CRHR Research Reports

Volume 1 Article 6

2015

Cultural Implications of Late Quaternary Environmental Change in Northeastern Texas

Michael B. Collins
Department of Anthropology, Texas State University, mc82@txstate.edu

C. Britt Bousman
Anthropology, Texas State University & GAES, University of the Witwatersrand, bousman@txstate.edu

Follow this and additional works at: http://scholarworks.sfasu.edu/crhr_research_reports

Part of the Archaeological Anthropology Commons, Environmental Studies Commons, History Commons, Other Social and Behavioral Sciences Commons, Remote Sensing Commons, Science and Technology Studies Commons, Social Statistics Commons, and the Spatial Science Commons

Tell us how this article helped you.

Recommended Citation
Collins, Michael B. and Bousman, C. Britt (2015) "Cultural Implications of Late Quaternary Environmental Change in Northeastern Texas," *CRHR Research Reports*: Vol. 1, Article 6.
Available at: http://scholarworks.sfasu.edu/crhr_research_reports/vol1/iss1/6

This Dr. James E. Corbin Papers in Archaeology is brought to you for free and open access by SFA ScholarWorks. It has been accepted for inclusion in CRHR Research Reports by an authorized administrator of SFA ScholarWorks. For more information, please contact cdsscholarworks@sfasu.edu.

CULTURAL IMPLICATIONS OF LATE QUATERNARY ENVIRONMENTAL CHANGE IN NORTHEASTERN TEXAS

Michael B. Collins[1] and C. Britt Bousman[1, 2]

[1]Department of Anthropology, Texas State University

[2]School of Geography, Archaeology and Environmental Sciences, University of Witwatersrand

NOVEMBER 2015

Originally drafted 15 March 1990

TABLE OF CONTENTS

1990 ACKNOWLEDGMENTS
PREFACE FOR THE 2015 PUBLICATION

I. INTRODUCTION

II. PERSPECTIVES

III. BACKGROUND

IV. MODERN CLIMATE

V. MODERN VEGETATION COMMUNITIES

VI. DEPOSITIONAL SYSTEMS AND FEATURES

VII. SOILS

VIII. TECTONICS AND SEISMICITY

IX. APPLICATIONS OF GEOCHRONOLOGICAL TECHNIQUES

X. USE OF REMOTE SENSING

XI. BOTANIC PALEOENVIRONMENTAL EVIDENCE

XII. STABLE ISOTOPES

XIII. COMPUTER SIMULATIONS OF PAST CLIMATES

XIV. FORMATIONAL PROCESSES OF THE ARCHAEOLOGICAL RECORD OF NORTHEASTERN TEXAS: IMPLICATIONS, QUESTIONS, AND PROBLEMS TO BE CONSIDERED IN FUTURE INVESTIGATIONS

XV. ENVIRONMENTAL CHANGE AND HUMAN ECOLOGY IN NORTHEASTERN TEXAS

XVI. REFERENCES CITED

FIGURE NO. CAPTION

1 Location of the Northeastern Texas area (after Brown, et al. 1982).

2 Major geologic units in the southcentral United States showing subparallel bands of progressively older.
rocks from the present coastline inward (after Thornbury 1976).

3 Topographic belts and escarpments in the western Gulf Coast Plain (after Fenneman 1938 and Thornbury 1976).

4 Northwest to southeast topographic section through Eastern Texas; note inland-facing cuestas and coastward facing fault escarpments; bedrock control of these topographic features is shown schematically
(after Fenneman 1938).

5 Major surface geologic units of Northeastern Texas (after Fisher 1965).

6 Average annual temperature of Texas (from Larkin and Bomar 1983: 50).

7 Monthly average high temperatures (degrees F) for weather stations in East Texas (data from Bomar 1983: 215-216).

8 Monthly average low temperatures (degrees F) for weather stations in East Texas (data from Bomar 1983: 212-213).

9 Average annual precipitation of Texas (from Larkin and Bomar 1983: 18).

10 Monthly average rainfall for weather stations in East Texas (data from Bomar 1983: 221-222).

11 Climatic regions of Texas (from Larkin and Bomar 1983: 3).

12 Contour map of net above-ground primary productivity (data from Owen and Schmidly 1986: Table 2).

13 Distribution of modern plant communities in Northeast Texas (after Diamond, et al. 1987).

14 Depositional environments common in Northeastern Texas.

15 Soil orders of Northeastern Texas (after Godfrey, et al. 1973).

16 Distribution map of pollen sites.

17 Linear regressions between radiocarbon sample depth and age at Boriack, Hershop and Weakly Bogs.

18 Total arboreal pollen percentages from Weakly, Boriack and Hershop Bogs (data from Larsen, et al. 1972; Bryant 1977; and Holloway 1987a).

19 Total arboreal pollen percentages from Boriack and South Soefje Bogs (data from Graham and Heimsch1960; and Bryant 1977).

20 Three sample moving averages of arboreal pollen percentages and matching grass pollen percentages from Weakly Bog primary counts and secondary counts (minus Alnus and Compositae) from Boriack Bog.

21 Estimated canopy cover through time at Boriack (secondary counts) and Weakly Bogs (data from Bryant 1977; and Holloway 1987a). Arboreal canopy cover cut off levels between forest (>60%), woodland (60-26%)
and grassland (≤25%) plotted according to Diamond, et al. (1987).

22 North Texas 5-year moving averages of PDSI (Palmer Drought Severity Index) estimated from tree-rings (data from Stahle and Cleaveland 1988).

23 Carbon atom structure with protons, neutrons and electrons.

24 Illustration of relationships between carbon isotope measurements, isotopes and plants.

25 C3 plant composition estimates for radiocarbon dated bulk humate samples from Jewett Mine, Leon County (data from Fields 1987; Fields, et al. 1989; Fields 1990a; Fields 1990b).

26 Carbon isotope effects under closed canopy forests (data from Vogel 1978a and van der Merwe and Medina 1989).

27 Percent of arboreal pollen at Weakly Bog and δ13C values of bulk sediments from Jewett Mine in Leon County, Texas.

28 Four δ13C sequences from northeast, south and west Texas.

29 Estimated C3 plants ingested by Bison from Lubbock Lake (Stafford 1984: Table 2).
30 Bulk soil humate and human bone collagen stable carbon isotope ratios from Willacy County, Texas (Bousman 1990).
31 Third order polynomial estimating mean annual temperature (oF) from δ18O in precipitation.
32 Linear regression between evaporation rates and stable oxygen isotope ratios from deer bone (data from Land, et al. 1980).
33 Linear regression between annual temperature and stable oxygen isotope ratios from deer bone phosphate (data from Luz, et al. 1990).
34 Linear regression between δ18O in soil carbonates and δ18O in local rain water.
35 Second order polynomial estimating mean annual temperature (oF) from dD in precipitation.
36 Linear regression between the D/H ratio in wood cellulose nitrate and associated water (data from Epstein, et al. 1976: Table 4).
37 Orbital parameters used in COHMAP climatic simulations.
38 Map of simulation grids over Texas.
39 COHMAP Project high resolution NCAR-CCM model simulated annual temperature and annual precipitation for East Texas.
40 COHMAP Project high resolution NCAR-CCM model simulated annual temperature and annual precipitation for West Texas.
41 COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer temperature for East Texas. Variations reflect differences from modern levels.
42 COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer temperature for West Texas. Variations reflect differences from modern levels.
43 COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer rainfall for East Texas. Variations reflect differences from modern levels.
44 COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer rainfall for West Texas. Variations reflect differences from modern levels.

LIST OF TABLES

Table 1. Late serial stage forest, woodland, grassland and other plant community dominant community types by major plant communities (from Diamond, et al. 1987).
Table 2. Slope, intercepts and correlation coefficients (r2) for linear regressions between radiocarbon sample depth and age at Boriack, Hershop and Weakly Bogs.

1990 ACKNOWLEDGEMENTS

Many individuals have contributed to the final outcome of this report. The Texas Historical Commission (THC) provided a great deal of guidance and yet the necessary scholastic freedom for a successful conclusion of this undertaking. Specifically Jim Bruseth and Nancy Kenmotsu of the THC are thanked for their encouragement, stimulation, and detailed comments. Paleobotanists who made available published and unpublished data, and/or willingly shared the breadth of their personal knowledge and experience on this subject include Vaughn M. Bryant, Jr. (Texas A&M University), Linda Scott-Cummings (Paleoresearch Laboratories, Colorado), Glen G. Fredlund (University of Kansas), Stephen A. Hall (University of Texas), Lois E. Albert (Oklahoma Archaeological Survey), Richard Holloway (University of New Mexico), Bonnie F. Jacobs (Southern Methodist University), and John Jones (Texas A&M University). Anton Scholtz and Madelon Tusenius (South Africa Museum) discussed the intricacies of EDXA charcoal analysis, and Madelon demonstrated the technique on samples at Southern Methodist University.

C. Reid Ferring (University of North Texas) made available unpublished data on soils, and shared his broad and detailed experience on late Quaternary paleoenvironments in northeast Texas. Pete Thurmond (Leeday, Oklahoma), Darrel Creel (Texas Archaeology Research Laboratory), Dee Ann Story (Wimberley, Texas), and University of Texas Bureau of Economic Geology staff members Tom Gustavson and E. W. Collins all provided guidance and shared of their knowledge which we greatly appreciate. Ernest Lundelius, University of Texas Geology Department, provided information and shared publications on stable isotopes. Pat Behling and John Kutzbach from the Center for Climatic Research at the University of Wisconsin-Madison provided the COHMAP climatic simulations. Such an effort is always easier if an example can be found, and Rolfe D. Mandel (University of Nebraska) kindly provided a copy of his paleoenvironmental chapter for the Kansas State Plan. Cues taken from the Kansas State Plan helped us to design, we hope, an equally excellent historic context for Northeastern Texas.

Thomas R. Hester, director of Texas Archaeology Research Laboratory, read an early draft and made valuable suggestions. Most importantly, under Texas Archaeology Research Laboratory auspices and Hester's directorship, all administrative details were handled with little or no effort on our part.

The personnel at Prewitt and Associates, Inc. are thanked for their many and numerous contributions and suggestions, especially Elton R. Prewitt, Ross C. Fields and Steve A. Tomka. Additionally Ross C. Fields is thanked for making available unpublished data from the Jewett Mine Project. Prewitt and Associates, Inc. also allowed C.B.B. to take a leave of absence from normal duties in order to focus on writing this report.

Lastly, but never least, C.B.B. especially would like to thank his wife, April, who courageously has endured the last few months of her first pregnancy with her husband out of town or locked away in his office, in an effort to finish this project before the baby arrives.

PREFACE FOR THE 2015 PUBLICATION

The research for this original manuscript was made possible by a grant awarded to Collins and Bousman from the THC in 1989 and administered by the Texas Archeological Research Laboratory at the University of Texas at Austin. The original manuscript, finished in March of 1990, was never published. Only a brief summary entitled "Quaternary environments and archaeology in northeastern Texas" by Collins and Bousman with a contribution by Tim Perttula was published a few years later in 1993 as a single chapter in "Archaeology in the Eastern Planning Region, Texas: a Planning Document" edited by N. A. Kenmotsu and T. K. Perttula at the THC Department of Antiquities Protection. While an enormous amount of new research has been conducted over the 25 years since the original manuscript was finished, this manuscript has not been updated. That would be a monumental undertaking and a number of the original ideas and concepts would probably be discarded. For example we now know that the stable isotope measurements collected for radiocarbon date fractionation corrections should not be used for paleoenvironmental interpretations, but at the time this was unclear. Even so, a number of discussions remain as relevant today as they were when written. As this manuscript stands, it provides a historical view of geoarchaeological developments in Texas in 1990. The only new changes undertaken in 2015 involved a number of re-drafted figures for this version, but the original sources of data were consulted. In this task, Ross Fields at Prewitt and Associates assisted by recovering some of these long forgotten files; we greatly appreciate his help. Finally we would like to than Dr. Robert Z. Selden Jr. and colleagues at the Center for Regional Heritage Research, Stephen F. Austin State University for selecting this manuscript for publication and ushering it through the process of review and layout.

I. INTRODUCTION

Northeastern Texas (Figure 1) is one of the most intensely studied archaeological regions of the state, principally for the two reasons that (1) archaeologically-rich Caddoan manifestations have long attracted interest and (2) many large land-modifying projects, such as reservoirs and strip mines, have occasioned environmental studies which include investigations of cultural resources. This greater amount of activity relative to other regions in the state has generally prevailed for more than a century (Guy 1990) and prospects are good that archaeologists will continue to intensely research the area in the foreseeable future. Unfortunately, however, they will be hard-pressed to keep pace with the destruction of archaeological sites. The region is growing in population and developing economically which inevitably results in land modifications destructive of archaeological evidence. Also, many sites are being willfully destroyed by commercial dealers in antiquities and by relic collectors.

This contribution to historic preservation planning is concerned with gaining a better understanding of the past environmental factors that stimulated responses by past inhabitants of Northeastern Texas, and the natural environmental context of the archaeological record in Northeastern Texas. The area has some overall environmental similarities--such as being in a single physiographic section, and falling within a single climatic region--that might be misconstrued to imply a uniformity of conditions critical in pre-industrial human adaptations. In fact, the conditions important in human ecology vary significantly across space and have varied equally significantly over time.

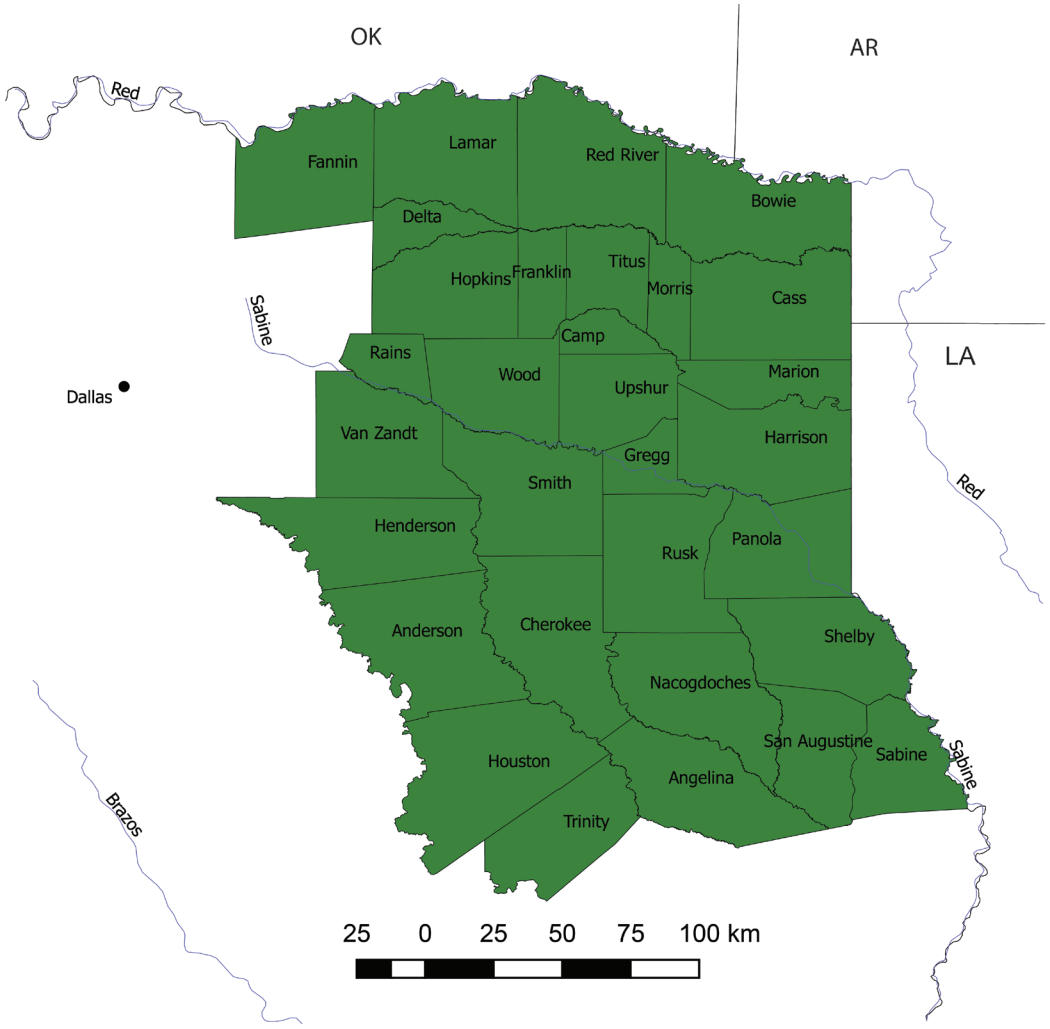

Figure 1: Location of the Northeastern Texas area (after Brown, et al. 1982).

