mosaic of oak-hickory forest and tall grass prairie is present along the eastern border of the study area. Westward through the region, the vegetation changes commensurate with decreasing precipitation: tall grass prairie, mixed prairie, and short grass prairie, respectively. The potential natural vegetation of the region, as described by Küchler (1964), is shown in Figure 4.

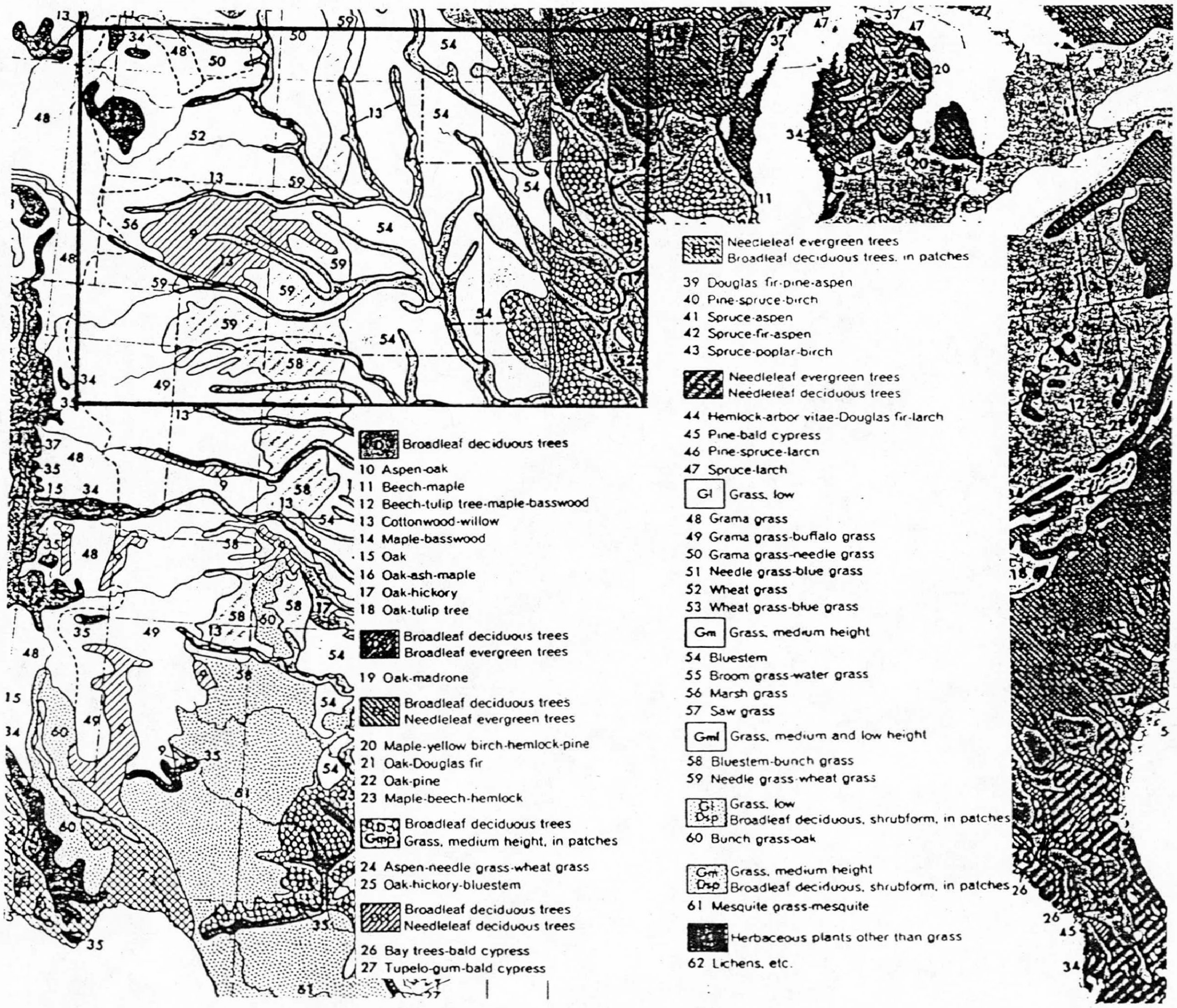


Figure 4. Potential natural vegetation of the study area

Mosaic of Oak-Hickory Forest and Tall Grass Prairie

The eastern fringe of the study area is characterized by a mosaic of tall grass prairie and oak-hickory forest. This mosaic is an ecotone between the oak-hickory forest to the east and tall grass prairie to the west. The dominant flora of the prairie areas are big and little bluestem (*Andropogon gerardi* and *A. scoparius*), switchgrass (*Panicum virgatum*), Indian grass (*Sorghastrum nutans*), and brome grass (*Bromus spp.*). The forested areas are dominated by white oak (*Quercus alba*), red oak (*Q. borealis*), shagbark hickory (*Carya ovata*), and bitternut hickory (*C. cordiformis*) (Küchler, 1964).

Tall Grass Prairie

The majority of the eastern half of the study area is in the tall grass prairie. The dominant vegetation types are warm season grasses, with the most important being big and little bluestem, switchgrass and Indian grass. Other characteristic components of the vegetation community include sideoats grama (*Bouteloua curtipendula*), sand dropseed (*Sporobolus heterolepsis*), wiregrass (*Sporobolus aster*), panic grass (*Panicum scribnerianum*), and June grass (*Koleria pyramidata*) (Küchler, 1964).

Mixed Prairies

The mid-section of the central United States consists of several types of mixed prairie communities, the largest of which is the bluestem-grama prairie. The vegetation of this prairie is dominated by a combination of species found in the tall grass prairie along with shorter grasses, such as blue grama (Bouteloua graciclis) and western wheatgrass (Agropogon smithii). To the west and north of the bluestem-grama prairie is the needlegrass-wheatgrass prairie. This mixed prairie community predominates in slightly more arid zones as the prairie begins a transition to short grasslands. The characteristic components of this mixed prairie are western wheatgrass, blue grama, needlegrass (Stipa comata) and green needlegrass (S. viridula) (Küchler, 1964).

Short Grass Prairie

The western fringe of the study area is a xeric environment, dominated by short grass prairie. This prairie is a fairly dense grassland of short grass, with somewhat taller grasses where there are transitions from the more mesic environment of the mixed prairies (Küchler, 1964). The dominant components of this short grass prairie are blue grama and buffalo grass (Buchloe dactyloides), with interfingerings of taller bluestem in depressions and along floodplains in moist years (Mandel, 1987).

IV. Literature Review

A. Holocene Climates and the Altithermal

The past 10,000 years in the central United States has been a period of dynamic climates. Situated at the southern margin of the Laurentide ice sheet at the end of the Pleistocene, the central U.S. was vegetated by a mixed spruce-deciduous assemblage (Martin and Neuner, 1978; Martin and Hoffman, 1987; Fredland and Jaumann, 1987). As the ice sheet wasted northward during the first millennia of the Holocene (Figure 5), this region underwent dramatic environmental changes (Wright, 1970).

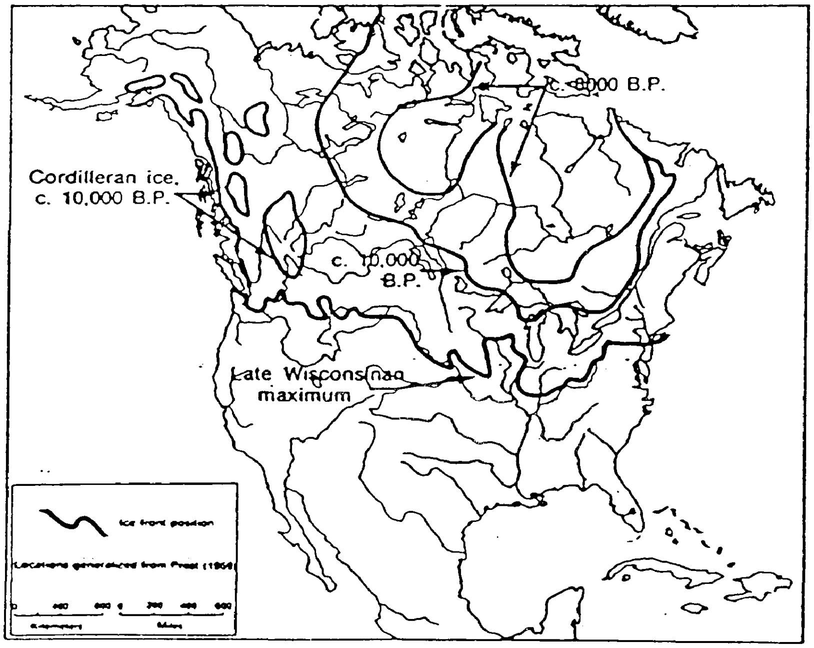


Figure 5. Position of ice fronts (from Knox, 1983).

The first important concept pertaining to Holocene environmental changes in the central United States was the idea of a protracted warm, dry episode termed the Altithermal (Antevs, 1955). This concept, derived from studies of Holocene pollen, found favor with paleoclimatologists, as it correlated well with the mid-Holocene warm, but moist, Atlantic episode postulated for northern Europe by Blytt and Sernander (Zeuner, 1952). Further study of the paleobotanical record suggested gradual climate changes throughout the Holocene, with attempts to simplify the climate trend into large, temperature-dependent categories (Deevey and Flint, 1957). The utilization of radiocarbon-dating techniques, and palynological analyses, allowed the reconstruction of Holocene climate change (Table II).

Date BP	Episode	δ(Years)
	Pre-Boreal	
9650	— — — —	240
	Boreal I	
9140		280
	Boreal II	
8450	— — — —	320
	Atlantic I	
7730		260
	Atlantic II	
7050		300
	Atlantic III	
5980		530
	Atlantic IV	
4680	— — — —	490
	Sub-Boreal	
2890	— — — —	510
	Sub-Atlantic	
1690	— — — —	410
760		470

Table II. Sequence of climatic changes (Bryson and others, 1970)

The works of Reid Bryson and his colleagues have contributed much to our understanding of climatic changes in the Holocene, and specifically the Altithermal episode. Bryson's analysis (1966) of air-mass frequencies over the North American continent laid the foundation for research into air-flow patterns which produce the climates of North America. Bryson and Wendland (1967) reconstructed the types and mean positions of air masses that have dominated the continent during the Holocene by using the current air-flow patterns as modern analogues. They suggested that as the ice sheet wasted, warm, dry, Pacific air was allowed to penetrate into the central U.S., setting up a zonal air-flow pattern.

Bryson and his colleagues correlated the vegetation data with the air-mass data to reconstruct frontal positions of dominant air masses during the Holocene (Bryson and others, 1970; Webb and Bryson, 1974). Bryson (1983) and Bryson and others (1970) have proposed a stepwise model of quasi-steady state climatic periods of dominant air-flow patterns, separated by rapid transitions in which there were changes in air-flow frequencies. The resulting classification of Holocene climate changes adopts the Blytt-Sernander nomenclature of Holocene climates. This nomenclature includes a mid-Holocene climatic optimum that is visualized as a group of climatic episodes.

Because the Altithermal was seen as the major climate transition during the Holocene, much research has focused on the environmental changes which accompanied this protracted warm, dry period. As noted in the previous discussion, evidence to support this and other climatic fluctuations, has come from geomorphological research (e.g., Denton and Karlen, 1973; Knox, 1983).

In addition to geomorphic evidence, research into environmental adaptations can be categorized into three major lines of evidence: (1) floral; (2) faunal; and (3) archeological. A few reports have attempted to synthesize differing lines of evidence into comprehensive studies (e.g., Reeves, 1973; Benedict and Olson, 1978; Buchner, 1979; McMillan and Klippel, 1981). This thesis synthesizes a paleoecological study for the end of the Altithermal from floral and archeological lines of evidence. The remainder of this review examines the research along these two lines.

B. Vegetation Changes During the Mid-Holocene

Holocene climates have been reconstructed largely through the use of paleobotanical data obtained from analyses of tree-rings, plant macrofossils, and pollen records (e.g. Wright, 1970; Wright, 1976; Webb, 1980). In the central U.S. most of these data have been recovered from moist sites on the periphery of the mid-continent (Wells, 1970; Baker and Van Zant, 1980). Analyses of fossil pollen from these sites have contributed the majority of this data (Bradley, 1985). Only a few archeological sites in the region have yielded pollen data, as preservation of pollen requires moist to saturated conditions (Baker and Van Zant, 1980; but see Agenbroad, 1977).

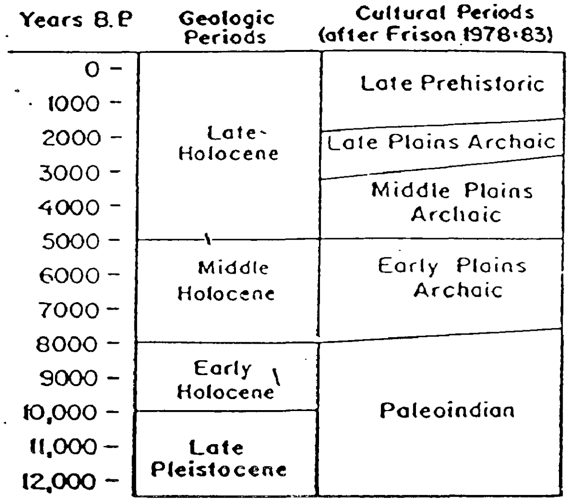
A close correlation between modern pollen fallout and the associated vegetation and climate regime for a given locality has been established (Webb and Bryson, 1972; Wendland and Bryson, 1974; Webb, 1980). Furthermore, interpretation of climatic episodes from pollen analyses has been achieved through a calibration method employing sets of canonical transfer functions (e.g. Webb and Bryson, 1972; Webb, 1980; Bryson, 1987). These transformations permit the translation of a record of pollen changes at a site into climatic changes scaled qualitatively or quantitatively.