Human ecology is the research perspective concerned with understanding how human groups respond to, and influence natural environments; archaeologically, this perspective is concerned with these issues over the culturally-relevant past (Butzer 1982). To effectively investigate and begin to understand the human ecological record in Northeastern Texas requires application of the human ecological perspective to two fundamentally separate data sets. It is first necessary to have data from archaeological contexts on the kinds of human activities evidenced, the times and places of these activities, and the patterns of change and stasis in these activities over the long term. It is also necessary to have data on the natural environments over time gathered from archaeological and non-archaeological contexts, where the record is not distorted by human interventions. Essential to integrating these two data sets is reliable chronological control. Fortunately, recent advances in geochronology can be used to estimate the ages of many natural environmental data with precision comparable to that of the dating techniques used in archaeology. Thus, data on cultural and natural phenomena gathered independently can be aligned in an absolute time scale and studied in concert.

The human ecological approach has not prevailed in much of the archaeological inquiry to date in Northeastern Texas, but there are important exceptions and data have been generated which indicate some of the relationships that existed between humans and their local environments, mostly for the Late Holocene. Such factors as soils, reliability of local water sources, and composition of local floral and faunal communities have been found to be intimately tied to the kinds of human behavior evidenced in the archaeological record. Such factors as erosion, sedimentation, soil conditions and modern land-use practices have profoundly affected the nature of the archaeological as well as the natural environmental record.

We address issues and strategies to be considered in investigating the natural environmental record as well as select human-ecological aspects of the archaeological record. Of particular concern are identifying and effectively investigating sources of data on past land forms, biota, and climate along with the nature of cultural evidence which relates to these variables. Traditional as well as non-traditional sources of data will be discussed. Davis (1989) addresses similar issues but from a slightly different perspective. On a general level a very good, thorough, and fairly current book for the lay-person and nonspecialist on paleoenvironments, paleoclimates, and the techniques used in such studies is The coevolution of climate and life by Stephen Schneider and Randi Londer.

Archaeological inquiry is increasingly dependent upon technological advances in ancillary disciplines and, although the prowess of these advances in investigating the past is highly beneficial, many are costly. The overall cost of doing modern archaeology is rising at such a rate that cost-effectiveness must become a central concern for all archaeologists; an obvious, but not tenable, strategy is cost containment where, simply, less archaeology is done. Less archaeology in times when loss of our irreplaceable archaeological heritage is accelerating is not the acceptable response. Instead, better archaeology concerned with more carefully selected data and greater information return is needed. Importantly, some of the technological advances available to archaeology are ideally suited to improving the cost effectiveness of archaeological inquiry. One of these is addressed in this plan--by knowing the geomorphological history of an area, the probable locations, approximate age, and something of the integrity of archaeological remains can be predicted with considerable confidence; archaeological verification of the predicted patterns is more cost-effective than using purely archaeological methods for establishing the patterns. More specifically, for project areas the magnitude of reservoirs or large strip mines, the basics of geomorphological history can be determined at less cost than comprehensive surface and subsurface archaeological survey and testing for the locations, ages, and integrity of sites. This is particularly true for completely buried sites. Operationally, then, a study of a project area's geomorphological history should precede archaeological studies.

Archaeology in Northeastern Texas today embodies several issues susceptible to at least partial resolution by investigations employing the perspectives discussed here. These issues range from specific questions about the human past to concepts about the nature of the archaeological record and its management to broad topics of human adaptation. We have selected for discussion a few of these issues that we consider representative of the many that relate to the region such as investigating past landforms, discovering buried sites, interpreting past biotic communities, assessing site integrity and the like. In reality, the issues are not so neatly bounded and we recognize that these issues are complex and some go far beyond the topics discussed. The discussion of issues is preceded by a brief synopsis of the current environmental setting. The archaeological background to this discussion is to be found in recent and excellent overviews, The Archaeology and Bioarchaeology of the Gulf Coastal Plain (Story, et al. 1990) and Tim Perttula's Historic Context on the development of agriculture in Northeast Texas.

One final introductory comment is necessary on the treatment of topics in this essay. We find that for most of the topics we have considered one of two situations exits: (1) voluminous data of greatly varying quality have been generated but not synthesized, or (2) almost nothing in regard to the topic exists for Northeastern Texas. In the first situation, for example, almost every report of archaeological field work contains information on soils, faunal remains (including statements of no faunal

recovery), kinds of chippable stone, and other routine matters. It is far beyond the scope of this effort to attempt any synthesis of these data and we confine our discussion to the potential these data have or may have for human ecological inquiry. At the other extreme where there are those topics for which little or no coverage exists, such as remote sensing, early Holocene faunal assemblages, or possible Holocene tectonic activity, we have drawn upon sources treating other regions either nearby (or far afield, if necessary). In these discussions, needs and potentials are addressed in a more abstract fashion.

There is one exception to these two situations. Just enough paleobotanic data are available from in and near Northeastern Texas to be re-evaluated and the findings presented. We consider these findings to be provocative and hope that other kinds of existing data will soon be synthesized and evaluated. Data that are prime for such regional evaluations include those on Holocene geomorphological changes and the role of soils in site formational processes.

II. PERSPECTIVES

The long-term objectives to which this essay is addressed can be summarized as the application of earth sciences toward improving the quality of the archaeological data base, broadening the areas of archaeological interpretation, and increasing the paleoenvironmental information base in Northeastern Texas. Of the numerous considerations and perspectives entailed in pursuing these objectives, eight are particularly critical: (1) inquiry must be focused on the highest quality data sources; in practice, these are generally areas of natural deposition. (2) Moderately dynamic environments of deposition are often preferable over ones that are extremely dynamic or nearly static. (3) The research approach must be cognizant of, and appropriate to, the scale of the phenomena under investigation. (4) Sequences of data at single loci or transects of data from multiple loci representing contemporary conditions are informative. (5) Environmental data must be gathered from non-cultural as well as from cultural contexts. (6) Research must take into account the ways in which natural processes may non-randomly affect cultural data at all scales. (7) Investigators should increase the application of geochronological, geophysical, and geochemical techniques of investigation. (8) Integrated sampling strategies should be applied in order to collect data sets that can be used to develop unified models of paleoenvironmental change that simultaneously considers geological and paleobotanical factors. Each of these is discussed more fully below.

1. For cost-effective, comprehensive investigation of the human past, particular attention must be paid to data quality. In practical terms, this involves selection of archaeological sites and non-archaeological localities (see below) for investigation using criteria derived from the tenets of human ecology. Active natural deposition produces the environments most favorable for the preservation of cultural and environmental evidence, including spatial patterning. Continued deposition favors stratigraphic isolation of contemporaneous assemblages of such evidence as well as construction of stratified sequences of these assemblages. The investigator needs to locate and identify natural deposits of appropriate age, assess them for content, and sample those most productive of data for his or her purposes. Natural deposits possess penecontemporaneous characteristics, known as primary structure, that reflect the mix of materials and processes that prevailed at the time of deposition and before a given deposit became isolated from the depositional conditions under which it was formed (penecontemporaneity). Primary structure includes such things as sediment grain parameters, bedding, sediment surface features, organic content, and structures produced by the activity of organisms. Details of primary structure provide the basis for inferring the nature of the environment of deposition and determining if it is suitable as a source of data for any particular purpose. Additional information may also be needed, as, for example, the age of the deposit and its overall geometry.

2. The dynamics of deposition vary greatly from one environment to another. The source and quantity of sediment, the amount and nature of energy transporting that sediment, the geometry of the area of deposition, and the characteristics of the surface on which deposition occurs, these are all variables that interact to control the primary structure of deposits. The quality of environmental or cultural evidence incorporated into deposits is controlled to a large extent by these variables. On the continuum from inactive environments of deposition, such as hilltops, to extremely active ones, such as areas of chronic landslides, those which are moderately active generally afford the best data. An ideal setting manifests rates of deposition that are at least occasionally rapid enough to preserve aspects of primary structure and sequences of change in primary structure.

Primary structure is subject to progressive alteration, such as pedogenesis or bioturbation, over time. The effects of alteration will be greater in environments of gradual deposition and in environments of little or no deposition because rapid rates of deposition bury a given deposit relatively quickly and under relatively greater amounts of material. This partially insulates the deposit from alteration. These relationships find practical application in the assessment data potential of a site. Well-preserved primary structure indicates that a given deposit may be very young or that it may have been quickly and deeply buried at a time in the past; independent lines of evidence are needed to determine which interpretation is correct. Archaeological content is a good example of the relationship between data quality and the depositional dynamic. It is common to find the greatest number of artifacts in environments of little or no deposition. Buried soils represent buried land surfaces that were stable for a time and artifacts concentrated at this level are potentially palimpsests of multiple occupations. Environmental data from such a setting may also reflect admixture from a series of changing environmental conditions. Under conditions of extremely rapid deposition, such as in high energy floods or landslides (known as mass wasting events), large volumes of material deposited in very short periods of time almost totally dilute any cultural or environmental contents and can easily mix materials from times and environments. The primary structure of such deposits is evidence of the depositional event which itself may be important, but the deposit is likely to be of almost no value as a host for other kinds of data. Moderately rapid rates of deposition, on the

other hand, have the potential to produce optimum temporal separation of assemblages of cultural or environmental evidence without diluting them beyond the reach of reasonably efficient data collection.

3. Scale is a critical dimension of research. If the three segments of a scale of archaeological inquiry proposed by Butzer (1982) are applied to a typical site investigation, the microscale segment would extend from the most minute entity of analysis (e.g. microscopic features on individual sand grains) to the site as a whole with its contour, structure, stratigraphy, features, artifacts, etc. The mesoscale segment would encompass the local environmental setting of the site outward to the limits of relative uniformity in land form, vegetation, etc., typically on the order of one to several hectares. The macroscale segment would be the aggregate distributions of the relevant environmental elements, such as perennial water, pine forest, sandy soils, etc. up to several thousand square kilometers in extent.

Typically, research focuses on the upper part of the microscale segment and part of the mesoscale segment--the artifacts, features, and immediate setting of a single site. Usually the macroscale segment is invoked only in reference to comparisons with other, selected sites. Systematic studies at the macroscale, exemplified by Thurmond's (1981) study of site distributions in and near the Big Cypress drainage or Johnson's (1989) evaluation of the distribution of late Paleoindian remains in eastern Texas and beyond, are indeed rare.

As archaeologists we tend to focus on the site and the distribution of macroscopic objects in that site. Although this is a critical segment of the research scale, it may not remain as pristine as higher and lower segments. Close ethnoarchaeological scrutiny of human behavior as regards artifact patterning in sites suggests that shifting of activities, movement of objects and general disturbance preclude the development of spatial patterning as it is envisioned by archaeologists (O'Connell 1987, Stevenson 1991). The problem of palimpsest distortion of intra-assemblage patterning is also greatest in this portion of the research scale (Clarke 1978:245-246). To overcome these data deficiencies, greater attention should be paid to the microscale and macroscale segments (O'Connell 1987). At the microscale, such patterning as chemical residues in the soil, microdebitage distributions, or wear patterns on artifacts are too small to be subject to some of the disruptions noted by O'Connell. An unusually clear example of this is seen at the Newtown Phase (late Woodland) Pyles Site in northcentral Kentucky. The site consists of an extensive, very dark-colored circular midden, roughly 150 m in diameter. An apparent midden-free circular area, approximately 50 m in diameter, occurs in the center of the midden. Controlled surface collection and limited excavation revealed lithic, ceramic, and macro organic (midden staining) concentrated in the dark band around the outside of the midden and they were virtually absent from the central area. However, the highest anthrosolic phosphate concentrations were found in this central area, indicating that a great deal of activity transpired in this area to produce the organic enrichment of the soil. It is likely that any durable objects such as flakes or sherds were kept from accumulating in this central work area, probably by sweeping or other behavior (Railey 1986).

Similarly, at the macroscale, patterns in the distribution of sites in relation to critical landscape variables are immune from blurring by human activities. However, the investigator must control for changes in the landscape by determining the distribution of those critical variables at the time under investigation. In a recent study of the relationship between burned rock middens and live oak savanna in westcentral Texas, Creel (1986) not only evaluated the present distribution of live oak savannas, but also considered historically documented stands that are now missing.

In investigating paleoenvironmental phenomena, procedures and sources of data must be appropriate to the scale of the phenomena under consideration. Climate is an example of a macro scale phenomenon. Micro- or mesoscale data alone are not adequate for paleoclimatic interpretation. Consistent findings over sufficient area to eliminate localized, nonclimatic variables are needed. For example, Hall (1990) finds contemporary stream incision events over a wide area of the south central plains are probably a response to regional climatic change. In addition Alford and Holmes (1985) have shown that stream meander lengths and radii, indicating river discharge, on the Montgomery, Prairie and Deweyville terraces of the Sabine River are significantly larger, while undated Holocene meanders are significantly smaller than the modern river meanders. In contrast to these studies, variation over time evidenced at a single locality, such as at Eagle Hill, Louisiana (Gunn and Brown 1982), might represent response to climatic change, however, regional patterns are necessary to corroborate the inference.

4. Archaeology is dependent largely upon the comparative method in which we seek to discover the relationship between variables in existing cases rather than through controlled experiments. Thus the relationship between an aspect of human behavior and certain environmental variables may be investigated by discovering cases where the states of the critical variables can be determined. With enough cases and great enough variation in the states of the variables under consideration, the relationship(s) between variables may be discernable. In the human ecological perspective advocated here, geologic context

can be used to maximize control of certain variables. This strategy may be implemented with either of two emphases, recovery of case data from a temporal sequence at a single locality or from multiple, contemporary loci. Thus if the question is whether people avoided flood-prone settings for camping in a given stream valley, a sequence of components spanning times of changing flood frequency could suffice, but so might a set of data on contemporary components in settings with different exposure to flooding.

Perhaps the greatest potential for reducing comparative effort in archaeology lies in applying chemical and physical analyses to questions traditionally investigated using only the comparative approach. Chemical residues in site sediments or on artifacts can be good indicators of activities and functions; also stable isotope ratios in plant or animal tissue samples can provide strong evidence of the environment in which the organism lived.

5. Environmental data must be gathered from both cultural and non-cultural contexts. Because humans disrupt the local ecology as well as selectively introduce into and exclude from their sites elements of the regional environment, archaeological sites are biased sources of data on natural environments. On the other hand, this behavior is specifically of interest in human ecological inquiry--to what extent and in what ways did various human activities disrupt the ecology in and around the site, what did people selectively introduce into or exclude from their sites? Comparison between data from sites and non sites is crucial in this line of inquiry. Geochronological techniques that allow the dating of natural deposits, soils, and organic specimens to the same degree of precision achieved in most archaeological dating is the basis for aligning contemporary site and non site data sets. It is desirable to compare evidence from analogous settings, such as data from an archaeological site on a levee with that from an unoccupied locality on that levee, to more sharply define the human effects. In some cases stable isotopes provide paleoenvironmental data that are not biased by human selection, and can be directly associated by stratigraphy to archaeological remains, thus eliminating the need to correlate between paleoenvironmental record and the archaeological record via radiocarbon chronology.