The Holocene vegetation record for the central U.S. has been reconstructed primarily from palynological data obtained from lake beds, bogs, and marshes (e.g., Sears, 1961; Wright and others, 1963; Watts and Winter, 1966; Watts and Wright, 1966; Watts and Bright, 1968; Grueger, 1973; Van Zant, 1979; Wright and others, 1985; Markgraf and Lennon, 1986). In general, the data suggest that the central U.S. underwent a transition from a mixed spruce-deciduous parkland at about 9000 years B.P., to a prairie environment by around 7500 years B.P. From about 7500 to 5000 years BP, the grasslands/prairie expanded eastward at the expense of forests. This prairie expansion continued until approximately 5000 years B.P., when the relative frequencies of grass pollen decreased in the eastern portion of this region, and pollen assemblages characteristic of a prairie-forest mosaic are found (Fredlund and Jaumann, 1987).

C. Human Adaptations to the Altithermal

Little is known about human responses to the Altithermal because of a paucity of archeological evidence. The relative absence of cultural evidence may be a direct result of the particular geologic processes that operated throughout this region during the Altithermal (Mandel, 1987). Specific studies have provided evidence of episodic alluviation and erosion on floodplains which may have either removed or buried archeological evidence dating to the Altithermal (Knox, 1976; Mandel, 1987; Bettis, 1990).

Previous studies have shed some light on prehistoric human occupation of the central United States during the Altithermal. Archeological evidence has shown that Early to Middle Archaic people (Table III) of this region were bison hunters (Agogino and Frankforter, 1960; Frison, 1975; Bamforth, 1988a). This evidence has raised questions about the human response to the Altithermal climatic change.



Years B.P	Geologic Periods	Cultural Periods (after Frison 1978:83)
0	Late-Holocene	Late Prehistoric
1000		
2000		Late Plains Archaic
3000		Middle Plains Archaic
4000		
5000	Middle Holocene	Early Plains Archaic
6000		
7000		
8000	Early Holocene	Paleoindian
9000		
10,000	Late Pleistocene	
11,000		
12,000		

Table III. Relationship between cultural and geologic periods
(Schweger, 1987)

In one of the first papers to deal with people and Altithermal climate flux, Wedel (1961) argued that the Altithermal climate reduced the northcentral Plains to desert. According to Wedel, this environmental change resulted in the displacement of all native game animals, forcing the people to either abandon the region or become foragers, subsisting on anything that was edible. The paucity of available archeological data from the north central Plains for this time period supported this hypothesis of a "cultural hiatus".

The idea of a cultural hiatus has since been refuted by a number of authors who have argued that instead of abandoning this region, the Archaic people adapted to environmental changes. Hurt (1966) argued that although human and game populations may have been reduced during the Altithermal, it is doubtful that total abandonment of the region took place. Rather, he suggested that people were drawn to favorable places (refugia) in the central United States, or on the margins of this region, in which they could exist with an adapted lifestyle (Hurt, 1966).

Studies of Early to Middle Archaic archeological sites on the margins of the central United States have supported Hurt's argument for changes in settlement patterns within this region, rather than human abandonment during the Altithermal. For example, investigators have analyzed periods of occupation at Rodgers Shelter in central Missouri (Klippel, 1971; McMillan, 1976; McMillan and Klippel, 1981). Archeological evidence from this site indicates that the shelter was occupied during most of the Altithermal.

However, the absence of cultural materials from strata which correspond to the period 6300-3000 years B.P. suggests that humans did not inhabit this refuge during the latter part of the Altithermal (McMillan,1976).

The idea of larger populations of people in peripheral refugia has led to anthropologic research into the settlements of these areas. Population curves from various mountain and plateau encampments in Colorado which date to the Altithermal show episodic population growth and decline corresponding to Holocene climatic fluctuations (Benedict and Olson, 1978; Benedict, 1979). Similarly, settlement patterns for archeological sites above 9000 ft. on the eastern edge of the Rockies provide evidence of populations accumulating and dissipating at various times during the Altithermal, suggesting relationships with periodic climatic fluctuations (Morris, 1987).

Reeves (1973; 1983) argued that the paucity of archeological data in the central United States from this time period was a function of sampling, geologic variables, and failure of the researchers to recognize artifact types. He suggested that shortgrass prairie increased during the Altithermal, and hence could sustain a sizeable bison population for hunting. Investigations of bison procurement on the western edge of the prairie during and after the Altithermal have suggested population adjustments to changing bison distributions (Agenbroad, 1977; Markgraf and Lennon, 1986). Archeological data from the McKean Complex in Wyoming suggests an increase in concentration of human populations on this margin of the central U.S. during the Altithermal (Frison, 1975; Kornfeld and others, 1987)

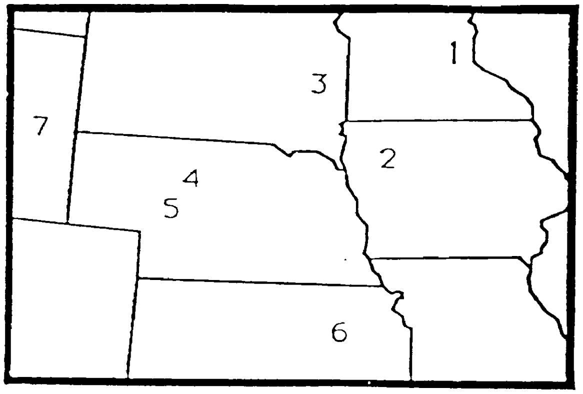
It must be cautioned that climatic changes inferred from human strategy decisions are only suggestive at best (Bamforth, 1988b). A broad spectrum of variables can be factored into decisions of prehistoric peoples, with physical environment variables representing only a fraction of that spectrum. However, the correlation of human adaptive decisions with vegetational changes will strengthen support for the inference of climatic change.

This chapter has provided an overview of the published reports concerning the central U.S. during the Altithermal. Noticeably lacking from the discussion is a body of evidence focusing on environmental and climatic changes at the end of this climate sequence. In the following chapters, published vegetational and archeological evidence dating to the end of the Altithermal will be presented. Analyses of these data will determine if any environmental information in the literature can be interpreted as suggesting climatic change. It is hoped that these analyses and interpretations can provide information about a much overlooked portion of the Altithermal.

V. Description of Sites Yielding Evidence

A. Vegetation Evidence

Pollen data are from seven sites in the study area (Figure 6). Sediment cores from these sites have yielded pollen assemblages which have been analyzed to determine the nature of the paleovegetation at each site. A brief discussion of each site follows.



1. Kirchner Marsh, Minnesota
2. Lake West Okoboji, Iowa
3. Pickerel Lake, South Dakota
4. Hackberry Lake, Nebraska
5. Swan Lake, Nebraska
6. Muscotah Marsh, Kansas
7. Antelope Playa, Wyoming

Figure 6. Sites yielding published pollen diagrams

1. Kirchner Marsh, Minnesota

This site is a marsh located in Dakota County, Minnesota, 17 miles southeast of Minneapolis. The marsh lies in the moraine of the Superior lobe of the Wisconsinan glaciation. The marsh, almost completely covered with vegetation, is surrounded by forest dominated by oak species, and grazed farmland. The pollen assemblage for this site was obtained from a 12.5 m-long core (Wright and others, 1963). Six radiocarbon ages determined on materials in the core range from 13,270 ± 200 to 1660 ± 90 years B.P.

Wright and others (1963) interpreted the sequences of vegetation change that have taken place at the site from the pollen assemblage obtained from the core (Figure 7). In general, the site was vegetated by a spruce forest around 12,050 years B.P. In postglacial times, the vegetative community changed to a mixed deciduous-coniferous forest at around 10,230 years B.P., and subsequently changed to a deciduous forest that persisted for about 3000 years. Prairie vegetation invaded and persisted between 7100-5100 years B.P., after which an oak forest was re-established.

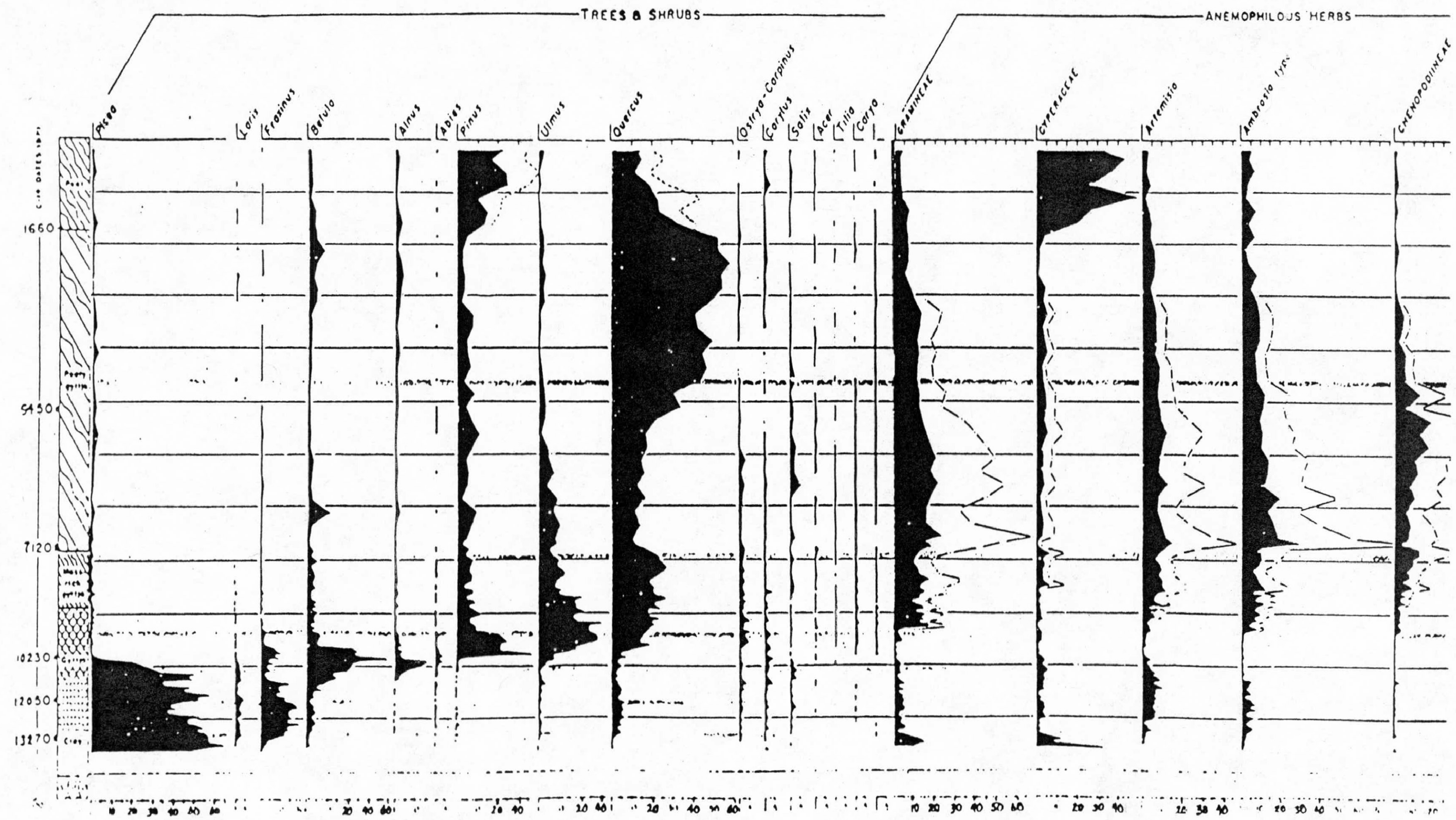


Figure 7. Pollen diagram from Kirchner Marsh, MN
(from Wright and others, 1963)

2. Lake West Okoboji, Iowa

This site is located in Dickinson County, in northwestern Iowa. The lake is situated within the moraines of the Des Moines lobe of the Wisconsinan glaciation. The lake is surrounded by deciduous trees, but farmland and prairie occur within a few hundred meters (Van Zant, 1979). The pollen assemblage for this site was obtained from an 11.68 m-long core taken at Little Millers Bay on the northwestern edge of the lake. Ten radiocarbon ages determined on materials in the core range from 13,990 ± 135 to 390 ± 55 years B.P.

Van Zant (1979) described the sequences of vegetation change that occurred at the site during late glacial and postglacial times (Figure 8). In general, the pollen analysis showed a shift from closed coniferous forest to a deciduous forest from 13,500 - 11,000 years B.P. The deciduous forest persisted until around 9000 years B.P. when nonarboreal species became prevalent, and prairie began to replace forest on the uplands. Prairie dominated until approximately 3200 years B.P. when deciduous trees, primarily oaks, returned.

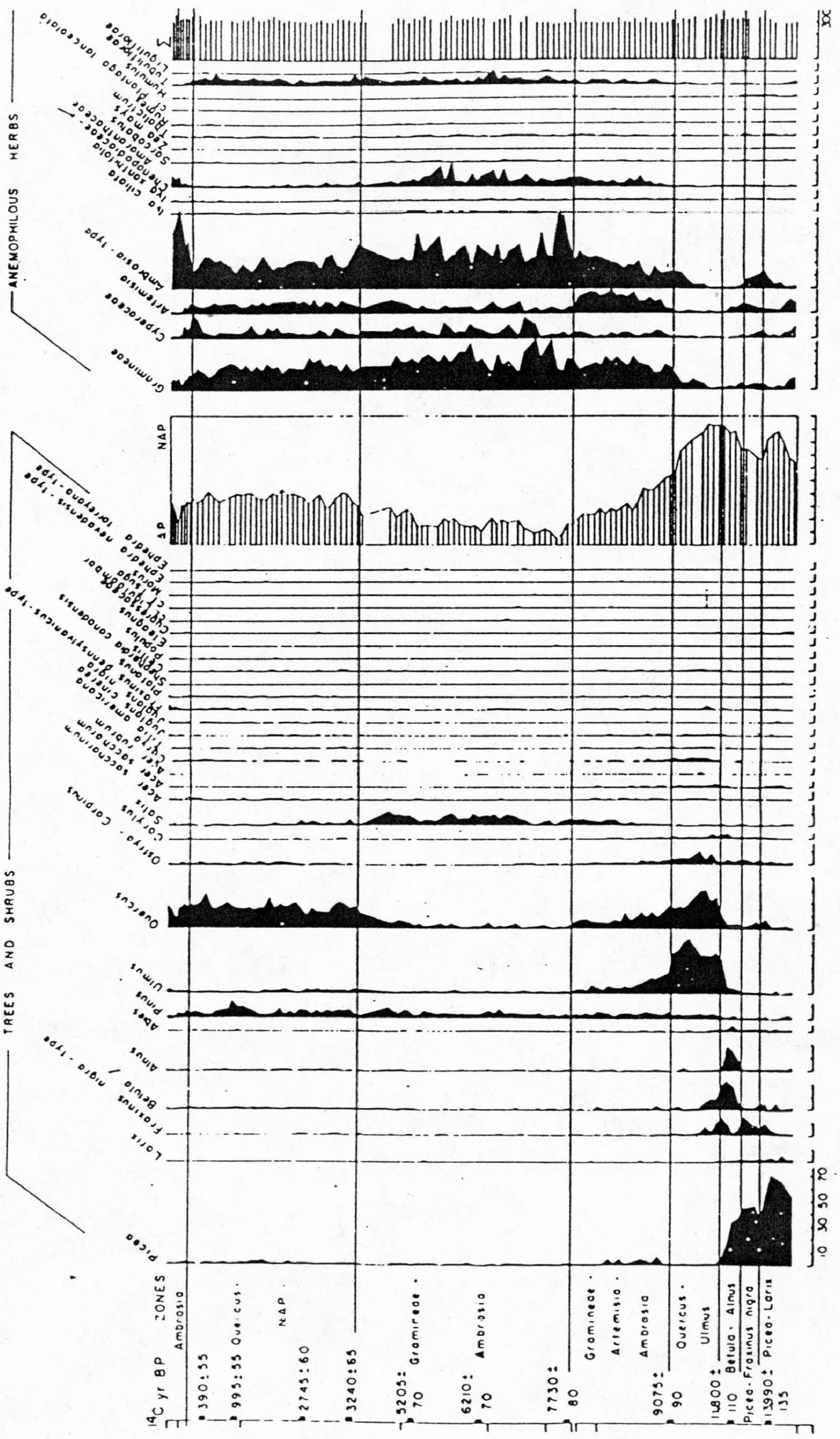


Figure 8. Pollen diagram fom West Lake Okoboji
(from Van Zant, 1979)

3. Pickerel Lake, South Dakota

This site is a lake located in Day County, northeastern South Dakota. It is formed in a glacially derived basin on the elevated Coteau des Prairies. Woodlands occupy steep slopes and gullies around the lake shore, and give way to prairie that occupies the rolling upland. The pollen assemblage for this site was obtained from a 9.8 m-long core, and a lone radiocarbon age of 10,670 ± 140 years B.P. was determined at the 9.5 meter depth (Watts and Bright, 1968)

Watts and Bright (1968) described the sequences of vegetation changes at the site from the pollen assemblage (Figure 9). In general, at 10,670 years B.P. the vegetation was dominated by a boreal forest that gave way to a mixed deciduous forest by 8000 years B.P. During this transition, the tree cover became less dense and openings of prairie began to appear. Between 8000 and 4000 years B.P. bluestem prairie dominated the upland and the deciduous forest disappeared, except for gallery stands along the lake or in gullies. Since about 4000 years B.P., the vegetation has stabilized with uplands dominated by prairie, and oak and ash stands found around the lake and in gullies.

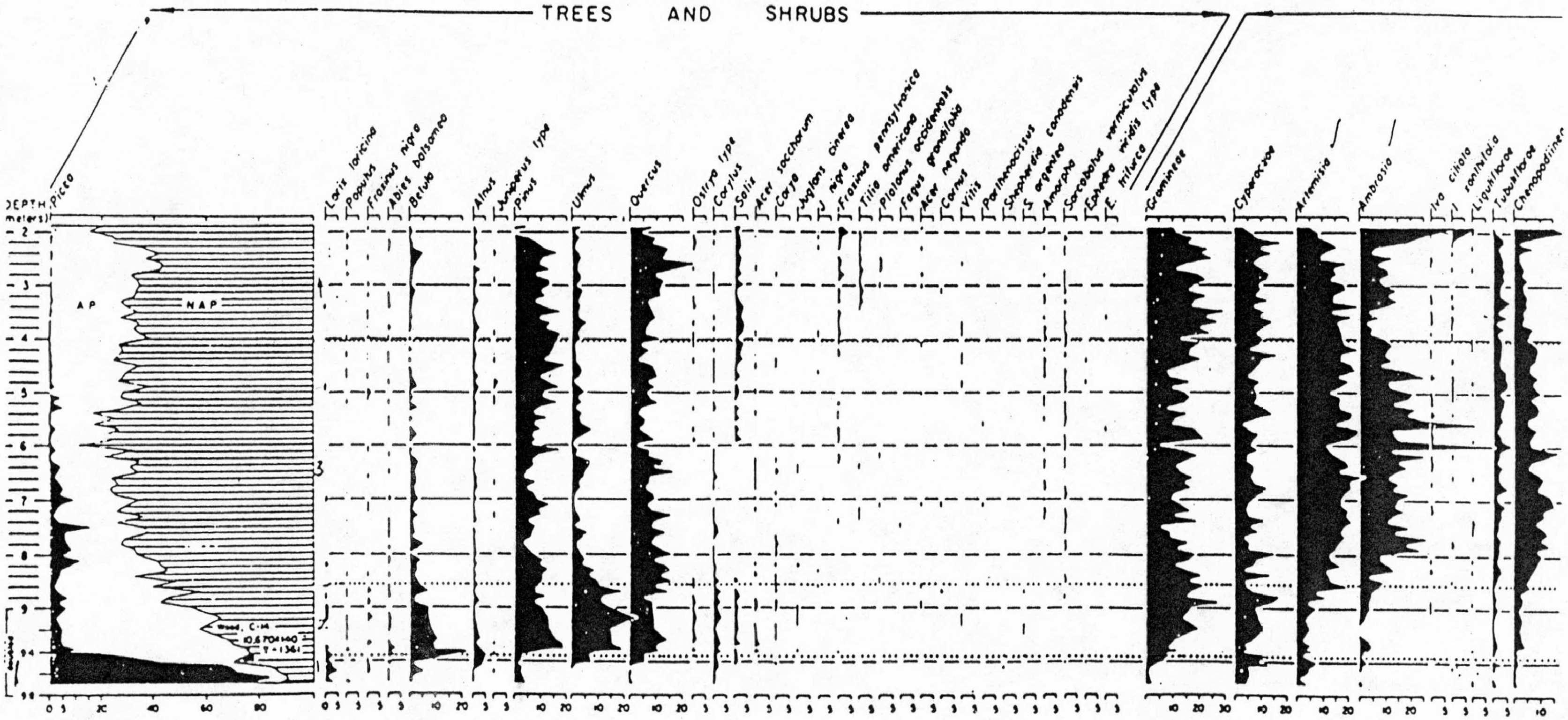


Figure 9. Pollen diagram from Pickerel Lake, South Dakota
(from Watts and Bright, 1968)

4. Hackberry Lake, Nebraska

This site is a Sand Hills lake located south of Valentine, Nebraska. It is an interdunal lake surrounded by the grasslands of the Nebraska Sandhills. A 4.8 m-long core was taken through the ice of the lake (Sears, 1961) and two radiocarbon ages of 5040 ± 95 and 1110 ± 75 years B.P. were determined.

Sears (1961) described the sequences of vegetation change that occurred at the site from the pollen assemblage (Figure 10). While a majority of grass pollen was found throughout most of the core, a maximum of forest pollen was found at the base. More than half of this forest pollen was pine, leading Sears to speculate that the site environment may have been cooler and wetter during the formation of the lake ca. 5000 years B.P.

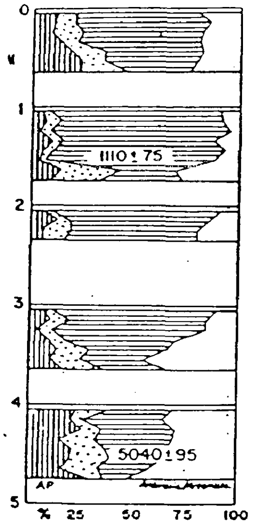


Figure 10. Pollen diagram from Hackberry Lake, NE (from Sears, 1961)

5. Swan Lake, Nebraska

This site is a lake located in the southwestern Sand Hills of Nebraska and occupies a swale between two dunes more than 30 m high (Wright and others, 1984). A 13 m-long core was taken through the ice and two radiocarbon ages date to 8950 ± 160 to 3680 ± 70 years B.P.

Wright and others (1984) interpreted the vegetation changes that have taken place at the site, from the pollen assemblage obtained from the core. The pollen diagram (Figure 11) is dominated by herbs , indicating vegetation cover throughout the time period resembling that of today. Tree pollen, in general, is only about 15-25% of the total pollen, and is "presumedly" derived from ponderosa pines (Wright and others,1984). They suggested that environmental variations over time are best evidenced by changes in the percentages of varying types of herbaceous pollen.

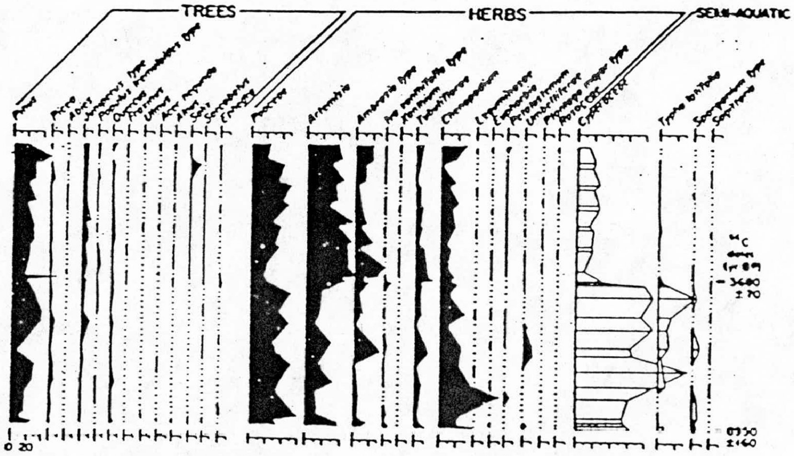


Figure 11. Pollen diagram from Swan Lake, NE (from Wright and others, 1984)

6. Muscotah Marsh, Kansas

The site is a marsh located near Muscotah Village in northeast Kansas. The marsh has developed on the eastern edge of the floodplain of the Delaware River, a tributary of the Kansas River. Grueger (1973) obtained a 9.24 m-long core from the marsh and four radiocarbon ages determined on materials within the core range from 23,040 ± 600 to 5100 ± 250 years B.P.

Grueger (1973) described the sequence of vegetation changes that have occurred at the site from the pollen assemblage (Figure 12). The pollen analysis indicates a spruce forest at ca. 23,000 years B.P., which persisted until around 15,000 years B.P. The vegetation changed from a mixed deciduous forest to a prairie between 11,000 and 9000 years B.P. Prairie vegetation then dominated until about 5000 years B.P., when re-expansion of trees began in the lowlands.