6. Human activities are not randomly distributed across the landscape and it is predictable that some kinds of activities are carried out in settings that are systematically (non-randomly) more favorable or less favorable for archaeological preservation (Collins 1975). To the extent that these can be predicted, paleogeographic data can be used to attempt to compensate for these biases. The canoe was probably a part of late prehistoric culture in Northeastern Texas. Evidence of this technology is most likely to be found in the form of sunken canoes preserved in streambed or lake bed deposits. Any search for such evidence would benefit from a clear understanding of the history of the stream or lake to be investigated. Of the myriad abandoned channel segments along the Red River, accessible ones dating between 200 and 2000 years ago as determined from meander sequences and limited chronological (radiocarbon-dating) control might be the place to begin to search.

7. The usefulness of geochronological, geophysical, and geochemical applications in archaeological and paleoenvironmental investigation is growing. Many of these techniques do directly what we as archaeologists have long attempted to do indirectly and inefficiently with ordinary techniques. To determine the function of a particular vessel form with traditional archaeological methods requires vast comparative data on contexts and associations; chemical residues on the interiors of a few sherds may quickly indicate function. The ages of many sites lacking suitable material for archaeological dating can be determined at least to some extent by direct dating of associated soils or deposits. Non-invasive techniques of geophysics are suitable for determining certain subsurface conditions useful in archaeological and paleoenvironmental inquiry.

8. This review and assessment of paleoenvironmental and paleoclimatic analysis will show that a number of powerful tools are now available for reconstructing past climates and environments. Certain approaches to sample selection are recommended, however. It is suggested that the collection of integrated, matched samples for pollen, phytoliths, charcoal, isotopes, sediment samples and all other types of paleoenvironmental information, and even faunal remains, should be a standard sampling procedure whenever possible. Integrated samples are multiple samples from the same exact location and stratigraphic position within a site. By using this sampling strategy, changes in one set of paleoenvironmental data, such as pollen, can be compared to other types of data, such as diatoms, molluscs, phytoliths or isotopes. With integrated samples interrelationships can be identified, analyzed, and assessed in true paleoecological terms. These paleoecological patterns then can be mapped through time and space. Integrated sampling provides the matching data sets necessary for obtaining a much fuller understanding of past environmental changes, and other sampling strategies will fail to provide the absolutely crucial cross-comparative framework. Models that consider botanical and geological data need to be developed and integrated sampling strategies allow for the

interpretation of both data sets simultaneously. Obviously changes in climate and plant cover can strongly influence geological processes, and models that bring all three factors together will elevate our understanding of past environmental changes to a level well beyond present day understanding.

With these perspectives in mind, we turn now to northeastern Texas and its human ecological history.

III. BACKGROUND

Fenneman's (1938) physiographic classification of North America is a generalized mapping of broad areas of overall similarity. In his classification, all of Northeastern Texas falls within the West Gulf Coastal Plain Section of the Coastal Plain Province. Low, gently rolling relief formed of relatively soft, sedimentary rocks prevails. The area is drained by generally southeasterly flowing streams and is well-watered. Soils, which vary with substrata and age, tend to be Ultisols, Alfisols and Vertisols in the uplands and Mollisols, Entisols and Enceptisols in the valleys. The flora trend from pine woods in the east through a belt of mixed pine and hardwood to Blackland Prairies on the west. The climate is subtropical humid, but wetter to the east and drier to the west. Fauna in the east are part of a faunal community extending eastward to the Atlantic seaboard whereas those to the west are similar in composition to those of the prairie and plains provinces of the south central United States; these interdigitate along the north-south prairie-forest interface through the center of Northeastern Texas. A more detailed look at these environmental characteristics of the region follows.

Figure 2: Major geologic units in the southcentral United States showing subparallel bands of progressively older.

The surface geology of the West Gulf Coastal Plain (Figure 2) consists of a series of latest Cretaceous and Paleogene-age sediments dipping gulfward and outcropping in arcs subparallel to the present coast line except where they wrap around the East Texas Embayment in the center of Northeastern Texas. These strata are of varying hardnesses and, accordingly, vary in their resistance to erosion. The resistant beds support ridges and inland-facing questas (Figures 3 and 4). There are also fault-related escarpments that step downward toward the coast, and increase in frequency near the coast.

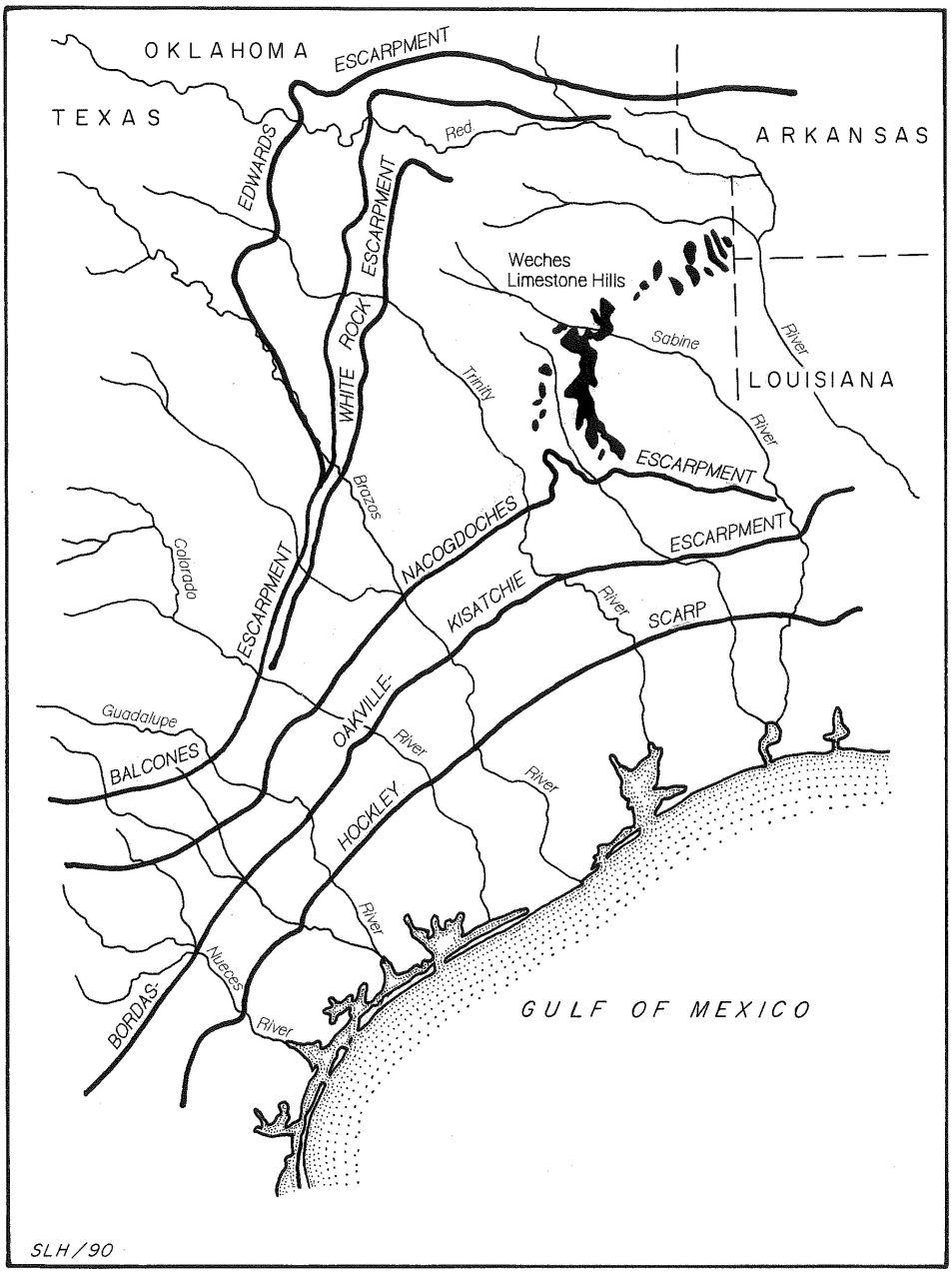

Figure 3: Topographic belts and escarpments in the western Gulf Coast Plain (after Fenneman 1938 and Thornbury 1976).

The outcrops are progressively younger gulfward. Formations composed largely of silt to sand-sized clasts comprise the bedrock over all but one relatively minor area of Northeastern Texas. The narrow band of upper Cretaceous-age rocks along the northern edge of the area consists of silty sandstone, limestone, chalk, shale and clay rocks (Figure 5).

Chippable stone is scarce in this setting. Aboriginal peoples had at their disposal widespread pebble to small cobble-sized pieces of quartzites and some jaspers. These are unevenly distributed in the uplands as well as in modern streambeds. They seem to be lag gravels from long-abandoned stream channels, which means that their distributions are not predictable from cursory knowledge of the landscape; one has to be familiar with actual occurrences. The quality of these quartzites for chipping is rather poor and the jaspers occur as such small pebbles that they are rarely usable. In spite of these disadvantages, these materials were used as raw material in prehistoric chipped stone technologies. Also widespread in gravels over much of Northeastern Texas and abundant in outcrops near the southern edge of the area is silicified wood. This material varies greatly in size and

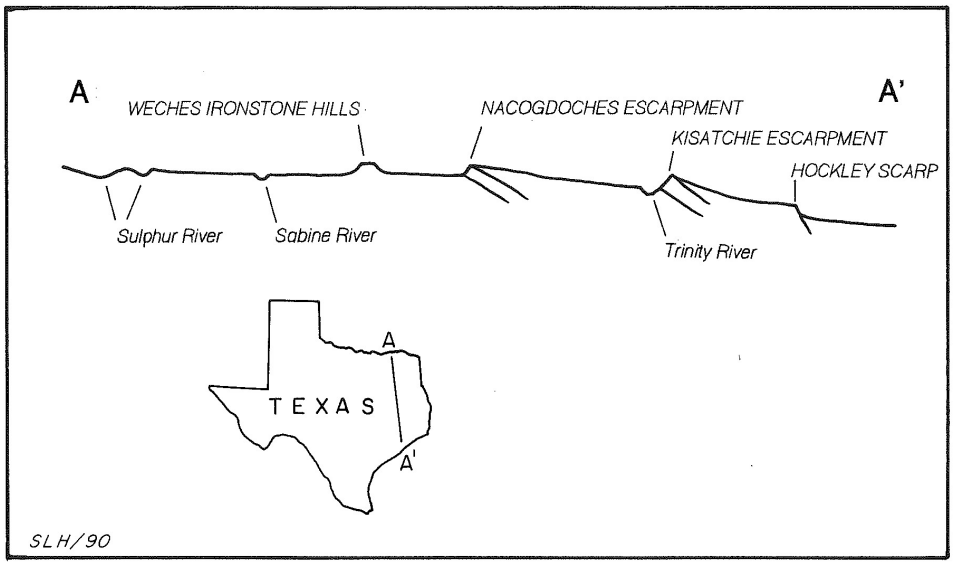

Figure 4: Northwest to southeast topographic section through Eastern Texas; note inland-facing cuestas and coastward facing fault escarpments; bedrock control of these topographic features is shown schematically (after Fenneman 1938).

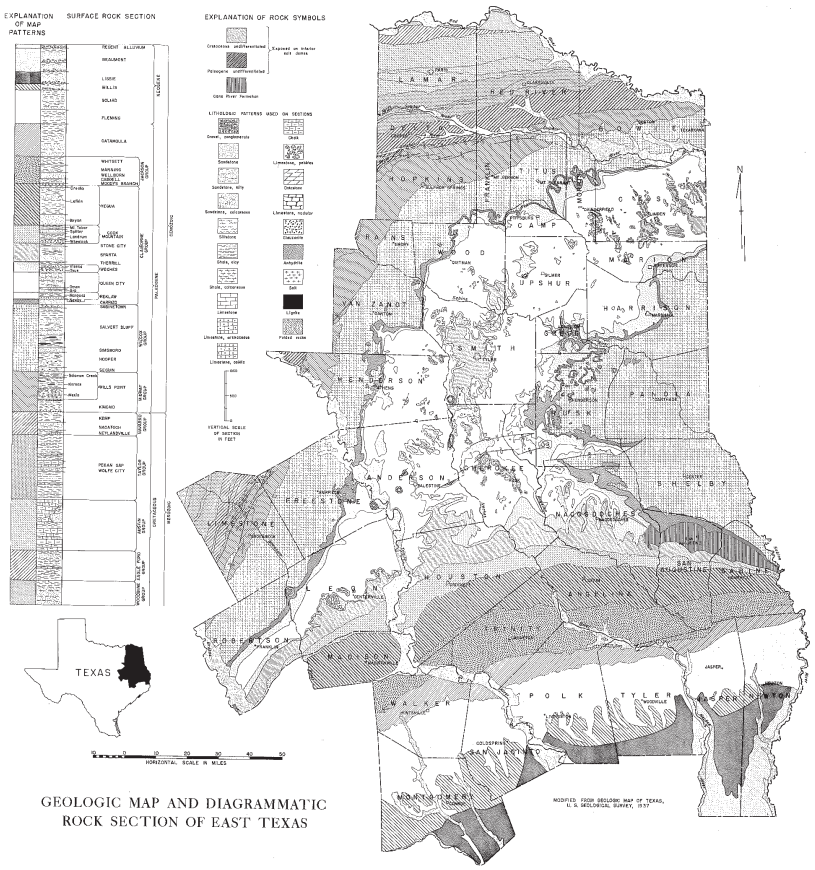

Figure 5: Major surface geologic units of Northeastern Texas (after Fisher 1965).

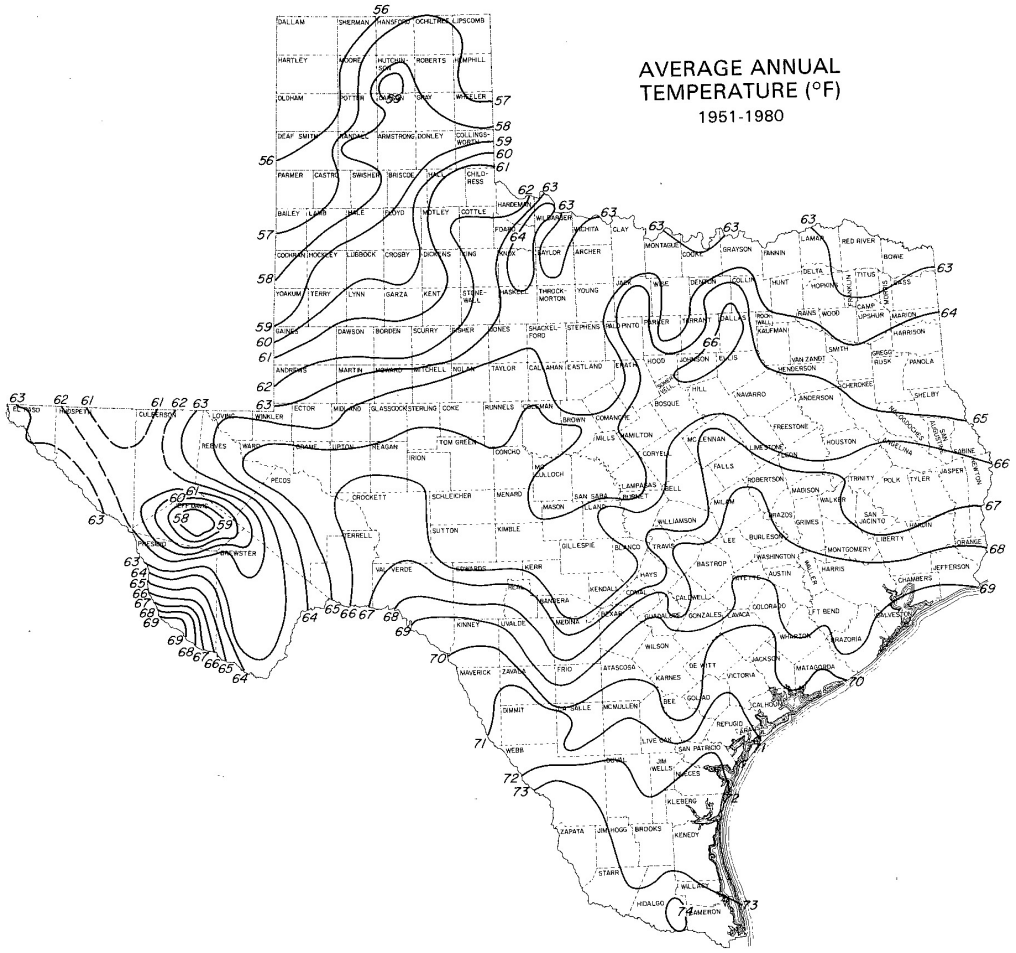

Figure 6: Average annual temperature of Texas (from Larkin and Bomar 1983: 50).

chippability. Although it is often found archaeologically in chipped form, it was satisfactory only for certain coarser artifact categories. Siltstone nodules from the Wilcox formation were used similarly for choppers and occasionally for points in the Richland-Chambers area (McGregor 1987). Another chippable material is Manning fused glass which occurs spottily along the southwestern edge of the Northeastern Texas area (Brown 1976). This material is a distinctive, vitreous product of volcanic tuff fused by intense heat. Subsurface burning of lignite in the geologic past produced heat which altered the lithology of overlying beds and in a few localities fused volcanic tuff into glass. Although this glass can be of extremely fine quality, it is generally found only in small pieces or in larger pieces with much internal fracturing. Were it not for these limiting conditions, this would likely have been an important raw material source. Along Pisgah ridge in Navarro County is found another limited source of chippable stone (McGregor 1987). This is a moderately to poorly chippable chert with very distinctive characteristics. It is not found widely in archaeological sites, owing most likely to its mediocre quality. As is obvious from the foregoing, aboriginal stone knappers were largely dependent on remote sources for suitable stone such as the Edwards Plateau (and streams which drain it) in Central Texas and outcrops in northwestern and north central Oklahoma (Banks 1984, 1990; Hofman 1989) as well as the mountains of eastern Oklahoma and Arkansas (Banks 1984; Story 1990).