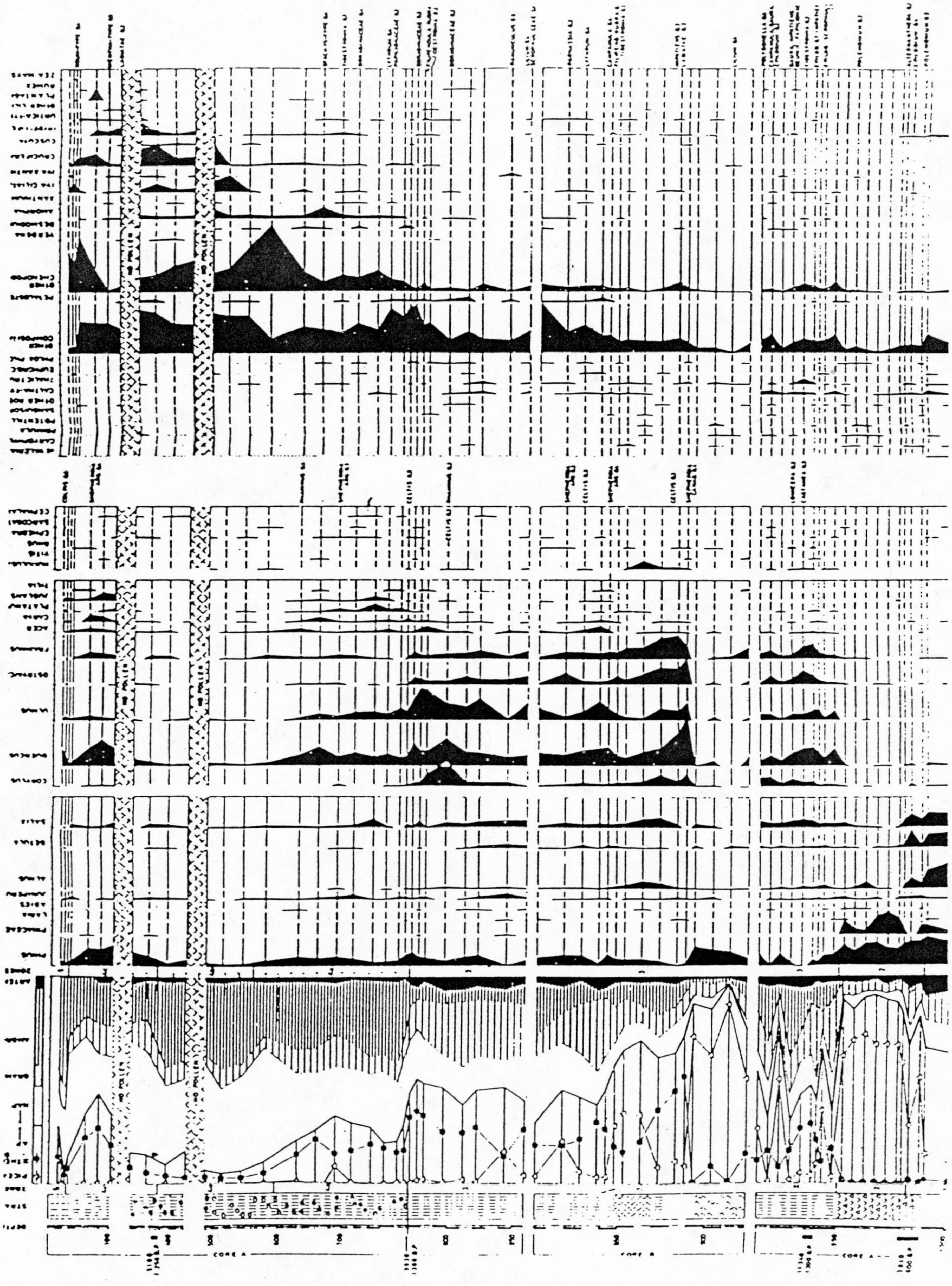


Figure 12. Pollen diagram from Muscotah Marsh, KS (from Grueger, 1973)

7. Antelope Playa, Wyoming

This site is a small, now dry playa located in eastern Wyoming near the town of Teckla. The pollen assemblage for this site was obtained from a 2 m-long core taken from the playa and three radiocarbon ages ranging from 13,020 ± 500 to 5130 ± 110 years B.P. were obtained.

Markgraf and Lennon (1986) interpreted the sequences of vegetational changes that have occurred at the site from the pollen assemblage (Figure 13). They reported no major floristic changes throughout the 13,000 years. Minor trends in percentages of different types of nonarboreal pollen show a decrease in more mesic flora, with an increase in xeric flora between 13,000 and 5000 years B.P. Since 5000 years B.P. the vegtetation has remained much as it is today.

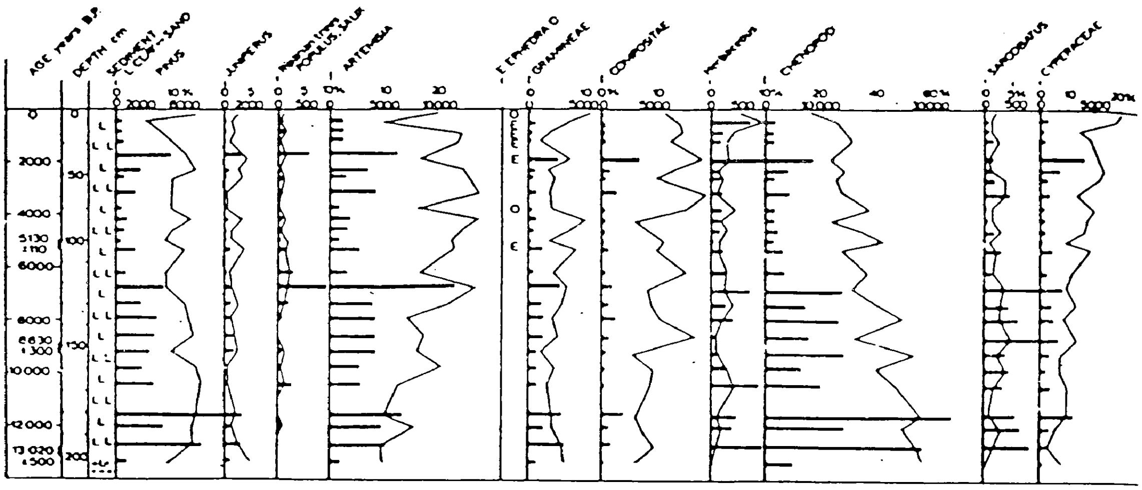
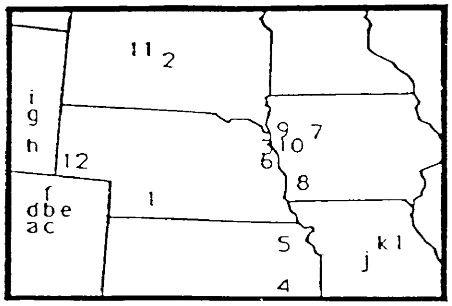


Figure 13. Pollen diagram from Antelope Playa, WY (from Markgraf and Lennon, 1986)

B. Archeological Evidence

Human settlement data come from the twenty-four archeological sites shown in Figure 14. The sites were selected as representative of Archaic human occupations within the geographic bounds of the study area. These sites were divided into two categories: (1) margin/refugia sites located on the periphery of the study area; and (2) Plains/prairie sites occurring within the grasslands section of the study area. This delineation enables the comparison of site occupations in environments offering protection from extremely warm, dry conditions (margin/refugia) with those on the more open, less protected grasslands. A brief description of each site follows.



<u>Margin/Refugia Sites</u>

a. Helmer Ranch site, CO
b. Albion Boardinghouse site, CO
c. Fourth of July Valley site, CO
d. Hungry Whistler site, CO
e. Ptarmigan site, CO
f. Lightning Hill site, CO
g. Hawken site, WY
h. Hell Gap site, WY
i. Powder River Canyon site, WY
j. Rodgers Shelter, MO
k. Graham Cave, MO
l. Arnold Research Cave, MO

<u>Plains/prairie sites</u>

1. Spring Creek site, NE
2. Walth Bay site, SD
3. Walker-Gilmore site, NE
4. William Young site, KS
5. Coffey site, KS
6. Logan Creek, NE
7. Cherokee Sewer site, IA
8. Turin site, IA
9. Hill site, IA
10. Lungren site, IA
11. Sitting Crow, SD
12. Signal Butte, NE

Figure 14. Sites yielding archeological evidence

Margin/refugia

a. Helmer Ranch site, Colorado

This site is located in the foothills of the Front Range of the Rockies in northeastern Colorado. Excavations at the site have yielded a cultural assemblage resembling that found at higher altitude, Front Range sites. Artifact analyses have led researchers to suggest a genetic cultural association between occupants of this site and of other sites in the Front Range during the Altithermal (Benedict, 1979). A radiocarbon age determined on charcoal places occupation of the site at 5780 ± 160 years B.P.

b. Albion Boardinghouse site, Colorado

This site is located near the present timberline of Green Lakes valley in northeastern Colorado. It is situated in the Front Range of the Rockies at an elevation of 3260 m. Excavations at the site have yielded cultural materials suggesting tool manufacturing at the site. Benedict (1979) reported a radiocarbon age determined on charcoal which places occupation at 5730 ± 145 years B.P.

c. Fourth of July Valley site, Colorado

This site is in Boulder County, north-central Colorado. It is located in the Forest-tundra ecotone, at an elevation of 3415 m, on a terminal moraine of Satanta Peak age. Benedict (1979;1981) has reported radiocarbon ages determined on charcoal which place site occupations at 5880 ± 120 and 6045 ± 120 years B.P. Analyses of tools suggest that activity at the site was associated with communal hunting, butchering, and tool repair.

d. Hungry Whistler site, Colorado

This site is located on Mount Albion, in the Front Range of the Rockies, northeastern Colorado. It is situated on a slope above the timberline, at an elevation of 3500 m. This is a high-altitude, low-temperature environment, with seasonal occupations during the late summer to early fall. Benedict and Olson (1978) reported radiocarbon ages determined on charcoal which place site occupations in a range from 5800 ± 125 to 5300 ± 130 years B.P. Artifact assemblages suggest the activity at the site was primarily tool repair/resharpening and final butchering of game.

e. Ptarmigan site, Colorado

This site is located on the North Fork of Middle Boulder Creek in northeastern Colorado. It is situated on a bedrock bench 15 m above the stream, at an elevation of 3460 m (Benedict, 1981). Excavations revealed a multicomponent Archaic campsite with a number of cultural strata. Two radiocarbon ages on charcoal place site occupations at 6450 ± 110 and 4690 ± 55 years B.P.

f. Lightning Hill site, Colorado

This site is located in the Front Range of the Rockies, in northeastern Colorado at an elevation of 2770 m. Excavations at the site have yielded cultural materials suggestive of hunting and gathering activities. Additionally, nearby quarries are presumed to have provided materials for tool manufacturing (Morris, 1987). A radiocarbon age determined on charcoal places site occupation at 5390 ± 165 years B.P.

g. Hawken site, Wyoming

This site is located on the Hawken ranch, seven miles south of Sundance, Wyoming. The site is an arroyo bison trap, where communal hunting and butchering of bison took place on a seasonal basis, most probably early- to mid-winter. Frison (1976) has reported radiocarbon ages on charcoal which place site occupations in a range from 6470 ± 140 to 6010 ± 170 years B.P.

h. Hell Gap site, Wyoming

This site is located in a small wooded valley at the base of a granite cliff on the North Platte River, in southeastern Wyoming. Excavations revealed a sequence of cultural remains from Paleo-Indian through Archaic components and suggest continuous occupation of the camp over long periods of time (Irwin-Williams et al., 1973). A radiocarbon age on charcoal associated with an Archaic period hearth is 5830 ± 230 years B.P.

i. Powder River Canyon site, Colorado

This site is located in north-central Wyoming, in the Powder River Basin. It is situated on a short, ephemeral tributary of the Powder River. The site is an arroyo bison trap, operated for the communal hunting and butchering of bison with a strong reliance on fall and winter communal bison procurement (Frison, 1978). Radiocarbon ages on charcoal are associated with site occupations at 7800 ± 110 and 3980 ± 70 years B.P.

j. Rodgers Shelter, Missouri

This site is located in a rock shelter within the Pomme de Terre River Valley of west-central Missouri (McMillan, 1976; Parmalee and others, 1976; McMillan and Klippel, 1981). Excavations revealed a multicomponent site composed of five discrete cultural horizons (McMillan, 1976) with radiocarbon ages on charcoal ranging from 10,500 to 5100 years B.P.

k. Graham Cave, Missouri

This site is a large rock shelter 100 km west of St. Louis on the east valley wall of the Loutre River. Klippel (1971) has placed the earliest occupation of the cave at ca. 9500 years B.P. Radiocarbon ages on charcoal from cultural deposits place Archaic occupations at 7360 ± 125 and 6800 ± 120 years B.P. An analysis of stone tools suggests that activity at this site was primarily associated with the hunting of mammals.

l. Arnold Research Cave, Missouri

This site is located in east-central Missouri at the eastern margin of the prairie-forest ecotone. It is considered to have been a base camp of recurrent occupation over long periods of time (Klippel, 1971; Benedict and Olson, 1978). A radiocarbon age on charcoal places the earliest occupation of the site at 9130 years B.P. Additional radiocarbon ages on charcoal associated with Archaic occupations range from 6720 ± 300 to 6180 ± 300 years B.P. Analysis of tools suggests that activities at the site were associated with a hunter-gatherer economy (Klippel, 1971).

Plains/prairie

1. Spring Creek site, Nebraska

This site is located on a T-2 terrace on the north side of Red Willow Creek in southwest Nebraska (Grange, 1980). Excavations have revealed it to be a multicomponent site. Artifact analysis yielded evidence of occupations ranging from Archaic to Historic American. A radiocarbon age on charcoal places the earliest occupation of the site at 5860 ± 160 years.

2. Walth Bay site, South Dakota

This site is located on the eastern shore of Oahe Reservoir in Walworth County, South Dakota. It is situated on a 22-m high terrace above the preinundation level of the Missouri River (Ahler, 1974). Excavations have revealed a number of subsurface cultural horizons yielding mammalian bone fragments and stone artifacts indicative of Late Paleo-Indian and Archaic occupations. A radiocarbon age on charcoal is associated with Archaic occupation at 7010 ± 210 years B.P.