Rocks suitable for pecking and grinding into useful objects are more readily obtainable in Northeastern Texas. Sandstone, siltstone, and quartzite can be obtained from various outcrops or secondary deposits. Such implements as grinding stones and hammer stones are commonly made from these materials. Objects such as adzes or axes require tougher metamorphic rocks which do not occur in the region (Fisher 1965). These were acquired from source areas in the Ouachita and Ozark Mountains and possibly from other regions (Story 1990). Many of the sandstones in the region are relatively soft; they are also rich in iron (Fisher 1965). The softness detracts from their usefulness as implements. The high iron content should make these rocks valuable for archaeomagnetic studies as discussed below.

Salt is abundant in the subsurface over much of the southern half of the region. In a few isolated localities, it comes to the surface dissolved in water where it would be available from springs or salt marshes using aboriginal technologies. Also, ceramic clay is unevenly but widely available in quantities and qualities suitable for pottery works and for large-scale commercial production. Clays of quality and quantity adequate for aboriginal pottery occur even more widely (Fisher 1965). Surface occurrences of bitumen are potentially important in aboriginal technologies. Oil seeps and oil sands occur in the southeastern part of the area, especially in Angelina, Jasper, San Augustine, Tyler, Nacogdoches, and Anderson counties (Fisher 1965). Use of this kind of petroleum for mastics for hafting tools to handles and medicines by native Americans was widespread and should be considered in archaeological investigations in Northeastern Texas (Collins 1981). Care in collecting and cleaning specimens is critical with adhering traces of petroleum (as it is with any chemical residues).

IV. MODERN CLIMATE

The discussion of the modern climate is crucial in order to understand the effects climate has on the distribution of plants and animals, and for establishing a foundation from which past climatic changes can be compared. Climate can best be understood as the long-term trend of weather. Weather consists of short-term variations in temperature, rainfall, relative humidity, wind, cloud cover, and a host of other atmospheric phenomena such as hail, snow, tornados, dust storms, hurricanes and the like. Climate is commonly discussed as averages of rainfall, temperature, wind direction and speed, and evaporation, but the reader must be aware that climates change and that modern climatic conditions might be short-lived. The ultimate control of weather and thus climate is from energy received from the sun. The summer increase and winter decrease in solar insolation provides the driving mechanism for the seasonal change in climate and the great variation in observable weather patterns throughout the State. Since Texas weather is rarely predictable, and since climate is always changing, it is important to understand what atmospheric factors control the Northeast Texas climate.

Air Masses, Pressure Cells and Jet Streams

The Northeast Texas climate is strongly controlled by the juxtaposition and interactions of air masses pulsating from four regions. These are the maritime polar, continental polar or arctic, continental tropic and maritime tropic air masses (Bomar 1983: 28-29). The names of the air masses indicate the various source areas, and air masses from each area differ in terms of temperature and moisture content. Continental polar or arctic air masses consist of cold dry air and the passage of this air mass usually marks a winter or early spring cold front. Maritime polar air masses are cool and humid, and they penetrate Texas mostly in the spring and fall which is the period of greatest rainfall. Maritime tropic air masses, centered on the Gulf of Mexico, are warm and humid, and today they dominate Northeastern Texas in the summer or other seasons when they are not displaced by other air masses. Continental tropic air masses are warm and dry. They dominate the western half of Texas and the interaction between continental tropic and maritime tropic air masses determine the east-to-west reduction in rainfall throughout the State.

The movement of cold air (i.e. cold fronts) from northerly latitudes is most common in the winter and early spring, although front can occur in any season. Often the passage of a cold front is accompanied by precipitation (either rain, or snow and freezing rain in cold months), but this depends on the moisture content of the air masses that are displaced by a cold front and the strength and height of the front. After a cold front fueled by a continental polar or arctic air mass moves through an area a high pressure cell often covers the region. High pressure cells are composed of descending air that rotates in a clockwise or anticyclonic direction, and they invariably are associated with dry weather.

Texas is so far south that polar or arctic air masses can never dominant the weather for long, and often cold air masses are replaced by warm air masses, and this type of air mass displacement is known as a warm front. Again, precipitation often accompanies a warm front and occasionally fog may occur. Both warm and cold fronts are marked by the movement of low pressure cells. Low pressure cells consist of rising air that rotates in an anticlockwise or cyclonic direction, and they often spawn violent weather, thunderstorms or precipitation. Warm and cold fronts can become stationary also, and this condition may help to stimulate precipitation if conditions are favorable.

During the summer the circulation systems are less energetic and a large high pressure cell dominates the region. This is known as the Bermuda High (Bomar 1983: 36), and it is fueled by an upper level circulation of descending dry tropical air. The overall effect is that temperatures can be very hot and precipitation is stifled because the air mass has descending motion. Since the heated surface air rises (this is known as a convectional low pressure cell), these two factors tend to act in tandem to suppress wind. The occurrence of drought in Northeast Texas is conditioned by the strength and stability of this high pressure cell which is known as a "blocking ridge". When the high pressure cell is in place it deflects or depresses low pressure cells that have the ability to produce rainfall.

At this point the crucial question is: "What controls the locations of these air masses?" Two strong upper level (25,000 to 30,000 feet) westerly wind streams, known as jet streams, steer the air masses (Bomar 1983: 37). These are the polar jet and the subtropical jet. Winds occur because of uneven air pressure due ultimately to uneven heating of the earth's surface by the sun. Thus uneven air pressure along with the spin effect caused by earth's rotation, known as the Coriolis Force, and the friction wind on the surface act to help create the polar and subtropical jets.

Wind speeds of the polar jet can vary greatly, but maximum speeds reach 150-200 miles per hour. The jet streams migrate north and south with the seasons so that in the winter the polar jet flows at its most southerly position. Conversely in the summer the polar jet migrates north and the region is dominated by the subtropical jet. In addition, as with any flow, these jet streams meander. These meanders are known as standing waves and they pass from west to east or change through time from relatively straight to curved.

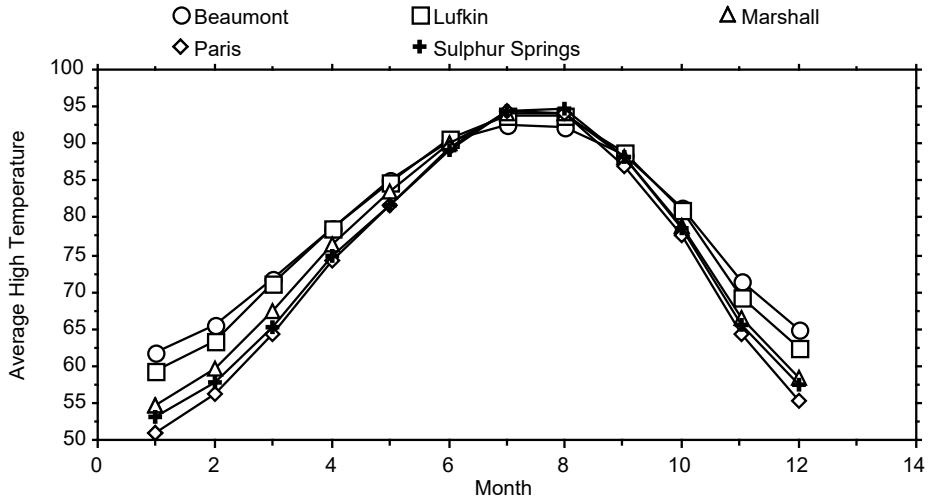

Figure 7: Monthly average high temperatures (degrees F) for weather stations in East Texas (data from Bomar 1983: 215-216).

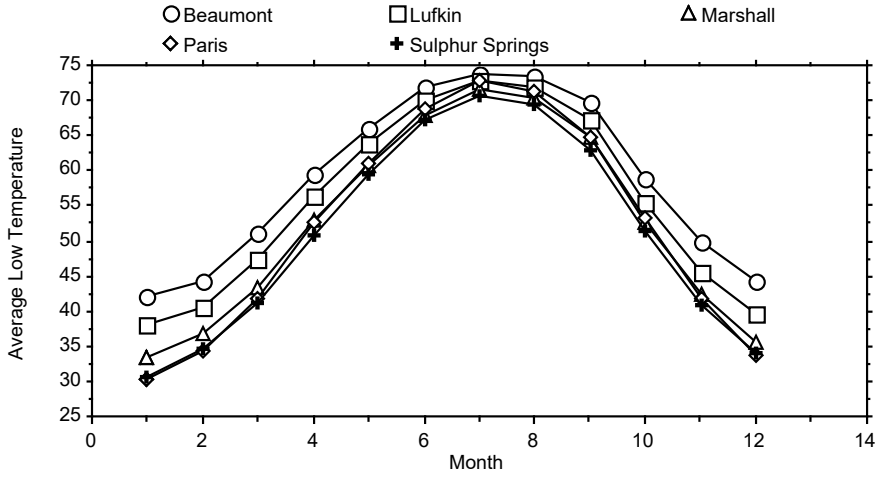

Figure 8: Monthly average low temperatures (degrees F) for weather stations in East Texas (data from Bomar 1983: 212-213).

For example in the winter when the polar jet is displaced south, often the outside curve of the meander extends from Washington or Oregon south into northern Texas and loops back north through the mid-Atlantic States. When the polar jet is in this position cold fronts (maritime polar or continental polar-arctic air masses) are often pushed south through the State and then steered to the northeast. If the polar jet meander moves eastward or becomes straighter and displaced to the north, then warm air replaces the cold air mass, and this can be relatively dry or moist depending on the source of the warm air.

In the late spring, summer and early fall the average path of the polar jet migrates north and Texas is no longer within its reach, however the subtropical jet can steer warm moist tropical air into Texas. The subtropical jet flows at a much slower speed (40-80 miles per hour) than the polar jet, and its flow is normally reduced during the summer when Texas weather is dominated

Figure 9: Average annual precipitation of Texas (from Larkin and Bomar 1983: 18).

by high pressure. Obviously the strength and activity of the polar and subtropical jets can strongly influence temperatures and precipitation throughout Texas by steering cold or moist air masses into the State. A weakening of the jets would tend to allow summers to be dominated by the Bermuda High Pressure Cell and favor drought conditions.

Temperature

Average annual temperatures for Texas show a general south to north decline (Figure 6). Average monthly high temperatures show warmer winters and slightly cooler summers in the south and greater range in the north (Figure 7). Average monthly low temperatures reflect the cooler temperatures in the north, even during the summer, but the greatest amount of temperature variation is in the winter (Figure 8).

Rainfall

The distribution of average annual rainfall for Texas demonstrates a marked decline in precipitation from east to west (Figure 9). Average monthly rainfalls for a selected group of towns from East Texas shows that most stations have two periods (April-May and September) of increased monthly rainfall (Figure 10). These data reflect the increased frequency of high pressure cells in the winter (following cold fronts) and in the summer (Bermuda High Pressure Cell). Beaumont has the weakest bimodal pattern and this is due to its position near the Gulf of Mexico.

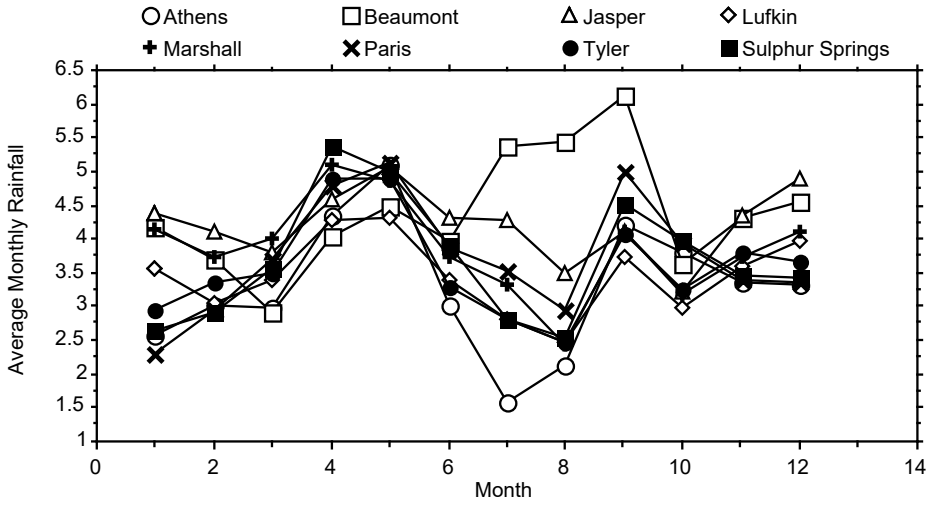

Figure 10: Monthly average rainfall for weather stations in East Texas (data from Bomar 1983: 221-222).

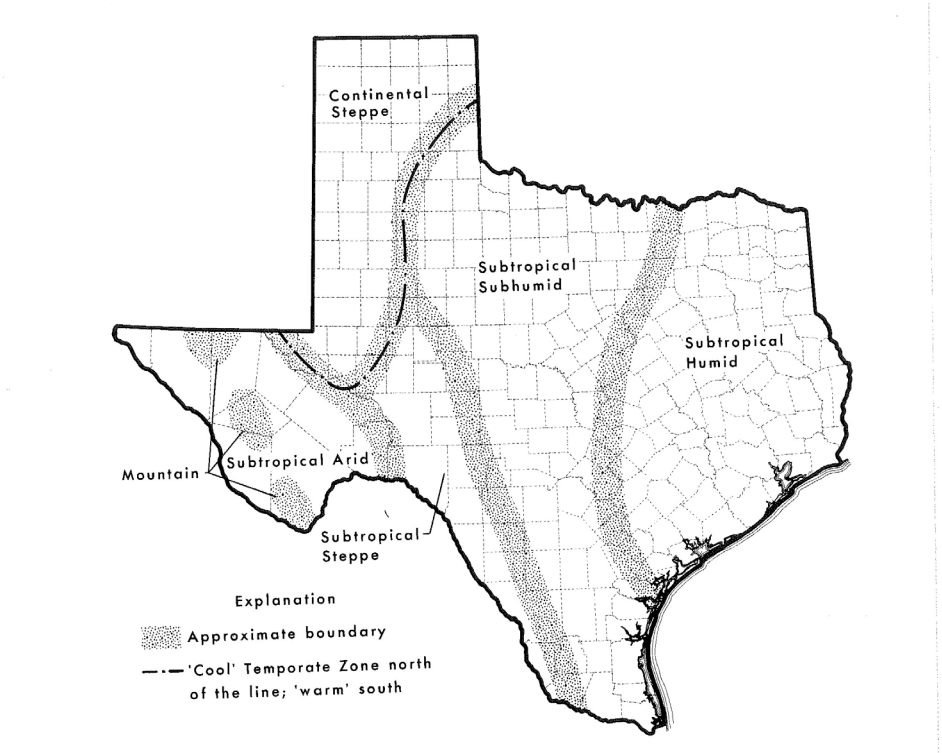

Figure 11: Climatic regions of Texas (from Larkin and Bomar 1983: 3).