3. Walker-Gilmore site, Nebraska

This site is located in Sterns Creek Valley, a tributary of the Missouri River in northeastern Nebraska

(Champe, 1946). The site is located on alluvial fill floodplain of the creek. A radiocarbon age on charcoal places site occupation at 6090 ± 500 years B.P.

4. William Young site, Kansas

This site is located on Munkers Creek of the Neosha River in southeastern Kansas. Excavations have revealed several cultural horizons extending to a depth of 2.2 m (Witty, 1962). Artifacts from the surface have been assigned to Late Archaic and Early Plains Woodland cultures. Two radiocarbon ages on charcoal from Archaic cultural horizons are 5340 ± 160 and 3100 ± 400 years B.P.

5. Coffey site, Kansas

This site is located on the east bank of the Big Blue River in northeast Kansas. The site is a complex of campsites situated at a bend in the river. Excavations revealed two series of stratified, Late Archaic cultural horizons (Schmits ,1980). Radiocarbon ages on charcoal place site occupations in a range from 6285 ± 145 to 2320 ± 60 years B.P.

6. Logan Creek site, Nebraska

This site is located on an alluvial fan adjacent to Logan Creek in northeast Nebraska. Excavations yielded evidence of five distinct cultural zones containing hearths and numerous post molds (Kivett ,1962). He suggested continuous site occupation during winter and summer over a long period of time. Radiocarbon ages on charcoal place site occupations in a range from 7250 ± 300 to 6633 ± 300 years B.P.

7. Cherokee Sewer site, Iowa

This site is located 3.2 km south of the town of Cherokee in northwest Iowa. Archeological excavations in the mid-1970's revealed three major mid-Holocene cultural horizons representing a cultural shift from Late Paleo-Indian to Prairie Archaic tradition. Anderson and others (1980) reported radiocarbon ages on carbonized wood and charcoal which place site occupations in a range from 10,030 ± 460 to 4615 ± 230 years B.P.

8. Turin site, Iowa

This site is located in the town of Turin in west-central Iowa. Four human skeletons and numerous artifacts have been recovered from the site (Frankforter and Agogino, 1959). A radiocarbon age determined on human bone suggests occupation of the site at 4720 ± 250 years B.P.

9. Hill site, Iowa

This site is located along Pony Creek, north of the town of Glenwood in southwest Iowa. It is a single component campsite with the main accumulation of cultural material 5.7 m below the surface of a terrace. Excavations at the site have revealed two burned areas and a fire pit containing cultural materials (Anderson and others, 1980). One radiocarbon age determined on charcoal places site occupation at 7250 ± 400 years B.P.

10. Lungren site, Iowa

This site is located along Pony Creek, approximately 6.5 km north of the town of Glenwood in southwest Iowa. Excavations of the cultural horizon revealed tools resembling those from cultural horizon I at the Cherokee site. Reeves (1973) has reported a radiocarbon age on charcoal which places site occupation at 6280 ± 120 years B.P.

11. Sitting Crow site, South Dakota

This site is located in central South Dakota, on the bluffs of the Missouri River. Excavations have yielded cultural materials suggesting an association with the McKean cultural complex of Wyoming (Neuman, 1967). Buchner (1979) reported a radiocarbon age on charred bone which places an Archaic occupation at 4475 ± 150 years B.P.

12. Signal Butte, Nebraska

This site is located in southwestern Nebraska. Analyses of artifacts suggest an association with the McKean/Oxbow cultural complex. Reeves (1973) reported radiocarbon ages on charcoal placing site occupations in a range from 4544 ± 220 to 3394 ± 150 years B.P.

VI. Limitations of Data Used in Paleoclimate Analysis

A. General

As noted earlier, the data analyzed in this thesis were obtained through deterministic sampling of published reports that focus on the middle Holocene. This requirement was met by utilizing only those reports containing data that had been placed into an absolute radiocarbon chronology. These radiocarbon ages appear in Tables IV and V.

All of the statistical analyses presented in the following chapter utilize paleobotanical and archeological data generated by other researchers. Hence, there may be problems with the data sets which result from inherent limitations in the techniques of pollen analysis and radiocarbon dating. These problems may affect the interpretations presented in this study. The following discussion identifies limitations in the data utilized in this thesis.

B. Pollen Analyses, Diagrams, and Problems

Pollen data have been a major source of climatic information for the period spanning the last 15,000 years (Webb, 1980). Pollen grains are the sperm-producing cells of vegetation which participate in sexual reproduction, and are dispersed by animals, insects, and wind. Pollen analysis, or palynology, is the study of fossil pollen, utilized to determine the record of past vegetation in an area (Bradley, 1985). These analyses depend upon the steady accumulation of aeolian particles on undisturbed surfaces, such as lakes and bogs. The sediments at such sites contain a variety of materials, including the microscopic pollen grains. Pollen that have either been blown or washed into the lakes and bogs are preserved in the accumulating sediment by virtue of durable, resistant cell walls (Moore and Webb, 1978). Pollen have also been recovered from alluvium, archeological sites, and wood rat middens, but lake sediments are the preferred sample of palynologists (Bradley, 1985).

Core sampling of the lake sediment yields a profile of stratified deposits which are subsampled and processed in a laboratory. Treatment of the subsamples with a variety of acids and bases dissolves away unwanted sediments, leaving a pollen-rich residue. Microscopic examination of the pollen allows the identification of genus, and sometimes species, based upon the morphology of the grains. For each sample, the number of grains of each pollen type are tallied, and then expressed as percent of total pollen. Complete and detailed discussions of the laboratory procedures can be found in Faegri and Iversen (1964) and Moore and Webb (1978).

The pollen data obtained from a sediment core are presented in a diagram displaying the spectra of pollen types from each level sampled (Moore and Webb, 1978; Bradley, 1985). Pollen diagrams are presented to depict regional vegetation changes, thus a wide variety of arboreal and non-arboreal pollen types are included in these diagrams (see Figures 6-12). Two assumptions underly the analysis of a pollen diagram: (1) the pollen spectrum at a particular level represents the pollen-producing vegetation which contributed to the pollen rain (Moore and Webb, 1978); and (2) the changes in the percentage of one species on the diagram reflect similar changes in the vegetation composition of the surrounding locale of a site (Bradley, 1985). Both of these assumptions have certain limitations from which problems of interpretation may arise.

A major limitation on the use of pollen analyses for paleoclimatic reconstructions arises from the nature of pollen production and dispersal. The amount of pollen produced by a plant species generally is inversely proportional to the probability of success in fertilization (Bradley, 1985). Plants which utilize insects (entomophilous plants) or other animals (zoophilous plants) have a more successful fertilization rate, hence produce less pollen, than plants whose dispersal agent is the wind (anemophilous plants). The impact of this relationship on pollen analysis is that the representative pollen data for a site are biased toward anemophilous species.

The analysis of pollen data is further complicated by the fact that wind-borne pollen grains have evolved structural modifications which aid their transport over long distances (Moore and Webb, 1978). Various studies have investigated the dispersal and deposition of pollen transported by the wind (e.g. Wright, 1953; Tauber, 1965). These studies reported a general decrease in pollen deposition as one moves away from the source. This relationship, however, oversimplifies the complexity of pollen dispersal when varying atmospheric conditions are taken into account (Faegri and Iversen, 1964). Thus, a major obstacle confronted when analyzing a pollen diagram, is that of understanding where the pollen has originated (Moore and Webb, 1978).

Since pollen diagrams are constructed largely from analyses of sediment cores, the possibility of fluctations in sedimentation rates presents a major variable in palynology. Differential settling of pollen occurs in the water, with preferential deposition taking place based upon the weight of the pollen grain. This gravitational sorting may result in the distortion of the original ratios of incoming pollen (Bradley, 1985). Sedimentation problems can also occur when changes in the concentrations of pollen take place at the site of entrapment. Certain pollen types may be concentrated in lake basins by inflowing streams, especially during periods of heavy run-off from the surrounding areas (Bradley, 1985). This may result in the distortion of the assemblage representing the surrounding vegetation. Additionally, resuspension and redeposition of pollen grains during periods of turbulent mixing, especially in shallow basins, may occur. This secondary deposition may result in either considerable confusion in interpreting the pollen diagram (Moore and Webb, 1978), or in masking the variations in pollen input, thus hindering paleoclimatic assessments (Bradley, 1985).

Other sources of error can hinder climatic interpretations of pollen diagrams. These sources range from sampling errors during the acquisition of the core, to counting errors made in the laboratory (Faegri and Iversen, 1964). Interpretation errors can be made when comparing pollen percentages of a single taxon between different sites. Maher (1963) reported that the variable factors present at differing sites of collection may render comparisons based upon percent of total pollen practically useless. The percentage value of a taxon depends not only on its absolute representation, but also on the amounts of other taxa in the sample. Therefore, percentage values for a particular taxon from different sites may vary even when the absolute abundance is constant, or may be represented equally when the absolute abundance actually differs (Maher, 1963). Maher also reported that comparisons between a taxon from different lake basins may be complicated by differences in topography, distances to the nearest forest, soil conditions, shoreline, and border herb zones.

Despite the limitations in pollen analyses, interpretation of the fossil pollen record remains a common practice for reconstructing past climates (e.g. Barnosky and others, 1987; Hall, 1990; Chumbley and others, 1990). Studies that have employed mathematical transformations of the pollen data to reconstruct specific climatic variables have provided further insight into the relationship between climate and vegetation changes (See Literature Review p. 19). Furthermore, the incorporation of palynological data into analyses using other independent data sets (i.e., archeological, paleontological, geomorphological) provides a means for maintaining a better control on complex paleoclimate reconstructions (Bradley, 1985).

C. Radiocarbon Dating and the Reliability of Radiocarbon Ages

Radiocarbon dating has proved to be one of the most useful techniques for studies of late Quaternary climatic fluctuations. The time-frame of useful radiocarbon dates spans the last 40,000 years, a period of major, global environmental changes, for which this technique provides dating control (Bradley, 1985). The technique may be used to date organic samples containing as little as 0.002 g of carbon. The principle of radiocarbon dating relies on the assumption that living tissues incorporate $^{14}CO_2$ in the same ratio as the inventory in the atmosphere (Ralph and others, 1973). This assumption has led to investigations of variations of atmospheric ^{14}C, which in turn have raised questions about the reliability of radiocarbon dates.

The basis of the dating technique is that during growth, plants and animals assimilate a small amount of atmospheric ^{14}C into their tissues through photosynthesis and respiration. At the time of death, the object ceases to exchange carbon with the atmosphere. The ^{14}C content of the organic sample decreases as the ^{14}C radioactively decays through β-particle emission to form nitrogen. The rate of ^{14}C β-particle decay is a function of time calculated in half-lives. A half-life is the time that it takes for half of a sample to radioactively decay, and for ^{14}C it has been calculated to be either 5730, 5568 or 5570 years (Ralph and others, 1973; Aitken, 1974). Hence, the technique involves measuring the amount of radioactivity due to ^{14}C that remains in an organic specimen. The age since the time of death of the specimen is then calculated based upon the half-life of ^{14}C, and the known constant ratio of ^{14}C in the atmosphere and living tissue.

A radiocarbon age for a specimen is merely a statement of probability, and it represents the mean value of disintegration occurrences measured during a specified amount of time. The mean date of a specimen is reported along with one standard deviation, to define a known level of probability of the specimen's age (Bradley, 1985). This method of reporting indicates a 68% probability that the accurate radiocarbon age of the specimen lies within the range of one standard deviation about the mean. The reports from which the data for this thesis were obtained have presented the radiocarbon ages in this manner. Therefore, interpretations will contain inherent limitations with respect to accuracy. Other sources of error in radiocarbon dating also must be considered.

Contamination of a specimen by more recent sources of carbon (modern carbon) may cause errors in calculating the radiocarbon age. Modern carbon contamination may take place by various means which have been described by Bradley (1985). For example, modern rootlets may penetrate into the sample zone of a specimen, and must be meticulously removed before dating the specimen. Specimens composed primarily of calcium carbonate continue to participate in reactions with water over time, permitting the exchange of modern carbon. Bone specimens pose a similar problem as a result of their composition, and react with modern carbon. One approach to bone is to isolate and date the carbon found in the protein collagen. The collagen in a sample slowly disappears with time, however, and the extraction methods currrently employed may be an additional source of contamination, giving rise to erroneous dates (Bradley, 1985).

As mentioned above, the fundamental principle of this dating technique is the assumption of atmospheric constancy of the ^{14}C ratio during the period of time for useful radiocarbon dates. It has recently become evident that this assumption is not strictly valid (Ralph and others, 1973; Blakeslee, 1983; Bradley, 1985). However, studies have assessed the causes and magnitude of atmospheric ^{14}C variations (e.g. Damon and others, 1978; Suess, 1980). An important finding was the discovery that many of the factors found to cause atmospheric ^{14}C fluctuations may themselves influence climatic change (Blakeslee, 1983). It has been shown that : (1) variations in solar activity affect inputs of ^{14}C into the atmosphere; (2) fluxes in rates of exchange of CO_2 with the atmosphere are influenced by temperature changes; and (3) volcanism and combustion of fossil fuels increase the amount of $^{12}CO_2$ in the atmosphere. Each of these factors are capable of affecting the ^{14}C inventory as well as climate (Bradley, 1985).