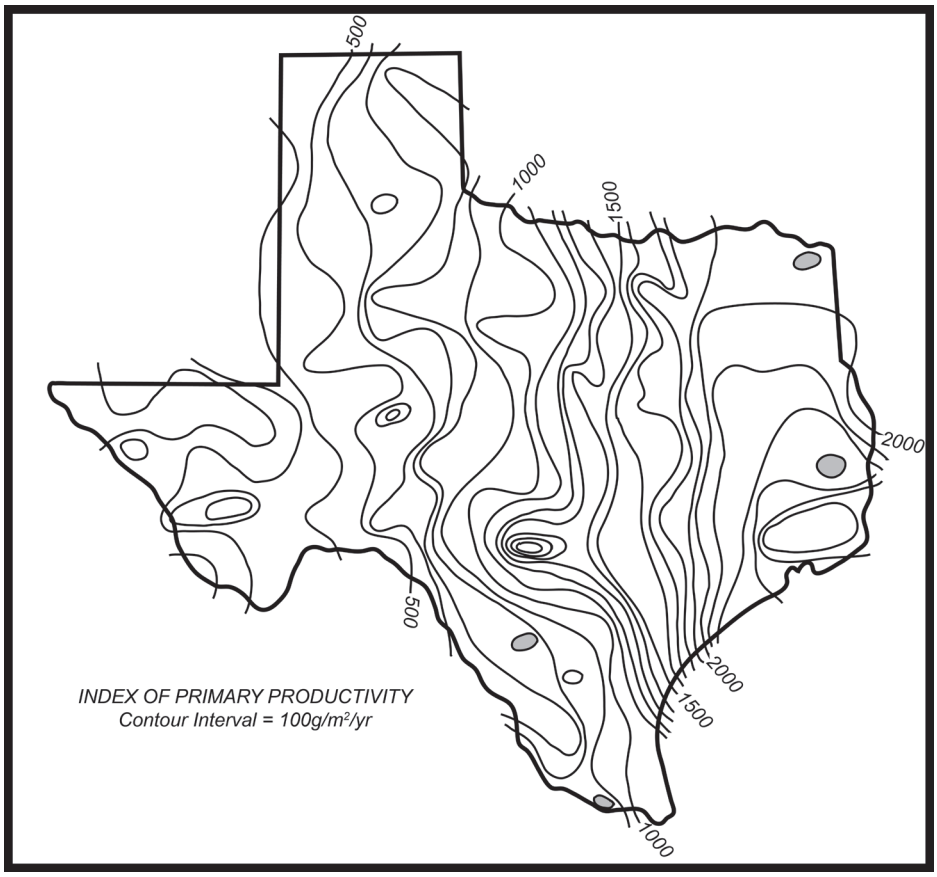

Figure 12: Contour map of net above-ground primary productivity (data from Owen and Schmidly 1986: Table 2).

Climate Classification

Climates are classified in order to distinguish similar and distinctive conditions over a given region. Larkin and Bomar (1983: 1-3) use the Thornthwaite (1931) classification system for all of Texas and their map of climatic regions in the State shows an expected east to west zonation (Figure 11). The Thornthwaite classification system is based on six grades of temperature efficiency, five grades of rainfall effectiveness, and four grades of seasonal concentration of rainfall. All of Northeast Texas is classified as a warm subtropical humid climate (see Figure 11). Annual shifts in climatic zone boundaries occur regularly and it is presumed that long term east-west migrations of climatic zone boundaries would be expected in Texas in at various times in the late Quaternary.

During the last 15,000 years it is expected that major variations occurred in the climatic parameters discussed above. The effects of these changes will be registered in an indirect or proxy record of diagnostic indicators such as sediments, pollen, animal remains, tree-rings, stable isotopes and others types of retrievable data. The ultimate task of many paleoenvironmental studies is to gain a better understanding of past animal or plant distributions, or other proxy paleoenvironmental or paleoclimatic data in order to reconstruct the characteristics of past climates. Thus the modern study of climates is undertaken in order to better understand its effect on plant and animals, so that these recoverable types of information can be used to work back to reconstruct past climates.

Climatic Estimates of Biological Productivity

Owen and Schmidly (1986) provide an index of net above-ground primary productivity of plants for 189 weather stations scattered throughout Texas. This index is calculated as grams per square meter per year (g/m2/yr), and it is based on evapotranspiration (AE) according to a formula developed by Rosenzweig (1968). Evapotranspiration (water loss

from respiration of plants and evaporation) can be viewed as the opposite of rainfall, and it is based on precipitation and temperature. As AE increases net above-ground primary productivity of plants decreases. The formula is: log10NAAP = (1.66±0.27) log10AE - (1.66±0.07) where NAAP is net annual above-ground productivity of plants in grams per square meter, and AE is annual actual evapotranspiration in millimeters (Rosenzweig 1968: 71). Accurate measurements of actual evapotranspiration (AE) are difficult to obtain, but both Rosenzweig (1968) and Owen and Schmidly (1986) use climatic estimates of AE developed by Thornthwaite and Mather (1957). These estimates of AE require latitude, and mean monthly temperature and rainfall. The climatically based estimates of annual above-ground primary productivity were plotted on a Texas map, and 100 g/m2/yr contour intervals were drawn (Figure 12).

In Northeast Texas this primary productivity contour map shows two important patterns. First, in the eastern portion of the region the most significant change is a north-to-south clinal increase in estimated primary productivity. This may help to explain some of the differences in East Texas forests discussed below. However near the western edge of East Texas the gradient rapidly shifts to an east-to-west cline. It is clear that dramatic changes in local relief such as occurs along the Balcones Escarpment or in the Davis Mountains can have significant influences on climate and conversely on estimates of primary productivity. Few such major topographic features exist in Northeast Texas, however. If the modern climatic patterns were to change, it is obvious that the dramatic east-west primary productivity gradient at the western edge of East Texas could shift to the east or the west with favorable or unfavorable conditions, and it is expected that plant communities would respond to these changes.

V. MODERN VEGETATION COMMUNITIES

The modern distribution of plant communities in Texas is conditioned most clearly by the distribution of rainfall, but other factors, such as soil characteristics, have a significant affect as well. In general the modern plant communities consist of pine forests in far East Texas. As one travels from east to west oaks and hickory begin to replace pine, then hickory declines in frequency, and finally oak is displaced by more and more grass until in the west grasslands dominate the landscape. While these plant communities are seen as climax communities for the area in which they are mapped, it is generally believed that the distributions are controlled by climatic patterns and that significant changes in regional climatic patterns influence the distributions of these plant communities in a predictable fashion. Thus, in a simplistic sense, the boundaries between modern plant communities can be seen as reflecting climatic thresholds, especially in terms of moisture availability, and as a certain level or amount (threshold) of moisture is approached the plant community begins to change. The rate at which plants respond to climatic changes is controlled by many factors, and different species respond at different rates because of variations in the efficiency of their dispersal mechanisms and maturation span before seed production.

Other nonclimatic factors also influence the distribution of plant communities. Soil characteristics, i.e. edaphic controls, exhibit a strong influence on plant communities by controlling the amount of moisture available to plants, soil pH, and other nutrients (Birkeland 1984: 17-22). This occurs on a local scale, such as within a single valley on hill tops, slopes and the floodplain (Marks and Harcombe 1981), as well as on a regional scale (Diamond and Smeins 1984, 1985). The retention and movement of water in a soil in influenced by sediment textures. As the surface area of sediment (per cubic unit of soil) increases water movement decreases, and water retention increases. Silts, clays and organic matter increase the surface area of a soil. Because

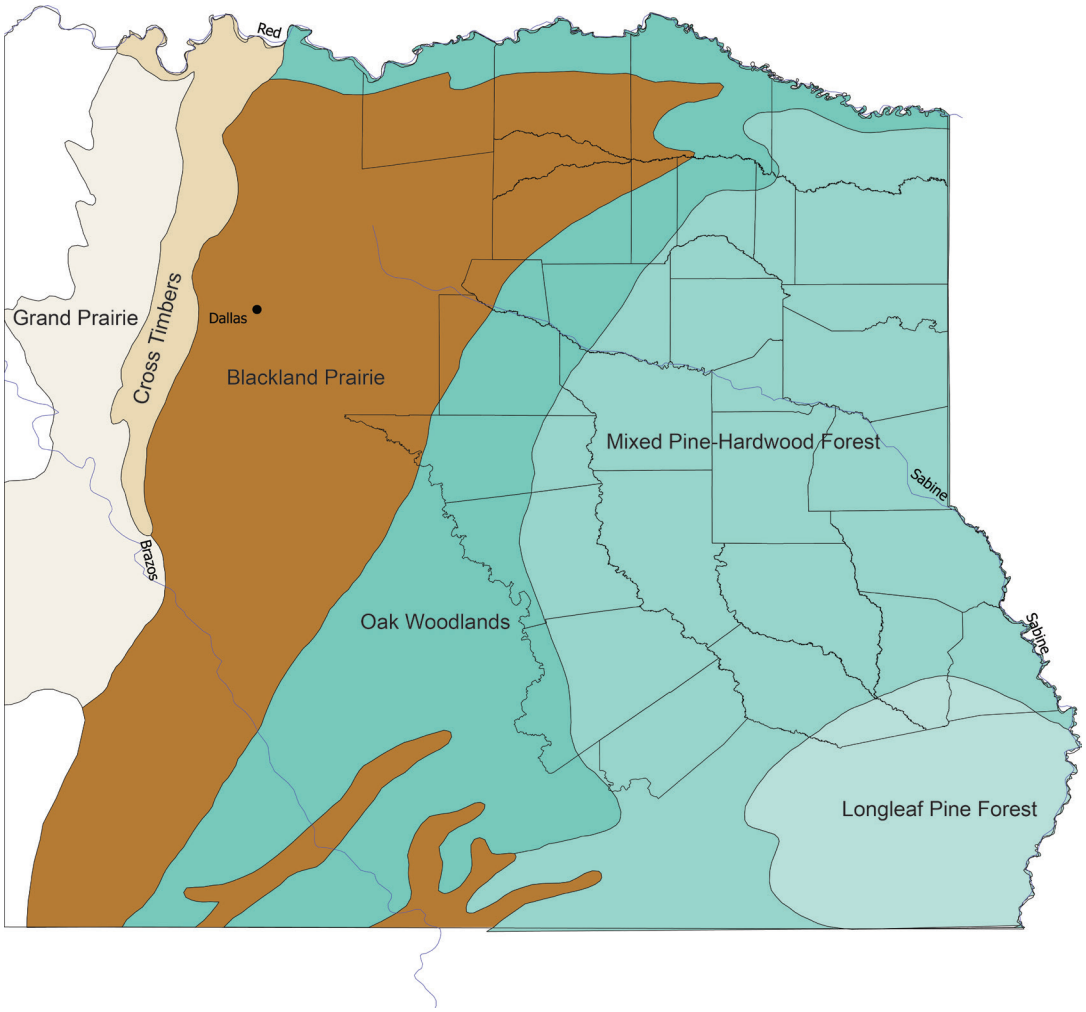

Figure 13: Distribution of modern plant communities in Northeast Texas (after Diamond, et al. 1987).

Dominant Communities	Piney Woods			
	Longleaf Pine	Pine-Hardwood	Oak Woodlands	Blackland Prairie
Beech-Magnolia	+			
Longleaf Pine-Rhynchospora	+			
Longleaf Pine-Tallgrass	+			
Loblolly Pine-Oak	+	+		
Swamp Chesnut Oak-				
Willow Oak	+	+		
Sweetbay	+	+		
Water Oak-Sweetgum	+	+		
Pine-Bluejack Oak	+	+		
Baldcypress	+	+		
Buttonbush	+	+		
Water Elm-Swamp Privet	+	+		
Bluejack Oak-Pine	+	+	+	
Shortleaf Pine-Oak		+		
Overcup Oak	+	+	+	+
Rush-Sedge	+	+	+	+
Sphagnum-Rhynchospora	+		+	
Post Oak-Blackjack Oak			+	
Gulf Cordgrass			+	
Sugarberry-Elm			+	+
Post Oak-Black Hickory			+	+
Gammagrass-Switchgrass				+
Little Bluestem				+
Silveanus Dropseed				+

Table1: Late serial stage forest, woodland, grassland and other plant community dominant community types by major plant communities (from Diamond, et al. 1987).

of less surface area and greater porosity (per cubic unit of soil) sand have less surface tension to hold water, and thus water infiltrates much more readily through sandy soils than through silts or clays. This results in a deeper depth-of-wetting in sandy soils for a given amount of rain. From a condition of complete saturation, called field capacity, the permanent wilting point, i.e. the point at which plants can no longer remove water from the soil through their roots, is reached faster in finer grained soils than in coarser grained soils, because the greater surface tensions of clays and silts hold more water (per cubic unit of soil) than sands at the permanent wilting point. In addition, water runoff rates increase as sediment textures become finer, because water infiltration rates are reduced. A horizons in most soils have increased porosity due to various forms of bioturbation and soil structure. Even though greater structure development in clayey soils, eg. blocky structure or vertisolic cracking, can significantly increase infiltration rates in these soils, generally clayey soils have lower infiltration rates than sandy soils. As both sandy and clayey soils are abundant in Northeast Texas, these edaphic influences on available soil moisture play a significant role in the distribution of modern and presumably past plant communities.

Stahle and Hehr (1984) have argued that a specific plant community may prosper on different soil types under different climatic conditions, for example Blackland Prairie grasslands (Diamond and Smeins 1985). The climatic point, e.g. average amount of annual rainfall, at which the vegetation on a given soil might shift from a grassland to a woodland is known as a climatic threshold. In other words in areas with similar annual rainfalls, coarse sandy soils have more available moisture for plant growth than fine-grained clayey soils, and the sandy soils might support an oak woodland while the clayey soil will only support a grassland. Certainly other factors such as soil nutrients must also play a role but for the purposes of this discussion these additional factors are not considered as important as water availability. In the future with more detailed analysis of

environmental controls on the distribution of plants other, nonclimatic factors may be judged to be more significant than are suggested here, but a primary purpose of this essay is an investigation of the relationship between biotic change and climatic change.

The distributions of the modern plant communities in East Texas are shown in Figure 13, and even a cursory examination of the distribution of annual rainfall and temperature, as discussed above, indicates significant correspondences between modern plant communities and climatic parameters.

Diamond, et al. (1987) provide a state wide classification of modern late stage serial plant communities. Their classification of plant communities in Texas is composed of a hierarchical framework of classes and subclasses that are grouped by plant communities. Classes are based on dominant growth form such as forest (tree communities with arboreal canopy cover more than 60 percent), woodland (tree communities with 26-60 percent arboreal canopy cover), herbaceous vegetation (communities dominated by grasses or forbs, and arboreal canopy cover 25 percent or less). It should be noted that woodland includes plant communities previously called savanna and open forest. Two additional classes are swamps and marshes which include wetland plant communities that are dominated by arboreal-shrub or herbaceous species, respectively. Subclasses are defined by and named after dominant species.

In Northeast Texas twenty-three subclasses, called community types, from the five classes were defined by Diamond, et al. (1987) and these were classified into to three major plant communities, one of which is subdivided (Table 1). The major plant communities are Piney Woods which is composed of the Longleaf Pine Forests and Mixed Pine-Hardwood Forests, the Oak Woodlands, and the Blackland Prairies. The Longleaf Pine Forests are confined to the far southern portion of Northeast Texas, and these forests are more characteristic of Southeast Texas. Most of the region is covered by Mixed Pine-Hardwood Forests, while the Oak Woodlands and Blackland Prairie occur as north-south trending strips mostly on the western edge of Northeast Texas.

Long-Leaf Pine Forest

This type of forest is most common in the far southern portion of Northeast Texas and it extends south into Southeast Texas. Detailed analysis of this modern forest community in Southeast Texas has demonstrated the existence of a variety of sub-communities, and their occurrences are strongly controlled by water availability and slope (Marks and Harcombe 1981). Today the dominant tree species in this forest is the long-leaf pine, but other types of pine (shortleaf and loblolly) also occur. A number of hardwood trees are associated with the long-leaf pine forest and these include white oak, southern pin oak, water oak, willow oak, overcup oak, hickory, birch, beech, magnolia and sweetgum especially in the bottomlands and floodplains. In swampy areas tupelo and bald cypress are commonly seen. Other species that are commonly associated with this forest community are plum, holly, yaupon, dogwood, redbud, and red and black haws. This forest community has been almost totally cut for lumber, but the junior author (Bousman) saw a small, 3-4 acre, plot of virgin, uncut beech-magnolia forest in northern Newton County in 1973. This forest had no shrubby undergrowth, a very tall closed canopy, and the beech and magnolia trees were approximately 2 to 2.5 meters in diameter. This suggests that the modern forests available for study may bear little resemblance to some of the virgin forest communities that existed in the prehistoric past.

Pine-Hardwood Forest

This forest community occurs north of the Short-Leaf Pine Forest, but still occupies much of far Eastern Texas. Pines, loblolly and short-leaf, are common and often found with a variety of oaks such as post, blackjack, white, yellow, red, water and willow oaks. Other arboreal species that characterize this forest community are birch, sweetgum, maple, magnolia, cottonwood, elm, walnut and willow. Shrubs consist of persimmon, redbud, holly wax myrtle, dogwood, black haw, sassafras, French mulberry, ironwood, and hornbeam. Small open prairies occur sporadically throughout this forest and appear to be responses to edaphic-water availability factors.

Oak Woodlands

The Oak Woodlands occurs as a band that extends from northeast to southwest across the region of Northeast Texas. Characteristic trees include post oak, blackjack oak, hickory, pecan, ash, sycamore, birch, and willow. Pine does not extend into this plant community. Other plants include juniper, yaupon and a variety of grasses. Prairie communities become more common and larger, and the western edge of the Oak Woodlands is bounded by prairie communities in some areas.

Blackland Prairie

Scattered prairie communities are found throughout the Northeast Texas region, but in general these communities only reach a significant size in the western portion of Northeast Texas (Diamond, et al. 1987). The distribution of grasslands is clearly related to rainfall as well as other soil characteristics such as clay content (Afisols versus Verisols) and pH (Diamond and Smeins 1985). The easternmost and largest grassland community is known as the Blackland Prairie, and it has two outlying communities known as the San Antonio Prairie and the Fayette Prairie. Grasses commonly found in these prairies include little bluestem, Indiangrass, switchgrass, big bluestem, side oats grama and eastern grama. A wide variety of composites and chenopods are also found within these prairie communities.

VI. DEPOSITIONAL SYSTEMS AND FEATURES

Paleoenvironmental inquiry as it relates to human history in Northeastern Texas is concerned with the last 12 millennia or so of the Late Quaternary, that is, the waning millennia of the Pleistocene and the entire Holocene. Quaternary deposits are shown on general geologic maps such as United States Geological Survey Quadrangle Maps or the Geologic Atlas of Texas sheets (Barnes 1964, 1966, 1967, 1968, 1970, and 1987). A brief review of such maps reveals that perhaps 11 percent of the region's surface is mapped as Quaternary-age deposits, mostly valley alluvium. These generalized maps provide a very rough guide to the occurrence of deposits of culturally-relevant age, but are not particularly accurate at the level required for the purposes addressed in this discussion. In reality, a much larger area than the 11 percent mapped as Quaternary deposits has been depositionally or pedogenically active in the recent millennia. Thus areas in Northeastern Texas mapped as Cretaceous, Tertiary or early Quaternary may be covered locally with thin veneers of deposits of culturally relevant age and regionally with soils that have been active in the last 12 or so millennia. It is, therefore, usually necessary to locally or regionally discover, describe, map, determine ages of, and interpret geologic deposits relevant to archaeological inquiry. In Northeastern Texas, deposits of fluvial origin are the most common, but colluvial, limnic, and possibly aeolian processes may impinge on the human history of the area and be represented by deposits.

Fluvial deposits are those laid down by the action of water moving in defined stream or river channels. Fundamentally distinct environments of deposition occur in and adjacent to streams. Those occurring in the stream produce channel deposits which directly reflect such aspects of the stream as its energy regime, size, position, and sediment source areas. Channel deposits may contain displaced artifacts as well as biotic remains transported from upstream points of origin. Adjacent to their channels, streams in flood stage lay down deposits in the overbank flood environment. These deposits frequently bury archaeological sites and in aggregate often provide excellent sources of data on past environments and human ecology including flood risk. The common kinds of overbank deposits are point bars, levees, valley ridges, crevasse splays, and flood basin fill (Figure 14). Alluvial fans develop as accumulated channel and overbank complexes under certain circumstances along valley walls (see Figure 14). Each of these kinds of deposits as they relate to human paleoecology in Northeastern Texas is discussed individually.

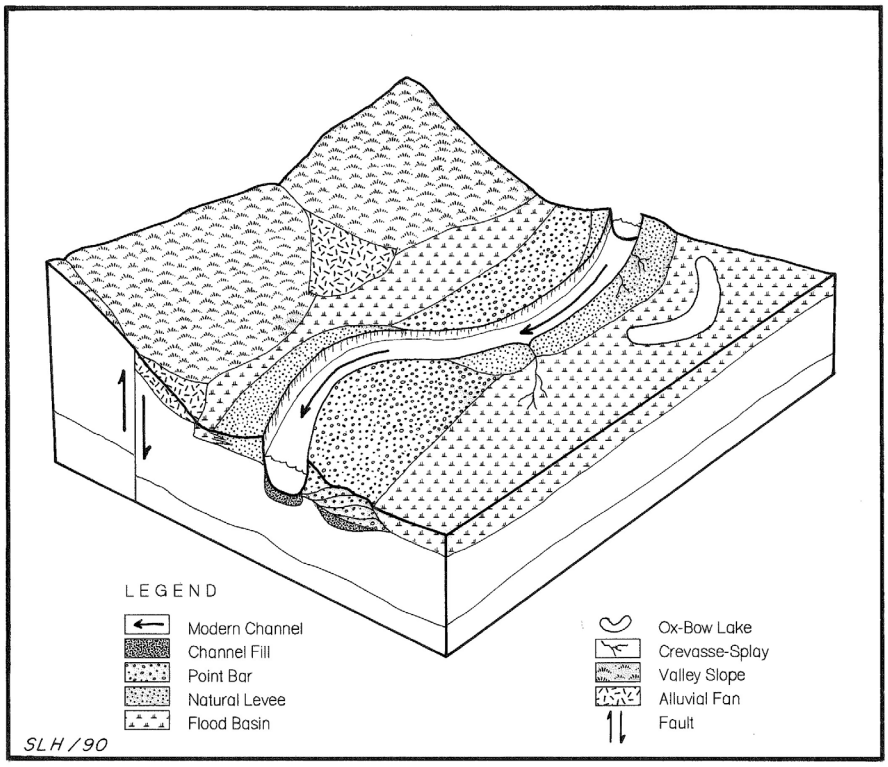

Figure 14: Depositional environments common in Northeastern Texas.

The nature of deposits along fluvial systems is the product of many variables including climate, vegetation cover, topography, bedrock and soil characteristics, and the geometry of the drainage basin (Knox 1983). These variables interact and the subtleties of their interactions and control are not well understood. In spite of this, a general idea of a stream's character and the nature of deposits it is likely to produce can be gained by reviewing general environmental data. In Northeast Texas, rainfall occurs in all seasons with the major peak in the spring and a lesser peak in the fall; heavy rains do occur, sometimes in rapid succession. The runoff that can be generated by heavy rains depends on the steepness of gradients and the capacity of the catchment to retard runoff by soil absorption and vegetative cover. Thus, for example, of two streams draining well vegetated basins of similar geometry, one with deep sandy soils might not flood as a result of heavy rain whereas one with thin clayey soils would; greater development of overbank flood deposits could be expected in the valley of the latter stream.

Classic works on fluvial systems (e.g. Leopold, et al. 1964, Allen 1965, Knox 1983, Reineck and Singh 1975) provide synopses of stream characteristics and behavior. A fundamental concept views a stream system as ideally having three reaches. Most large rivers simultaneously manifest all three. The upper reach occurs in the mountainous headwaters where various small tributaries join to form the drainage system. These tributaries are mainly erosional agents, descend at relatively high gradients, and occupy steep-sided valleys with narrow floors.

The intermediate reach of a river system occupies a broader valley of less steep gradient, meanders on the floor of its valley, and is joined by fewer but larger tributaries. Importantly, even though the intermediate reach of a stream is capable of locally eroding and is in the process of transporting sediment from upstream to points farther downstream, it is actively building a floodplain, primarily in the form of lateral accretion deposits called point bars.

The lower reach of a river occurs near its mouth in the coastal region. Here the stream often develops distributary networks and produces extensive deposits which coalesce with those of other streams since no significant divides separate streams along mature coastlines. Streams in Northeast Texas are mostly of intermediate character with active upper reaches. Minor streams also have locally developed distributary systems where they flow onto flat valley floors or into small lakes. But the dominance of intermediate stream morphologies, characteristically sinuous in relatively broad valleys, has profound implications for paleoenvironmental and archaeological research in Northeastern Texas.

Sinuosity is a stream characteristic that can be examined using existing maps. There appears to operate a fundamental relationship between width of a channel and the meander length as well as between channel width and radius of curvature in stream bends. Since width is an expression of discharge, these relationships allow recognition of changes in stream volume over time in some cases. Abandoned channels often leave scars on the floodplain of a meandering stream. If, for example, the radius of bends in these scars is greater than bends in the present channel, it would be evidence that flow was previously greater than at present. Streams may also entrench their channels into the valley fill. If, when entrenchment began, stream discharge was greater than at present, the present stream may be small in comparison with the radii of the fossil bends it follows; such a stream is referred to as "underfit" and can be inferred to have experienced a reduction in discharge.

The index of sinuosity (ratio of channel length to valley length) of streams in Northeastern Texas is almost invariably greater than 1.5 and is as high as 2.8 (for example on the Tom Quadrangle stretch of the Red River). The significance of an index of 1.5 or greater is that the channels of such streams meander, cutting on the convex side of bends and depositing on the concave sides. The areas of deposition are known as point bars. Point bars grow laterally as well as vertically when flood-born deposits are added to their surfaces. Because the main energy of the stream is directed toward the outside of the bend, the point bar is a relatively low energy environment of deposition. Since deposition is favored over erosion, point bars are excellent sediment traps for the capture and preservation of materials useful in cultural and environmental inquiry. During times of normal flow, a majority of the point bar surface is exposed and affords a comparatively clean, open stream bank area that is often attractive for human utilization. Evidence for such activities is often buried during the next episode of elevated flow and successive occurrences of this cycle can produce excellent stratified sites. Since lateral accretion generally exceeds vertical accretion in point bars, there is produced a strong horizontal dimension to the stratified sequence of deposits comprising a point bar. It is therefore advantageous to investigate a point bar in an alignment parallel to its axis of lateral growth (which is roughly perpendicular to the channel at the outer most extent of its bend). Although vertical stratigraphy prevails at any given place on a point bar, stacks of deposits will span progressively earlier intervals of time the further they are from the apex of the point bar. Because the surface of the point bar rises gradually away from the stream, and because the surfaces more remote from the stream are traversed by lower energy flood water, there is a decrease in volume and coarseness of deposits with distance from the stream. Typically after a flood the fresh deposits on the surface of a point bar will be sand or gravel next to the stream, sand to silt on the gentle slope, silt to clay near the crest of the slope, and mud or clay from the crest of the point bar back toward the valley wall (the flood basin, discussed below). Vegetation is unevenly distributed across active point bars. The stream edge tends to be more open because few species

tolerate rapidly aggrading surfaces. Thus, point bar surface nearest the stream may afford the most attractive environment for human habitation if flood risk is not unacceptably high. This favors rapid burial and preservation of cultural vestiges as well as the construction of stratified and totally buried sites.

Many Northeastern Texas streams meander at relatively slow rates and any given point bar may build for many centuries or several millennia. This means that working from near the present stream bank toward the valley wall, an investigator may find very long sequences of deposits with few or no hiatuses (interruptions in the depositional record). Archaeological sites in these settings are rarely visible from the surface and must be sought using subsurface techniques (see below). Sites buried in point bars are especially scarce among those reported from Northeastern Texas. (For example, maps showing the locations of sites recorded during archaeological surveys of Bob Sandlin, Lake Lavon, Palestine, Lake Fork, Monticello, and Big Pine reservoirs are virtually devoid of sites in the settings where point bars should occur [Hsu 1969, Sullivan n.d., Lorrain and Hoffrichter 1968, Anderson 1971, Mallouf 1976, Bruseth, et al. 1977, Hyatt and Mosca 1972, McCormick 1973]). This could mean that aboriginal site preferences selected against point bars or it could mean that such sites are under-represented in our archaeological samples. That the latter is the case is suggested by two observations. First, point bars in Northeastern Texas are often low, heavily vegetated, and subject to flooding, conditions which reduce the likelihood of subsurface sites in point bars being discovered unless specifically targeted by a sampling design. Second, even under more favorable conditions, sites buried in point bars have often gone unnoticed by archaeologists. In western Texas, most streams have entrenched in recent centuries leaving point bars of middle to Late Holocene age well above ground water table and most flooding. Such point bars lost their riparian plant cover and many have been subject to erosion which has exposed buried archaeological remains. In spite of these favorable conditions for discovery, sites buried in point bars along the Colorado River were not recorded in the pre-construction archaeological investigations of Buchannan (Jackson 1938), Travis (T.A.R.L. files), and Robert Lee (Shafer 1967) reservoirs. Very few were recorded in the initial survey of Stacy reservoir (Wooldridge, et al. 1981). No subsequent records are available for Robert Lee (now Spence) and Buchannan lakes, but at Stacy (now Ivey) and Travis lakes, more recent examination reveals that buried sites were numerous in both areas. At Stacy (Ivey), several large point bars were specifically examined for evidence of buried sites (Bryan and Collins 1989) between the time of the initial survey and inundation. At Lake Travis, during periods of low water since the reservoir was first impounded, numerous lag concentrations of archaeological detritus have been found in deflated areas where point bars had previously existed (TARL files). The question that these observations suggest is whether concerted sampling of point bars in Northeastern Texas for buried sites would discover such sites.

Levees are complex parts of the overbank flood deposit regime and, like point bars, are commonly preferred settings for various human activities. Levees develop as ridges along the stream channel edge. In section perpendicular to the channel, a levee is wedge-shaped, being thickest at or near the edge of the channel and tapering off gradually away from the stream. Sediment suspended in flood water is dropped as the flood waters overtop the stream banks and experience an abrupt reduction in velocity and, therefore, capacity to transport sediment. Levee deposits are coarsest close to the stream and become finer with distance from the channel. Levees contain floods of less height than the top of the levees unless a crevasse (break) occurs at which point a crevasse-splay deposit is created. A crevasse-splay is a tongue-shaped deposit extending from the crevasse out into the flood basin. Crevasses are most often found on the exterior of bends. Splay deposits are made up of coarser material than are the flood basin deposits on which they are spread. Although probably not of much importance as sources of paleoenvironmental data, buried splay deposits seen in section in otherwise fine flood basin deposits are easily misinterpreted as resulting from events of greater magnitude.