The problem of ^{14}C variation has not been insurmountable. Ongoing research efforts attempt to recalibrate radiocarbon ages to true dates. These recalibrations correct radiocarbon ages to calendar ages obtained from dendrochronologies, the most reliable of which has been the bristlecone pine chronology (Ralph and others, 1973). Published calibration curves and tables allow researchers to adjust the measured radiocarbon age of a specimen to a true age (e.g., Ralph and others, 1973; Suess, 1980; Klein and others, 1982; Linick and others, 1986; Pearson and others, 1986). The acceptance of either an adjusted date or an uncorrected date for a specimen may have great impact on a paleoclimatic study, especially if one or the other date confirms a preconceived notion (Bradley, 1985). For this reason, the reader is cautioned that the radiocarbon ages presented in this thesis may deviate from calibrated dates.

In summary, the limitations inherent to the data used in this thesis may weaken the climatic interpretations. However, taking these limitations into consideration, it is hoped that the reader will be able to judge the following interpretations for what they are: climatic inferences synthesized from a sampling of previously published data.

VII. Data Analysis

A. Methods of Investigation

1. Vegetation

Vegetation data are derived from the pollen assemblages for each site (Figure 5). Radiocarbon ages provided absolute dates between which trends in the pollen diagrams could be analyzed (Table IV).

Selected pollen types for this analysis were: arboreal pollen (AP), and the herbaceous pollen from the genera *Artemisia*, *Ambrosia*, and *Chenopodiineae*. AP includes pollen from the genera *Pinus*, *Picea*, *Juniperus*, *Populus*, *Quercus*, *Fraxinus*, *Betula*, *Ulmus*, *Acer*, *Alnus*, and *Salix*.

Analyses of individual herbaceous pollen diagrams provide indication of fluctuations in the environment too small in magnitude to be detected by trends in the AP (Webb, 1980; Fredlund, pers. comm.). *Artemisia* are the sagebrush-type plants. Though found on arid soils, they can survive in a variety of environments ranging from tundras to prairies. Many species are halophytic; thus they have the ability to thrive in relatively salty soils. *Ambrosia*-type pollen come from ragweed and related plants that grow in, but are not limited to grasslands. These plants grow in areas of soil disturbance, and are able to survive in a wide range of environments. Some of these plants can withstand periods of low moisture by virtue of extensive root systems.

Chenopodiineae (Chenopodiaceae) are salt marsh plants found growing as weeds in salt-rich soils and opportunistically in disturbed areas. Some species are halophytic and are often associated with arid conditions. These plants exhibit xerophytic adaptations which allow them to exist during periods of drought (Humphries, 1985).

The selected pollen diagrams were placed into a common chronology for direct comparison of any pollen trends (Figure 15). Inspection of overall trends in the pollen diagrams from each site, and not absolute values at specific time intervals, was done to minimize errors from possible unconformities or changing sedimentation rates. Finally, these diagrams are included on the correspondence chart (Figure 19) for direct comparison with the archeological data.

Table IV. Radiocarbon ages used in the analysis

Site	Dates Used (RCYBP*)	Reference
Swan Lake, NE	3680 ± 70 8950 ± 160	Wright and others, 1984
Pickerel Lake, SD	10,670 ± 140	Watts and Bright,1968
Kirchner Marsh, MN	1660 ± 90 7120 ± 110	Wright and others, 1963
Hackberry Lake, NE	1110 ± 75 5040 ± 95	Sears, 1961
Muscotah Marsh, KS	5100 ± 250 9930 ± 300	Grueger, 1973
Lake West Okoboji, IA	3240 ± 65 7730 ± 80	Van Zant, 1979
Antelope Playa, WY	5130 ± 110 8830 ± 300	Markgraf and Lennon,1986

* = Radiocarbon years before present

2. Human Settlement

The twenty-four archeological sites (Figure 14) were divided into two categories: (1) refugia sites located on the margin of the study area; and (2) Plains/prairie sites occurring throughout the Plains/grassland section of the study area. Each site has been briefly described in chapter V. This delineation allows assessment of population movements off the unprotected Plains and into margin/refugia in response to Altithermal conditions (Benedict, 1979). Some archeologists have offered the alternative possibility that Plains dwellers may have merely relocated to refugia sites within the Plains region (Wedel, 1986), as some Archaic sites are located along streams where gallery growth may have afforded protection. This analysis of site occupation presupposes movement off the Plains.

Radiocarbon ages associated with periods of occupation at the sites were plotted (Figure 16) and used to construct maps of the areal distribution of site occupations at 500-year intervals from 7750-4000 years B.P. (Figure 17). Histograms of site occupation for the two categories were made (Figure 18) to allow the analysis of trends in human site occupation throughout the Archaic cultural period (8000-2000 years B.P., see Table III, p. 21). These histograms also were placed on the correspondence chart (Figure 19) for direct comparison with the pollen data.

Table V. Radiocarbon ages for archeological data

Margin/refugia

Site	**Ages (RCYBP)**	**Material**	**Reference**
Helmer Ranch site, CO	5780 ± 160	Charcoal	Benedict and Olson,1978
Albion Boardinghouse,CO	5730 ± 145	Charcoal	Benedict and Olson, 1978;Benedict, 1979
4th of July Valley site,CO	5880 ± 120	Charcoal	Benedict and Olson, 1978;Benedict, 1981
	6045 ± 120		
Hungry Whistler site, CO	5300 ± 130	Charcoal	Benedict and Olson, 1978; Benedict, 1981
	5520 ± 190		
	5730 ± 130		
	5800 ± 125		
Ptarmigan site, CO	6450 ± 110	Charcoal	Benedict and Olson, 1978; Benedict,1981
	4690 ± 55		
Lightning Hill site,CO	5390 ± 165	Charcoal	Benedict and Olson, 1978; Benedict, 1979
Hawken site,WY	6010 ± 170	Charcoal	Frison, 1975
	6270 ± 170		Benedict and Olson, 1978
	6470 ± 140		
Hell Gap site, WY	5830 ± 230	Charcoal	Benedict and Olson, 1978;Benedict, 1979
Powder River Canyon, WY	3980 ± 70	Charcoal	Buchner, 1979; Morris, 1987
	7800 ± 110		
Rodgers Shelter, MO	6300 ± 590	Charred wood	McMillan, 1976; McMillan and Klippel, 1981
	7490 ± 170		
	7010 ± 160		
	5200 ± 200	Charcoal	
	5100 ± 400		
Graham Cave, MO	6800 ± 120	Charcoal	Klippel, 1971
	7360 ± 125		Benedict and Olson, 1978
Arnold Research Cave, MO	6180 ± 300	Charcoal	Klippel, 1971
	6280 ± 350		Benedict and Olson, 1978
	6500 ± 300		
	6720 ± 300		

Plains/prairie

Site	Date (RCYBP)	Material	Reference
Signal Butte,NE	4544 ± 220	Charcoal	Reeves, 1973 Buchner, 1979
Spring Creek site, NE	5860 ± 160	Charcoal	Grange, 1980 Benedict and Olson, 1978
Walth Bay site, SD	7010 ± 210	Charcoal	Benedict and Olson, 1978; Benedict, 1979
Sitting Crow,SD	4475 ± 150	Charred bone	Reeves, 1973 Neuman, 1967
Walker-Gilmore site, NE	6090 ± 500	Charcoal	Benedict and Olson,1978;Benedict,1979
Logan Creek,NE	6633 ± 300	Charcoal	Kivett, 1962 Benedict and Olson, 1978
	6900 ± 280		
	7250 ± 300		
William Young site, KS	3100 ± 400	Charcoal	Benedict and Olson,1978;Benedict,1979
	5340 ± 160		
Coffey site,KS	2320 ± 60	Charcoal	Benedict and Olson,1978;Schmits,1980
	2480 ± 55		
	5125 ± 70		
	5240 ± 70		
	5285 ± 70		
	5355 ± 70		
	5505 ± 105		
	5850 ± 135		
	6285 ± 145		
Cherokee Sewer site, IA	4615 ± 230	Charcoal	Anderson and others,1980; Semken and Falk, 1987
	5950 ± 80		
	6300 ± 90		
	6500 ± 200		
	6800 ± 190		
	7145 ± 75		
	7340 ± 75		
	7600 ± 80		
	7770 ± 80		
	8000 ± 270		
	8570 ± 200		

Turin site,IA	4720 ± 250	Bone	Buchner, 1979 Anderson and others, 1980
Hill site,IA	7250 ± 400	Charcoal	Benedict and Olson,1978; Anderson and others, 1980
Lungren site,IA	6280 ± 120	Charcoal	Benedict and Olson,1978; Anderson and others, 1980

B. Results

1. Vegetation

Pollen assemblages at each site can be visually compared by reading horizontally across the chart of pollen diagrams (Figure 15). A reference percent of total pollen is plotted on the horizontal axis at the bottom of each diagram. The scale for these reference percentages is site-dependent, and is included to display relative differences between the same pollen types from different sites.

Noticeable shifts in the percentages of AP may represent dramatic environmental changes. Trees have the ability cope with high frequency, low magnitude climatic variations (Bryson, 1974). Therefore, trends in AP may suggest responses to high magnitude climatic shifts. Trends of decreasing AP percentages seen at each site suggest periods of drier climate with possibly warmer temperatures (Figure 15). In contrast, trends of increasing AP percentages suggest periods with greater availability of moisture. The periods of increased moisture may have resulted from climatic episodes characterized by: (1) increased precipitation; (2) cooler temperatures resulting in less evapotranspiration; or (3) a combination of cooler temperatures and increased precipitation. Very general trends of increases in AP percentages containing periods of fluctuations can be seen in the diagrams from Kirchner

Marsh, Pickerel Lake, Muscotah Marsh, and Antelope Playa between 6000 and 4000 years B.P. (Figure 15). AP percentages at Lake West Okoboji, Swan and Hackberry Lakes remain at a constant level during this time. The AP data from Kirchner Marsh, Pickerel Lake, Muscotah Marsh, Swan Lake and Antelope Playa suggest a general trend toward increasingly available moisture (Figure 15).

The trends in herbaceous pollen at the sites suggest fluctuations in the climate during this general trend of increasing available moisture. Dramatic and sudden increases in the percentages of herbaceous pollen can be seen in the diagrams from Lake West Okoboji, Pickerel Lake, Hackberry Lake and Swan Lake between 6000-4000 years B.P. These patterns may suggest periods of years (decades to centuries) of sudden shifts away from the general moistening trend (Figure 15). High frequency, low magnitude climatic shifts, such as years of deficient rainfall, are a characteristic of the climate in the central U.S. (Trewartha, 1941), and these drought episodes can result in noticeable changes in herbaceous communities (Thornthwaite, 1948). Therefore, a climatic explanation for these dramatic rises in herbaceous pollen percentages would be the presence of periods of drought.

There exists the possibility that other explanations could account for these increases in herb pollen. Though these and other herb taxa do respond to climate changes, the individual responses of any one taxon are unpredictable. These herb taxa are considered to be weeds which may survive in a wide variety of environments (Humphries, 1985; Baker, pers. comm.). Changes in the diagram of one herb at a site are not always corroborated by similar changes in another herb at that same site (Figure 15). Abrupt rises in percentages of any one herb pollen could be attributed to something as climatically irrelevant as a localized shift in the wind or disturbance of the soil surface (Bradley, 1985; Baker, pers. comm.). Common causes of fluctuations in percentages of herb pollen are changing sedimentation rates at a site. Changes in rates of runoff in a basin, and resuspension and resedimentation caused by turbulence, especially in shallow parts of a basin where most cores are obtained, will distort the actual pollen representation (Bradley, 1985). The pollen diagram obtained from the analysis of such sediments may show fluctuations which more closely reflect the nature of the sedimentation process than the surrounding vegetation and climate. Therefore, even though these plants are more sensitive to subtle changes in climate than arboreal species, the ubiquitous nature of these grasses and the problems arising from the transport and deposition of their pollen, limit the climatic inferences based on their percentages. In this study,

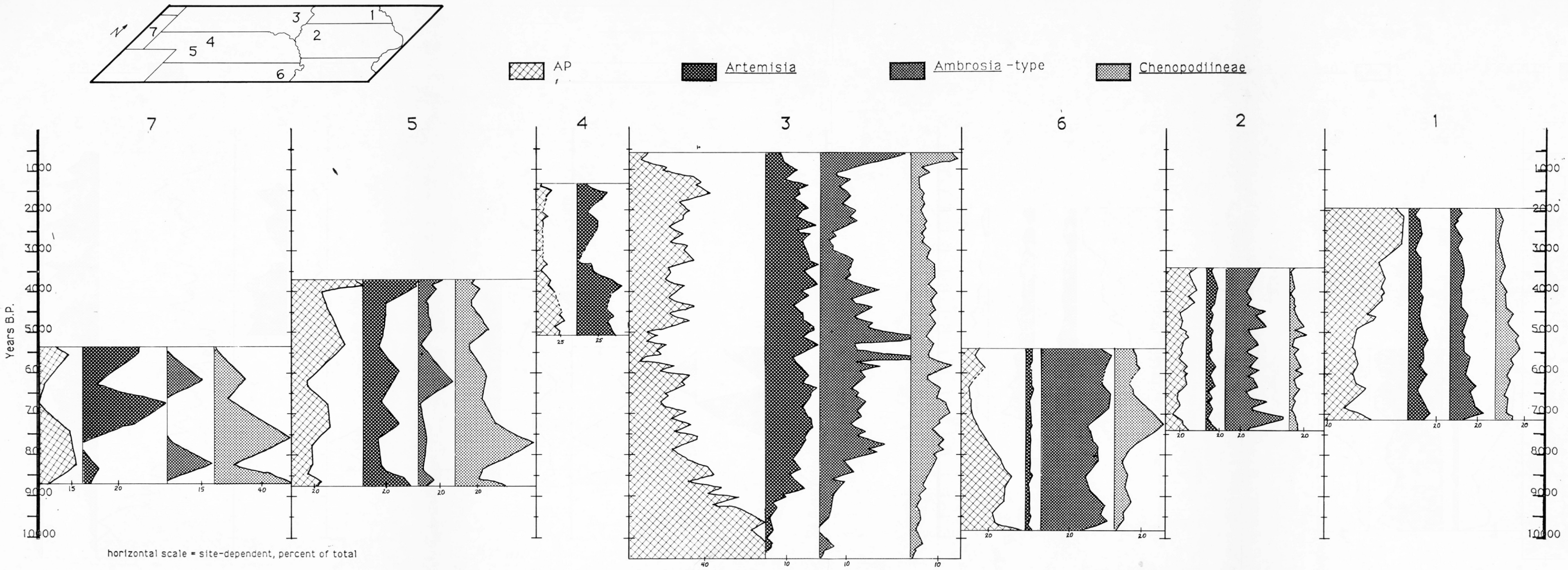


Figure 15. Comparison of the pollen diagrams from each site. Each diagram is truncated by the radiocarbon ages in Table IV.

trends in the herbaceous pollen are interpreted in conjunction with trends in the other data sets. Studies which base inferences of climate change solely upon responses of these and other herbaceous taxa should be read with caution.

2. Human Settlement

Graphic comparison between occupancy dates of margin/refugia and Plains/prairie sites is shown in Figure 16. From this graph, qualitative differences in the patterns of occupancy between the categories can be detected. The majority of margin/refugia site occupations fall between 7000-5000 years B.P. On the other hand, Plains/prairie settlements exhibit a more diffuse occupancy pattern, spanning a larger portion of the Archaic period.

The spatial distribution of site occupations at 500-year intervals between 7750-4000 years B.P. is shown in Figure 17. Margin/refugia occupation increases until a peak occupation at 5750 years B.P., then declines and ends at 4000 years B.P. Plains/prairie occupations generally increase until a peak in occupation at 6250 years B.P., then decrease until a second peak at 4750 years B.P. These occupation differences possibly resulted from population movements out of the margin/refugia and onto the Plains/prairie region in response to major climatic changes.

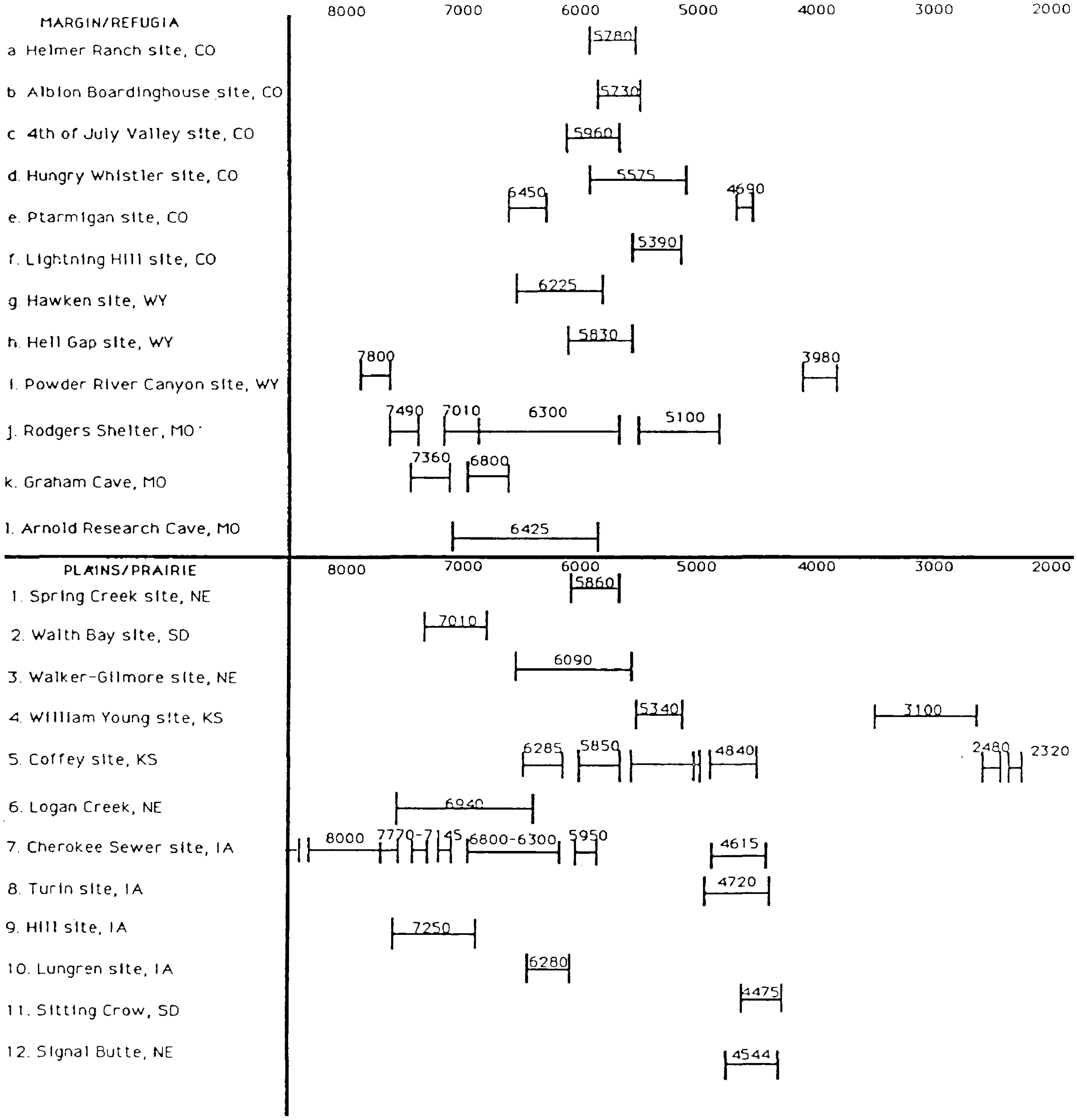


Figure 16. Graph of site occupation in the study area. Each radiocarbon age is plotted with its 1 standard deviation error bar.

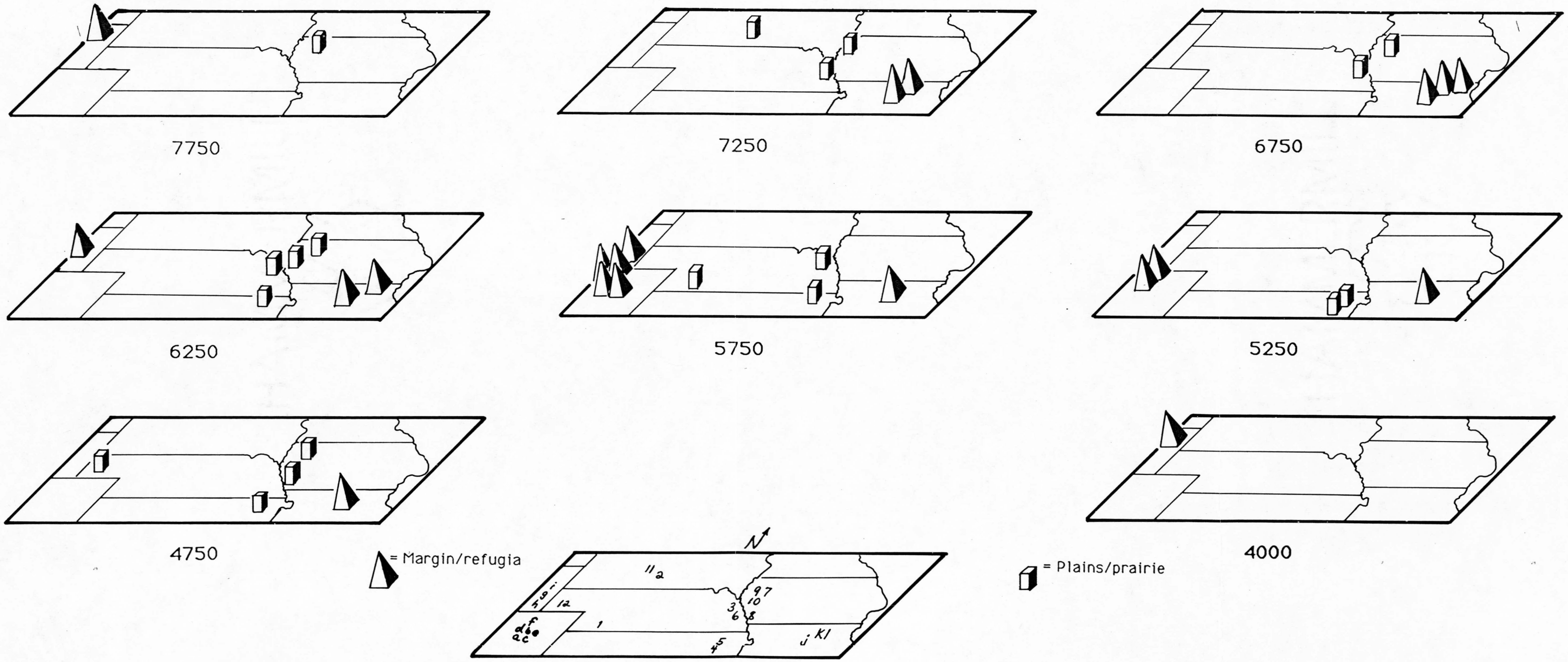


Figure 17. Surfaces of site occupations from 7750-4000 B.P.

Histograms representing the numbers of sites occupied in each category at 500-year intervals, are presented in Figure 18. Plotted to the side of each histogram is the weighted mean occupation date and one standard deviation for each category. Qualitative differences can be determined by visual inspection of the histogram patterns. Mathematical difference in site occupation is evidenced by the 274-year difference between the weighted mean occupation dates (Table VI). Statistical evidence for the difference between site occupations of each category is exhibited by their coefficients of variation (C.V.). A lower C.V. for margin/refugia sites indicates a clustering of the data around the weighted mean. The larger C.V. for Plains/prairie sites is representative of the greater spread and variability of site occupations throughout the Archaic period (Table VI). Trends in site occupation from the surface diagrams (Figure 17) and patterns of occupation on the histograms both show agreement with population movement patterns plotted by Benedict and Olson (1978).

Table VI. Statistical differences in patterns of site occupation

	Margin/refugia		**Plains/prairie**
Weighted mean (yrs. B.P.)	6013		5739
Difference		274 years	
Std. Dev.	1196		1906
C.V.	0.199		0.332