Levees are considered to be vertical accretion deposits, and this is undoubtedly the usual case. However, downstream progradation has been documented in "floodplain ridges" along the Ohio River in Indiana and Kentucky (Gray 1984). These were found upon close investigation to grow by accretion on the downstream extremity in a progradational pattern much like point bars. The significance of this to archaeology and paleoecology is that long sequences of deposits result which are stratified vertically as well as down-valley. Downstream progradation may occur more commonly than is suspected, and may be a factor in most levee formation. The accretion of floodplain ridges investigated by Gray occurred at the confluence of small tributary streams with the Ohio River. The down-valley accretion of the ridge progressively forced the confluence downstream to produce a distinctive map pattern in which a side stream approaches the main stream at high angle, turns downstream behind the floodplain ridge, and flows a considerable distance down-valley and nearly parallel to the river before turning and entering the river. The ridges Gray documented were each several millennia in age. This distinctive pattern occurs in valleys of Northeastern Texas and may be evidence that downstream progradation has occurred (see, for examples Goodwater and Choctaw creeks as they enter the Red River in Choctaw County, Oklahoma [S.W.Frogville Oklahoma-Texas Quadrangle] or Mud Branch as it enters the Red River in Fannin County, Texas [N. W. Monkstown Quadrangle]).

Flood basins are the expansive areas laterally distant from stream channels and generally behind levees. Overbank flood waters reaching these areas is extremely slow-moving and carries only fine suspension load. Flood basin deposition is gradual and flood basins are often swampy and heavily vegetated. Organic-rich clayey deposits are characteristic. Flood basins may be scarred by relict channels which, if conditions are right, will fill with water (oxbow lakes and swamps) permanently or seasonally. These are excellent sediment traps for environmentally sensitive floral and faunal remains. Flood born sediment is periodically added to these basins and well-stratified deposits with preserved organic remains may result. Flood basins in Northeastern Texas are rich in floral and faunal resources of value to humans but do not afford hospitable environments for camping. Occasional evidence of human presence may occur in flood basin deposits, but concentrations resulting from encampments should not be expected.

When a stream entrenches into the floor of its valley, it becomes lower in elevation and, more importantly, it becomes lower in relation to the surface of its floodplain. This results in less frequent flooding and, eventually, the former floodplain may become abandoned in the sense that its height above the stream is so great that no floods from the stream overtop it. These relatively high former floodplains whether completely or partially abandoned by the stream are referred to as terraces. It is important to note that terraces are not themselves depositional environments and statements like "terrace deposits" are inappropriate. Rather, terraces are made up of deposits in formerly active channel, point bar, levee, crevasse-splay, and flood basin depositional environments. The term "fossil floodplain" is quite descriptive and paleoenvironmental and archaeological data recovered from formerly active areas of deposition preserved in a terrace relate to these contexts. Once a stream has downcut and formed a terrace of its former floodplain, the scarp along the streamward edge of the terrace becomes equivalent to the valley wall in the sense that the now active floodplain extends to the toe of that scarp. Multiple episodes of stream entrenchment result in multiple terraces which conform to the well-known principle that higher terraces are successively older. Thus, each suite of component deposits should be in successively older stacks from lower to higher terraces. This is not a perfectly reliable relationship as streams sometimes overtop older terrace surfaces and add deposits contemporary with those on the lower floodplain surface. Besides the value terrace sequences have for relative chronological ordering of constituent deposits and surfaces, the timing of episodes of valley filling and stream entrenchment is important paleoenvironmental information in its own right, as discussed more fully below.

Alluvial fans occur along the margins of valleys in those settings where the valley wall is a fault plane with the valley floor moving down relative to the adjacent upland. Intermittent streams crossing the fault plane build large fan-shaped bodies of comparatively coarse sediment where the gradient drops from relatively steep in the tributary valley to relatively flat in the main valley floor. Deposits at the wide base of an alluvial fan merges with the margin of those comprising the fluvial valley fill. From the apex of the alluvial fan, distributary channels radiate out over the surface of the fan. Given the intimate relationship between the formation of alluvial fans and the presence of active faults, one would not expect such features in Northeastern Texas, however, recent research in Cooper Basin on the south side of the Sulphur River valley has documented the presence of what appear to be a fault and an associated alluvial fan (Ferring, personal communication). The evidence is preliminary and conclusions highly tenuous, but the fault may have been active during the last 9,000 years and it is likely that a corresponding fault exists on the opposite side of the valley. Subparallel faults with the land between them moving down relative to land outside of the faults is known as a graben; if the Sulphur River is flowing in an active graben valley (cf. Darwin, et al. 1990: Figure 3), it would explain the presence of the thick Quaternary-age fill found there (Bousman, et al. 1988). [This issue is discussed more fully in later sections on tectonics and on valley filling/cutting cycles].

Alluvial fans may become buried or partially buried by aggrading valley fill. In such cases, restricted exposures of the sort often utilized by archaeologists might encounter beds of contrasting texture in a valley floor. If the exposure is too limited to determine the geometry of these beds, it may not be possible to determine if one is seeing alluvial fan deposits or deposits resulting from changing energy levels in the fluvial system. Drastically different paleoenvironmental conclusions would be indicated depending on which of these interpretations was made in the investigation. If the coarse deposits exposed at Finley Branch in Cooper Basin do in fact turn out to be part of an alluvial fan Bousman, et al. (1988) made precisely this error by assuming that they were seeing fluvial material and therefore not investigating the geometry of the exposed deposits.

Extensive, undifferentiated Quaternary valley fill characterizes most of the wider valley floors in Northeastern Texas (see Geologic Atlas of Texas, Dallas, Palestine, Sherman, Texarkana, Tyler, and Waco sheets; see also most maps of archaeological surveys in reservoir basins). Very little published information exists on these fill deposits as to their actual ages, the depositional environments (levees, point bars, etc.) of which they are comprised, and their archaeological and paleoenvironmental data content. It becomes part of the archaeologist's task to insure that these aspects of archaeological context are considered and treated adequately; most importantly, geological and archaeological inquiry benefit from being fully integrated.

Most fluvial deposits are subject to direct dating using various geochronological techniques (see discussion below). Streams remove, transport, and deposit sediments. The specific relationships among these actions manifest by any stream at any given time is the product of complex and interactive variables among which the geometry of the stream system, vegetative cover, runoff rates, substrate, and nature of sediments being transported are probably the more important. A tentative premise, at least for the sake of discussion, would be that if runoff rates are relatively constant, a stream system will be cutting in its upper reaches and depositing in its lowest reaches. In the intermediate reaches (which predominate in most of Northeastern Texas) the prevailing action will be lateral meandering of low to moderate intensity. Erosion on the outside, and deposition on the inside, of bends will be characteristic with cutoffs of meanders or avulsions (abrupt shift of channel location) occurring occasionally. This condition of near equilibrium will prevail until one of the controlling variables changes. Assuming that no force external to the system, such as subsidence or faulting, alters the geometry of the drainage system, the most probable alteration to the system is likely to be in runoff which may increase, decrease, or become less regular. Climate is the primary control on runoff both directly in terms of amounts and patterns of precipitation and evaporation and indirectly via its effects on vegetation cover. Stream response to changing runoff patterns will be shifts in rates and locations of erosion and deposition. In the lower reaches, channels may begin to build up with sediment in response to a drop in erosive capacity. Sustained channel filling will lead to accumulation of sediment in the valley beyond the channel. Conversely, if a stream's erosive capacity is increased in its middle reaches, it may cut its channel more deeply into the valley floor. Cycles of valley cutting and filling produce observable consequences of climatic change in the geologic record. One situation is that in which there are seasonal shifts where channel filling prevails part of the year and cutting the rest of the year. Complexes of levees, flood chutes, avulsions, and other expressions of this instability are likely to result.

Extensive terrace sequences are common along most of the streams in Northeastern Texas, especially notable examples being those along the Red and Trinity rivers (Gilmore and McCormick 1982). There are also major fossil floodplains similar to the Deweyville (Mandel 1987) and extensive valley fills such as found in Cooper Basin (Bousman, et al. 1988). There is a great deal of paleoenvironmental information to be gained from comprehensive studies of such sediments. In the past, unrealistically simplistic models, such as glacial advance and retreat events, have been used to explain and correlate the formation of terraces. Comprehensive study must integrate the findings of paleontology, palynology, stratigraphy, pedology, archaeology, and geomorphology. The most important single tool in integrating these fields is absolute dating (cf. Autin, et al. 1990; Blum and Valastro 1989). Synthetic interpretations of Quaternary environments and human ecology will rest primarily on data from fluvial systems such as these (see Saucier's [1990] discussion of the setting of the Sloan Site [N.E.Arkansas] for an example of this type of synthesis).Only when multiple stream systems are shown to manifest correlated cycles of cutting and filling, soil histories, and biotic sequences is the inference fully warranted that climate is responsible. A single case could result from localized causes of another kind. More investigations of the kind recently reported by Hall (1990) for the Late Holocene in the south central United States are needed. A concerted effort to discover and document evidence of valley filling and cutting during the terminal Pleistocene, early Holocene, and middle Holocene is particularly needed.

Once regional patterns are established, it becomes critical to explain localized episodes of cutting or filling that do not correspond to the established pattern. Such occurrences may signal important localized conditions, such as subsidence or disruption of vegetation cover, with important implications to local human ecology.

Colluvial Slopes

Areas with significant relief are subject to development of colluvial slope features. Two meanings are generally attributed to the term, colluvial fan, and some confusion may derive from the fact that the more common meaning would not be expected to apply in Northeastern Texas. The usual meaning of colluvial slope is coarse detritus accumulated at the base of a steep slope. Less often the term is used to designate alluvium deposited at the base of a slope by unconcentrated surface runoff, a situation occurring fairly often in Northeastern Texas. At the toe of such slopes there is often interfingering with fluvial valley fill and the surface of the colluvial and fluvial masses merge imperceptibly. Colluvial slopes often afford gentle rises along the margins of flood basins where people can be close to flood basin resources but be above all but the highest of floods. Sites resulting from human activities in these settings occur in moderate frequency (e.g. at Lake Fork, Big Sandy and Big Pine Lake [Bruseth, et al. 1977; Perttula, et al. 1986; Mallouf 1976]) and it is important to recognize the ways in which natural depositional processes on colluvial slopes differ from those of flood basins. The energy as well as the sediment derive from the immediate slope area in response to local runoff conditions as opposed to up-valley conditions. The potential for contrasts between these will be greater in larger stream systems. Changes in the depositional regime of a given stream may result in either burial of colluvial slopes in aggrading flood basin deposits or isolation of them at the back side of terraces (fossil flood plains). In cases where all or part

of a colluvial slope has been buried in fluvial valley fill, it will exist as a wedge-shaped unit near the valley wall, thinning with distance from the valley wall. In almost all cases, colluvium will be coarser than flood basin deposits, but not necessarily greatly so in settings common in Northeastern Texas. It therefore behooves an excavator who encounters coarse beds in a valley fill to determine the geometry of the beds to avoid confusing a colluvial slope with a change in stream behavior exactly as mentioned above in reference to alluvial fans.

Colluvial slopes in Northeastern Texas have received little attention from archaeologists other than the occasional recognition that sites occur on such features. The potential for well stratified sites to occur in colluvial wedges and the possibility that the physical stratigraphy of such wedges may sensitively reflect local runoff conditions and therefore be useful in environmental reconstruction should warrant closer scrutiny. In many settings, as for example in Cooper Basin, colluvium would contrast with fill introduced from up valley by the fluvial system in two regards--it would be coarser and it would be less well sorted. In addition, where the lithology of the local valley wall contrasts with lithologies found up valley, the colluvium should also be of contrasting materials.

In some areas of Northeastern Texas, there are valley systems where bedrock, valley fill, and colluvial materials are virtually indistinguishable. Where clay dominates the bedrock or where bedrock is unconsolidated sand, colluvial slopes are texturally similar to other kinds of valley deposits (e.g. in the Big Sandy drainage [Perttula, et al. 1986]).

In these instances colluvial slopes may easily go unrecognized unless clearly expressed topographically. In general, we know so little about the human ecological implications of colluvial slope environments, that almost any research will prove important, even it demonstrates that colluvial slopes have relatively little information value.

Limnic Depositional Systems

Lakes, ponds, marshes, and bogs are important aquatic environments of sedimentary deposition. Lakes are relatively large bodies of open water in an area of low elevation. By definition, there are at least some areas where the water is too deep to sustain rooted plant life. Ponds are similar, but smaller. Marshes are predominantly found along small streams in areas of elevated water table and may be permanently or intermittently saturated. Marshes are generally completely vegetated--often with grasses--but do not favor the formation of peat. Bogs are waterlogged and spongy areas in which mosses and other decaying vegetation produce an acidic environment; peat often develops from this decaying vegetation. Each of these aquatic environments provides a potential sediment trap where cultural and/or environmental evidence may accumulate. Lakes and ponds in Northeastern Texas are generally of fresh water, aerobic, and basic. These may contain excellent physical stratigraphic records, and even fossil bone, but are not favorable for botanical preservation. Bogs, on the other hand, are anaerobic, acidic and may have remained permanently saturated over long periods of time. These are almost optimal environments for the preservation of the entire spectrum of organic remains (Bryant 1989). Furthermore, bog material is itself suitable for radiocarbon dating. The few analyzed bog pollen columns (see below) available for the region are probably a bare minimum of those that exist. Systematic searches for additional bogs and preserved peat deposits constitute a high priority for paleoenvironmental research in Northeastern Texas. When coring and analyzing future bog and lake or pond sequences, more samples should be submitted for radiocarbon dating as existing dates from analyzed bogs are not sufficient for the detailed types of analyses undertaken these days. Other lines of investigation--at least including isotopic determinations--are needed to augment plant taxa studies.

Fisher (1965:Plate V) maps at least 50 areas where "principal marshes containing peat deposits" [bogs would be the more accurate term] occur in Northeastern Texas. Many of these occur in the broad belt of Eocene sands, but a few are mapped as occurring in the alluviated Red River Valley. According to Vaughn M. Bryant, Jr. (personal communication), many of those shown on Fisher's map in the Eocene belt have been visited by him and his associates and found not to be promising sources for pollen and related data, but not all have been visited and certainly not all have been mapped. The conclusion seems obvious that important sources of data are there to be tapped. Particular emphasis should be on finding suitable bogs in the northeastern part of the region to complement the data from east central Texas.

Oxbow lakes and marshy floodplain settings can be seriated by temporal order in some instances using maps of meander patterns. Relative chronologies based on geomorphic seriation can be effectively tied to an absolute chronology with a few carefully selected radiocarbon samples. Once a series of oxbows has been dated, coring for data from targeted time periods is possible.

The major natural lake in Northeastern Texas is, of course, Caddo Lake. Surprisingly little investigation of the natural history of this lake and its implications to human ecology has been performed. The origin of the lake is not even known. The case seems to be firmly made that the lake existed prior to the early 19th-century New Madrid earthquake and folklore attributing the formation of the lake to that event is inaccurate (Davis, et al. 1989). On the other hand, it appears likely that the lake is not greatly old. The interpretation put forward by Gibson (1969) that ceramic-age sites were submerged by the formation of the lake

is provocative, but must be considered only a possibility until firm data are presented. A consideration of Caddo Lake as one of numerous lakes along the Red River drainage system may help focus research issues posed by the lake.

Along the Red River from north of Paris, Texas, to near Coushatta, Louisiana, are numerous indications that the Red River floodplain is aggrading more rapidly than the floodplains of its tributaries. Doering (1963) noted an up-valley dip to the surfaces of Sulphur River terraces near the confluence of that stream with the Red River and, correctly we think, attributed this to relatively more rapid aggradation of the Red River. That Doering's observations do not reflect a localized condition is clear from topographic and drainage patterns along the river, particularly in Louisiana. There are extensive areas in the vicinity of Shreveport where the floor of the Red River valley slopes down from the margin of the present channel toward the valley wall. This slope extends laterally an average of 5 km where the valley is constricted and up to 8 km in the vicinity of stream confluences. Dendritic drainages reflecting this slope are well developed. Minor streams flowing away from the river join near the valley wall and flow long distances down valley before joining the main stream. In addition to the numerous oxbow lakes along the river, extensive lowlands, some marshy, boggy, or even containing lakes, are fairly common in tributary valleys. These may be analogous to Caddo Lake and all represent drainages with gradients reduced by relatively more rapid aggradation along the Red River. Should this be the case, it would be important to know when this condition began.