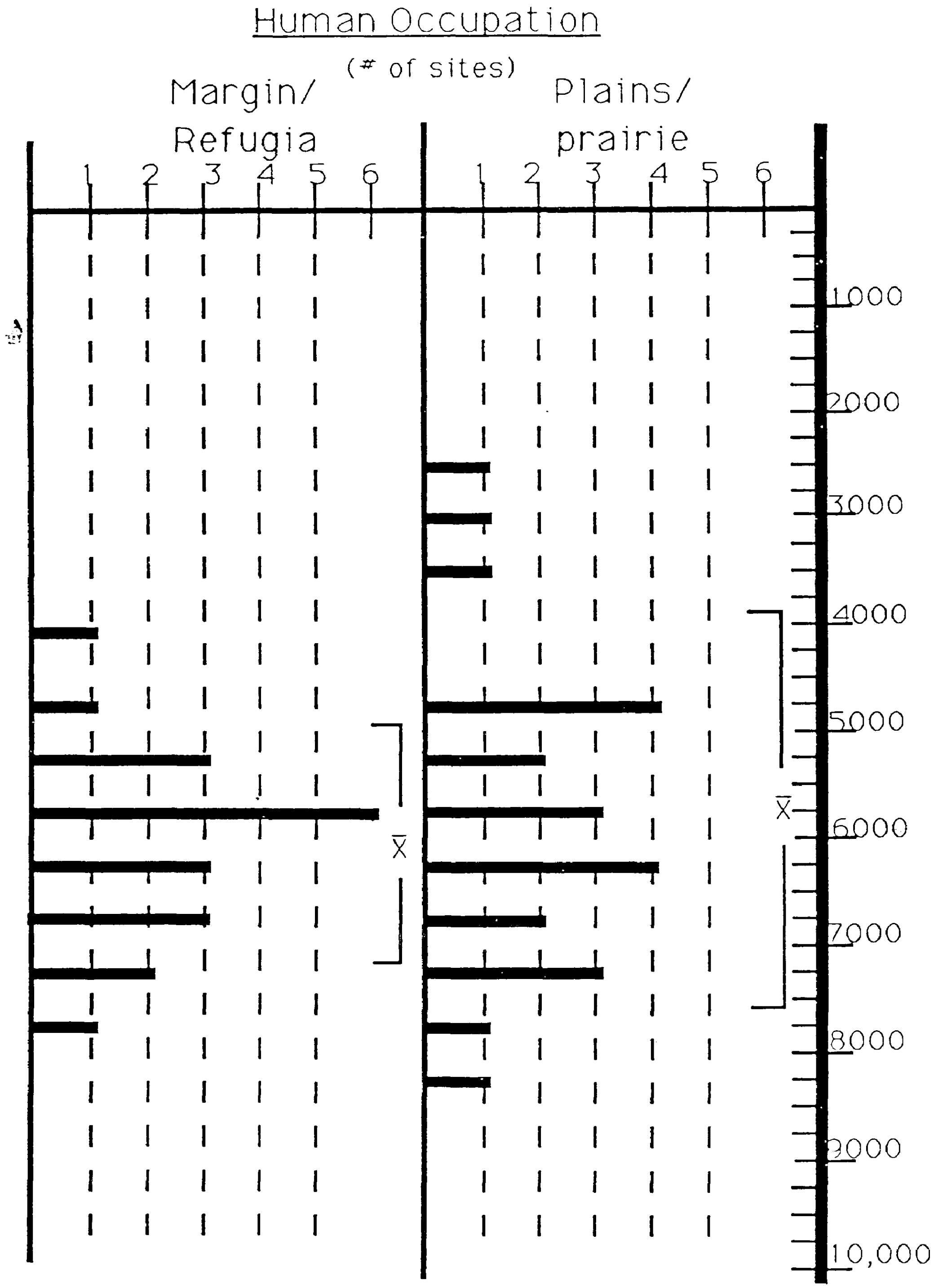


Figure 18. Histograms of site occupation

C. Interpretation of Correspondence

1. Correspondence Chart

A correspondence chart has been prepared to enable direct comparison between the trends in the palynological and archeological data (Figure 19). This chart places the information from each line of evidence into a common chronology. Qualitative inspection of trends in both the vegetation and human settlement of the region may be done by reading horizontally across the chart. It is the correspondence of trends in the data which is sought to allow inferences about the climatic conditions (Table VII).

2. Discussion

The data plotted on the correspondence chart provide evidence of trends in the environment of the central U.S. during the Holocene. Though a broad spectrum of explanations could be offered for the causes of these trends, nonclimatic explanations will be left to other studies. For the purposes of this reconstruction, trends in each line of evidence are interpreted as reflecting environmental responses to changing climate. Coincident trends in these vegetation and archeological data on the correspondence chart may be indicative of climatic fluctuations in the region. For this discussion, a favorable climate is considered to be one with mesic conditions of available moisture and moderate temperatures. An unfavorable climate is considered to have the inhospitable regime of a xeric environment characterized by low available moisture and extremes in temperature range.

The following interpretations are presented with the knowledge that a time lag between actual climate change and changes in environmental data could exist. It is possible that certain vegetation populations, such as a tree community, could take hundreds of years to adjust to climate flux (Bryson, 1974). Likewise, humans may exhibit a variety of responses to environmental changes; technological adaptations may allow people to endure changes in an environment for an unmeasured amount of time before relocating due to inclement conditions (Bamforth, 1988b). However, it is also entirely possible that a climatically insignificant spell of harsh weather may force human relocation. Since no hard and fast measurements of lag times between climate change and shifts in these data have been offered in the literature, no calibrations will be applied to the timing of climate change inferred from these data. The calculation and application of lag times between environmental and climatic changes will be left to future studies.

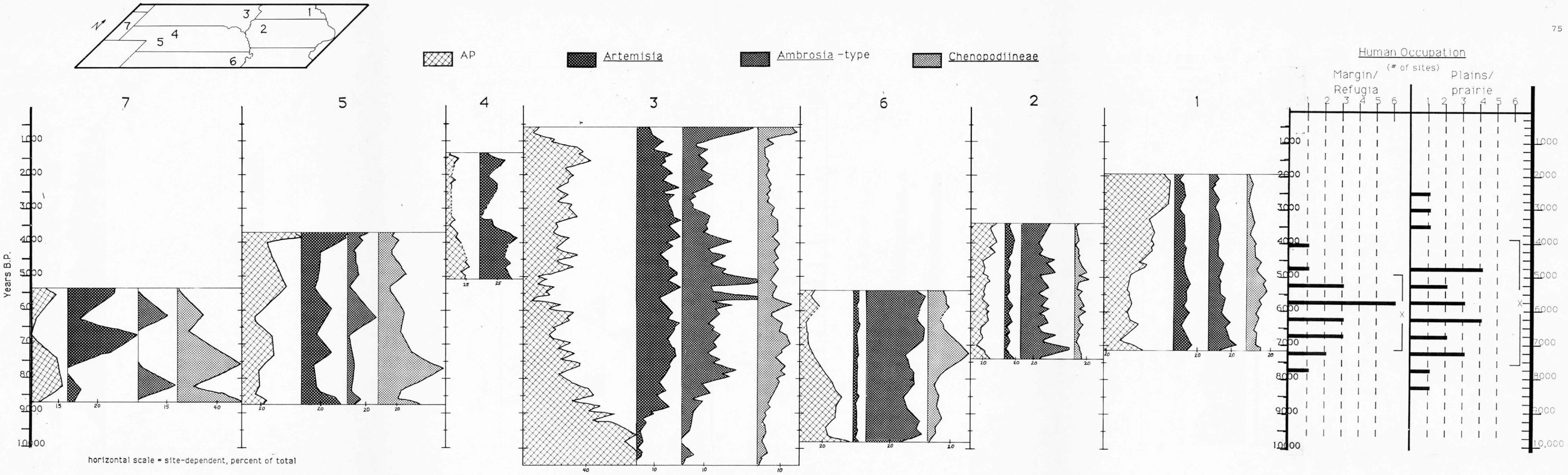


Figure 19. Correspondence chart of the data

Between 7750-6750 years B.P., AP percentages decrease at Muscotah Marsh and Antelope Playa, decrease followed by fluctuation and increase at Kirchner Marsh and Lake West Okoboji, and decrease with fluctuation at Pickerel Lake. Hackberry Lake is not represented in this time period (Figure 19). Synchronously, general but at times significant increases in herbaceous pollen percentages (e.g. Ambrosia-type) can be seen at these same sites. The human occupation data for this period show a steady increase in margin/refugia sites along with an increase and decrease in Plains/prairie sites. Excepting the Plains/prairie data, these trends suggest a warming and drying of the environment. Increases in margin/refugia sites may have resulted from movement of some Plains Archaic people off the unprotected prairies. Increasing Plains occupations during the Early Archaic may have been a result of an immigration of Woodland Archaic people from growing populations to the east (Stephenson, 1965; Reeves, 1973).

From 6750-5750 years B.P., AP curves show both increases and decreases at all sites except Antelope Playa. Likewise, the curves of herbaceous pollen rise and fall erratically at all of these sites (Figure 19). These fluctuations may be attributed to climatic causes, though other factors must be considered (see Chapter VI). Margin/refugia site occupations remain constant, then peak during this millenium, while Plains/prairie sites fluctuate with increases and decreases in number. These patterns suggest major variations in the climate pattern over the central U.S. This millenium may have experienced unfavorable climatic swings, with droughty periods juxtaposed to decades of more mesic environments.

The period 5750-4750 years B.P. contains evidence of having the most unfavorable climate conditions of the study period, followed by increasingly favorable climate. Trends in AP at the start of the millenium show decreasing or low percentages at Kirchner Marsh, Muscotah Marsh and Pickerel Lake, and AP percentages decrease then fluctuate at Lake West Okoboji. Herbaceous pollen begin the millenium with general increases and peaks in percentages in at least one herb diagram at each site except for Swan Lake. After about 500 years, however, AP percentages shift toward an increase at Kirchner Marsh, increase and fluctuate at Lake West Okoboji and Pickerel Lake, and fluctuate with an increase at Hackberry Lake. The herbaceous pollen at these sites exhibit general, and at times drastic, increases and decreases (Figure 19). Human site occupation data show margin/refugia occupations peaking at the start of this millenium suggesting high populations taking refuge from harsh conditions elsewhere in the region. The trend in these site occupations shifts toward dramatic decreases by the end of the millenium. Plains/prairie occupations decrease until 5250 years B.P., then peak at 4750 years B.P. (Figure 19). All of these trends suggest a highly unfavorable climate in the central U.S. from 5750-5250 years B.P. Between 5250-4750 years B.P., the archeological evidence, with support from the pollen data from Kirchner Marsh, Lake West Okoboji and Pickerel Lake, suggest an overall amelioration of the unfavorable conditions. It is presumed that during these 500 years, the region experienced the onset of mesic climatic conditions.

By the period 4750-3750 years B.P., the climate in the region may have stabilized into patterns of weather much like those of the modern climate (see Chapter III). The pollen data suggest that vegetation patterns in the region became established commensurate with an east to west decrease in precipitation. AP percentages fluctuate then increase at Kirchner Marsh, increase with fluctuations at Lake West Okoboji, fluctuate at Pickerel and Swan lakes, and decrease at Hackberry Lake (Figure 19). Herbaceous pollen fluctuate around persistent levels at the majority of sites, without exhibiting the drastic peaks and troughs of earlier millenia. Documented margin/refugia site occupations drop to zero during this time period, excepting a lone site occupation at 4000 years B.P. Plains/prairie site occupations have peak numbers during the the first half of the millenium, suggesting climatic conditions on the grasslands which afforded a favorable environment for human existence.

The correspondence in this evidence suggests that by 5250-4750 years B.P., Altithermal climatic conditions in the central U.S. had ended. The paucity of documented archeological sites from 4500-3500 years B.P. may be the result of erosion or burial since this time period (see Chapter IV, section C).

VIII. Conclusion

The Altithermal climatic episode began in North America ca. 8000 years B.P. This prolonged warm, dry sequence of climate permitted the spread of prairie environments across the central U.S. Varying periods of time have been suggested for the duration of Altithermal conditions in the mid-continent. A south-to-north time transgression for the demise of the Altithermal can be found in the literature, with an earlier reported time for its cessation in the southern Plains of the U.S. than in the central Plains of Canada. Some authors whose works have been concerned with the northern Plains and Canada have speculated that the Altithermal persisted until some time more recent than 4000 years B.P. (e.g., Antevs, 1955; Wright, 1968; Reeves, 1973; Buchner, 1979). However, authors working in other parts of the mid-continent have placed the demise of the Altithermal at an earlier date, corresponding with the onset of a neoglaciation about 6000-5000 years B.P. (e.g. Denton and Karlen, 1973; Benedict, 1979; Knox, 1983).

Results of the present study suggest that the Altithermal ended in the central U.S. about 5250-4750 years B.P. This inference was arrived at by analyzing the trends in the published paleobotanical and the archeological records, and is summarized in Table VII.

Table VII. Summary chart of data and climate for the period 6250-4250 years B.P.

Sequence of years B.P.	Pollen trends		Site Occupation		Climate Inference
	AP	Herbs	Margin	Plains	
4250 4750	increase and fluctuate east decrease west	fluctuating and decrease east increase west	decrease to none reported	decrease to none reported	stabilized moisture gradient
4750 5250	general increase then increase east decrease west & Kansas	fluctuation and majority decrease	decrease	increase and peak	demise of Altithermal and stabilization of climate
5250 5750	majority decrease followed by general increase	fluctuating with peaks and decreases	peak then decrease	decrease	fluctuating climate with hot and dry periods
5750 6250	decrease & flux in east, increase in west and Kansas	flux and increase east decrease west	increase	decrease	warming & drying of east

Some authors may have interpreted warm periods more recent than 5000 years B.P. as vestiges of the Altithermal, thereby extending the timespan of its existence (e.g., Reeves, 1973; Buchner, 1979). However, in the central U.S., these more recent warming trends may represent the typical fluctuations which characterize the climate of this region. Further research yielding evidence allowing better resolution of the period 8000-4000 years B.P. may redefine the Altithermal. In light of a better understanding of the variability of climates, the notion of a 3000-year period of one dominant climate regime in a region may seem unlikely. A corollary description for a mid-Holocene Climatic Optimum may entail a 3000-year period of climate fluctuations - certainly containing decades to centuries of xeric conditions - but not depicting a three millenia period of a uniform climate pattern. This description would corroborate Bryson's (1983) caution that within the broad definition of a climatic episode, it would be likely that various climatic fluctuations would take place.

This thesis has attempted to resolve the climatic situation in the central U.S at the end of the Altithermal. This has been done by comparing two lines of published environmental data. There were times in the analyses when trends in the data provided strong evidence for climate changes. At other times, however, the data resembled mere noise, even to the point that trends in different data sets were contradictory. Based on some of the trends in the evidence presented, it appears that the Altithermal desisted in this region between 5250 and 4750 years B.P.

The knowledge of paleoclimatology gained from this study is that any number of interpretations could be assigned to these trends in the published evidence. Presented here is but one climatic inference from the environmental data. Other researchers could have interpreted the data as reflecting a variety of non-climatic causes, and more significantly, the data trends may be viewed by some as nothing more than environmental noise. Certainly, much more evidence needs to be uncovered and published about the environment of the central U.S. during the mid-Holocene, as the existing data lead to tenuous conclusions about the climate of that period. This thesis will have contributed to the body of knowledge about the end of the Altithermal if, in the least, it arouses readers to attempt better paleoclimate assessments than have been offered here for the demise of this climatic episode.

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