Hall (1990) has documented widespread valley cutting beginning roughly 1000 years ago. It is not known if this extended east of about the 95th meridian (ie. slightly east of Houston and north through Mount Pleasant), and if so, what its effects and duration may have been. The topographic evidence just reviewed suggests that the tendency for the Red River to aggrade its valley more rapidly than its tributaries has prevailed for much of the Late Pleistocene and most of the Holocene. If this is the case, the famous Red River Raft may have begun to form as the valley cutting noted by Hall began to reach into headwater streams along Red River and drop the valley water tables. Trees cut off from reliable ground moisture may have died and eventually entered the river system to be transported downstream. In northwestern Louisiana the Red River gradient became too gradual to continue to transport them and the log jam began to form. Once in place, it continued to grow until artificially breached in the 1870's (Lenzer 1980). The consequences of a log jam the magnitude of the Red River Raft to tributaries of low gradient could be extensive (ibid). There may be deposits in the Red River Valley that formed as a consequence of the raft. A study of these could potentially produce valuable ecological information.

Perhaps ponds and marshes in subsidence features over salt domes should also receive closer scrutiny from researchers interested in the paleoecology of Northeastern Texas. Some of these are saline (Jackson and Seni 1984:79-81; Fisher 1965). The presence of salt at the surface has important implications for human ecology. Animals attracted to salt as well as the salt itself make such localities attractive to humans. Saline water is also potentially favorable for the preservation of some kinds of archaeological and paleoecological data (Gagliano 1967; Kolb 1976; Kolb and Fredlund 1981).

In addition to the natural limnic features, cultural sediment traps need to be considered as well. Borrow pits were excavated by prehistoric inhabitants for the construction of large mounds. These borrow pits may contain sediments that immediately post-date mound construction. For example the borrow pit for the Caddoan mounds at the Hale Site in Titus County (41TT12) was excavated on a flat upland platform and held water into the early part of this century (Houston Berkhart, 1972 personal communication to Bousman). This borrow pit is now nearly full of sediment that presumably accumulated through natural deposition. The infilled sediments could contain pollen, phytoliths, diatoms, charcoal and other proxy paleoenvironmental evidence that might provide a detailed sequence of past environmental change at the Hale Site. Other archaeological sites and other man-made depositional catchments that have the potential for providing similar types of data should be explored.

Aeolian landscape features pose a particularly murky topic for Northeastern Texas. There are extensive sand deposits at the surface in many areas of Northeastern Texas. At any time that vegetative cover is disrupted, these are subject to modification by wind. Some indications of aeolian modification of sand deposits has been noted (e.g. Perttula, et al. 1986; Gunn and Brown 1982; Mandel 1987) in and near the region. However, at present, the validity of some of these interpretations, the possible extent of Quaternary aeolian-modified landscape, and timing of any increased aeolian activity are at question. Concerted and thoughtful inquiry into this issue is needed as part of the more general question of Quaternary landscape modifications from all causes --fluvial, colluvial, aeolian--throughout the sand belt.

VII. SOILS

Not all of Northeastern Texas has been mapped in detail using modern soil designations, but soils data useful in environmental and archaeological inquiry are available. At the very general level, soil Orders are mapped for the entire state of Texas (Godfrey, et al. 1973). Relatively recent maps of Soil Associations and Series are available on a county-by-county basis (U.S.D.A., Soil Conservation Service, County Soil Surveys) for a majority of Northeastern Texas counties. Soils reflect the composition of the substrate on which they form, the length of time over which they have formed, and the environmental conditions prevailing during their formation. Therefore, soils data provide clues to age, character, and environmental context of the parent material on which they formed. When a modern soil survey is available for any particular research area, the data it provides include a general soil map of the entire county as well as detailed mapping of individual soil series (the most detailed level in the hierarchical soil classification scheme), both of which are useful. Also provided is usually a table giving the Family, Subgroup, and Great Group classification for each soil series mapped in the county. Patterns in the distributions of these soil classes can be used to predict soil conditions important in paleoenvironmental research (Birkeland 1984).

As mentioned, upland areas of Northeastern Texas are generally distinct from valleys as regards soils. Soils in the uplands are most often forming directly on bedrock and have been in place for very long periods of time. These fall primarily into the four

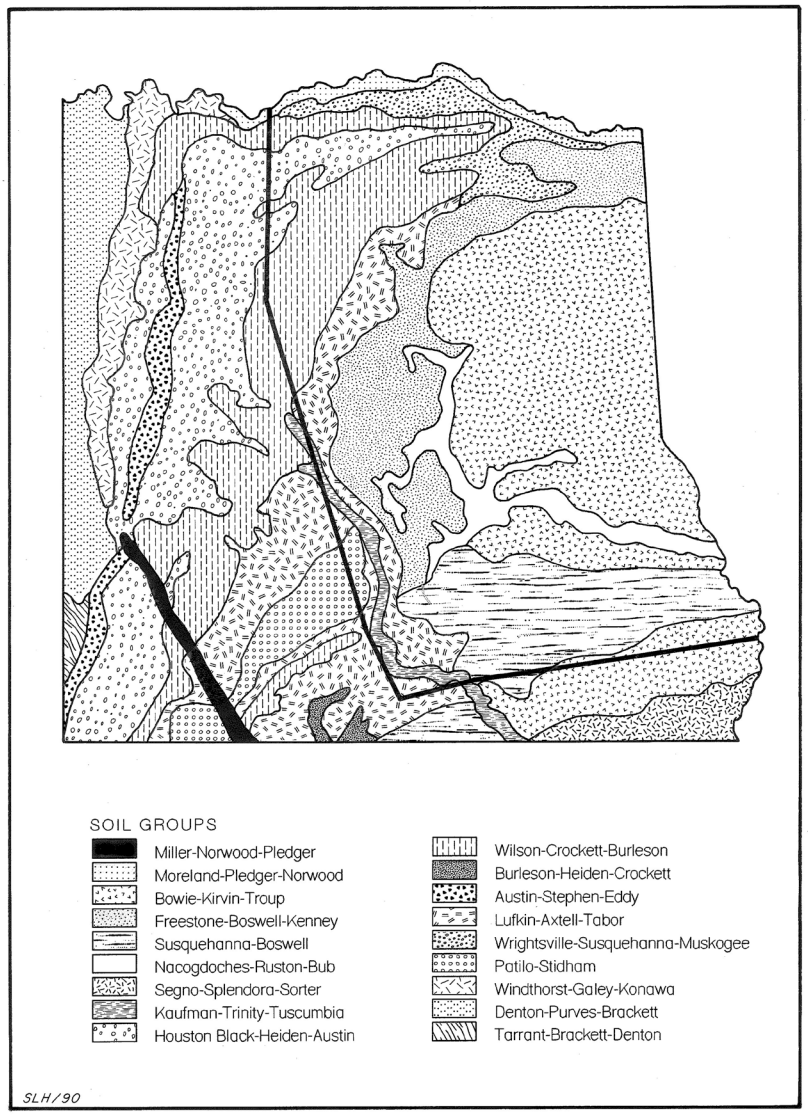

Figure 15: Soil orders of Northeastern Texas (after Godfrey, et al. 1973).

Orders: Alfisols, Ultisols, Vertisols, and Mollisols, in descending order of extent (Figure 15).

Alfisols, which have light-colored, loamy A horizons with clay-enriched B horizons and tend to be basic, in Northeastern Texas commonly include soils in the six Great Groups, Albaqualfs, Ochraqualfs, Glossaqualfs, Paleudalfs, Paleustalfs, and Haplustalfs. Albaqualfs are seasonally wet with a bleached layer abruptly on clayey subsoil; Glossaqualfs manifest tongues of bleached layers into the subsoil. Ochraqualfs lack bleaching and are seasonally wet with the surface layer grading into the subsoil. Paleudalfs are commonly moist, occur on ancient landscapes, and have a deep, reddish subsoil. Paleustalfs are usually moist and very deep; they have reddish subsoil horizons and occur on old land surfaces. Haplustalfs are usually moist and deep to moderately deep; the clay content in the subsoil decreases with depth. Alfisols in general because they are basic afford conditions slightly favorable to some preservation of bone and other organic remains, but not for extended periods of time, especially under conditions of alternate wetting and drying. These soils are also subject to extensive bioturbation, especially by burrowing animals (Boul, Hole and McCracken 1989).

A good example of archaeological materials in an Alfisol context is the Manton-Miller site in Delta County (Johnson 1962; Hyatt and Doehner 1975; Ressel 1979). The long stable surface responsible for the formation of this Vertic Paleudalf soil accounts for the virtual lack of stratigraphic separation between components representing several millennia of human utilization of the locality. Without any excavation, this situation could have been predicted from the soil-geomorphic setting.

Ultisols are light-colored, acid soils formed in warm humid regions (Boul, Hole and McCracken 1989). A-horizons are sandy to loamy over a clayey subsoil. In Northeastern Texas, these are the soils of the pine forests and consist mainly of Hapludults and Paleudults. Paleudults occur on old, stable land surfaces and are moist, very deep, reddish to yellowish soils with reddish mottles in the subsoil. Hapludults, too, are moist but the subsoil is reddish throughout and they are found in eroded areas. All Ultisols are destructive of organic materials. At the Mothershead Spring Site (Henderson 1979) only recent bone was preserved. This is an area of Ultisols (Godfrey, et al. 1973), and this pattern of brief survival of bone is characteristic. The implications of Ultisols for archaeological materials can be found in the Eagle Hill Site monograph (Gunn and Brown 1982: 134-139).

Vertisols occur along the northwestern edge of Northeastern Texas. The soils are seasonally dry or wet and support primarily prairie grass vegetation. Vertisols are clayey throughout, basic, with high shrink-swell potential (Boul, Hole and McCracken 1989). These soils shrink and develop deep, wide cracks when dry. When wet, they swell and the cracks close. Slickensides and gilgai are common features of Vertisols. These characteristics adversely affect the integrity of paleoenvironmental data when the three-dimensional relationships of objects in the soil are lost by downward movement in the vertical cracks and by mixing with soil movement (Duffield 1970). These soils have favorable chemical properties for the preservation of organic remains, but are mechanically damaging or destructive in many instances. Among the common Vertisols, Pellusters are gray to black, whereas Chromusters are brownish to reddish, at and near the surface. At site 41DL184 in Dallas County, cultural materials occurring in a Pellustert had been subject to extreme vertical and horizontal displacement and bone, for example, was severely broken but not greatly altered chemically (Peter, et al. 1988:99-125).

In the valleys in Northeastern Texas is found a variety of soils reflecting the ages and compositions of alluvial parent materials. Most of these fall into the Mollisols Order although Inceptisols and Entisols also occur.

Mollisols are very dark-colored at the surface and have relatively high organic contents. They are basic. They are commonly soft, granular, and do not become particularly hard when dry. These soils form under conditions of limited leaching in subhumid areas where high base--especially calcium--material is in contact with decomposing organic matter beneath, rather than on, the surface (Boul, Hole and McCracken 1989). Common Great Order occurrences are Haplaquolls, Hapludolls, and Haplustolls. Haplaquolls are permanently or commonly saturated, have dull colors, and grade from surface to subsurface horizons with little to no increase in clay content. Hapludolls are similar except that they are typically moist with little seasonal variation. Haplustolls are seasonally moist, but often dry. Otherwise, they are similar to Hapludolls and Haplaquolls. Mollisols afford favorable conditions for the preservation of organic materials and are valuable in paleoenvironmental research.

Inceptisols are commonly encountered in recent alluvium and manifest limited soil development (Boul, Hole and McCracken 1989). In areas of erosion, the lack of soil horizonation may be the result of equilibrium between erosion and weathering, an important factor to consider when using extent of soil development as an indicator of age of parent alluvium. The Neely Site in Red River County (Mallouf 1976: 305-358) occupies an area mapped as Inceptisols, but rather than being advantageous as part of an aggrading landscape, the site was eroding due to modern land clearing.

Entisols, too, manifest almost no soil development either because they are on extremely recent geomorphic surfaces or because the parent material is resistant to alteration (as quartz-rich sediments). The Arnold Site in Hopkins County (Doehner and Larsen 1978) manifests minimum soil development and reasonably good bone preservation due to its occurrence in an Entisol.

Anthrosols occur where ever human activity has been sufficiently intense to modify the soil characteristics. In many archaeological sites, soil attributes such as organic content or pH have been altered. In these limited settings, regional trends in the preservation of organic matter may be altered. Hence bone might survive in an Anthrosol whereas it would not in the surrounding native soil. An example of this is noted by a single feature filled by an Anthrosol, yielded almost the entire faunal assemblage from the Bison Site Area B (Woodall 1969: 47).

Soils in settings, usually valleys, where very gradual depositional accretion persists over long periods of time develop thickened A-horizons. These cumulic soils, as they are called, are generally clayey and rich in organic matter. The presence of a cumulic soil, whether at the surface or buried, is evidence that very regular, low-volume sedimentation has persisted at a rate sufficiently slow to allow substantial weathering of the successive surfaces. Since this is a slow process, thickened A-horizon soils have been in place for long periods of time during which no significant change in sedimentation rates have occurred. The Navarro Paleosol (Bruseth, et al. 1987) documented in the Richland-Chambers Archaeological Project is the best-documented example of this phenomenon in Northeastern Texas. In the Richland-Chambers area, low-energy, clay-rich overbank flooding persisted for 1.2 millennia (from A.D. 670 to AD 1820). A similar soil, found in Walnut Creek valley in southeastern Tarrant County persisted for an estimated 5 millennia (from earlier than 3820± 70 B.C. to later than A.D. 830± 80 [uncorrected radiocarbon years]) (Collins 1988). These and comparable soils, named Copan, found widely on the south central plains have been described and dated by S. A. Hall (1977, 1982, 1990).

A major indication of once stable land surfaces is the presence of buried soils. Soils of various kinds can become buried if deposition occurs on surfaces previously stable or nearly stable. A buried soil is sometimes traceable over wide areas and interpreted as conforming to an earlier landscape. Exposed in a single profile, a buried soil indicates a time of little or no aggradation. Buried cultural materials are often found in association with buried soils.

Major, widespread episodes of erosion are evidenced in much of Northeastern Texas by truncated soils. Ancient, well-developed B horizons beneath more youthful A horizons are characteristic of, for example, much of the Eocene sand belt (cf. Fields, et al. 1986: 7). No synthesis of this evidence has yet been attempted, but a tentative edaphic history formulated by such an effort is needed.

Paleoenvironmental as well as archaeological research in Northeastern Texas has benefitted from integration with information on past and present soils conditions, but far more potential exists in application of soil-geomorphic perspective at all scales of research. Soil-geomorphology is a research strategy in which the relationships between land forms and soils, past and present, are determined, mapped and interpreted toward comprehensive paleogeographic histories (cf. Birkeland 1984; Boardman 1985; Boul, Hole and McCracken 1989; Butzer 1982; Catt 1986; Hall 1983 and 1990; Mandel 1987). Archaeologists who are not versed in soils can contribute to soil-geomorphic data for Northeastern Texas by fully utilizing and reporting existing soil survey data. It is particularly helpful when the level of classification is given along with the soil Series because this information immediately conveys useful soil-geomorphic information. Also, guides such as that of Birkeland (1984, Appendix 1), Olson (1981), or Soil Survey Staff (1975: 459-477) can be used in the field to organize descriptions of soil profiles.

Active soils are largely made up of living organisms and organic matter from dead organisms. This organic content of soils is retained for long periods of time and is subject to radiocarbon dating. Directly dating samples taken from soils is an important aid to research discussed more below in the section on geochronology.

VIII. TECTONICS AND SEISMICITY

Northeastern Texas is not part of any of the principal active tectonic regions (where folding, faulting are commonplace) of North America either in terms of historically-recorded major tremors or of earthquake risk (Coffman, et al. 1982; Woollard 1958). However, the region does have evidence of extensive Tertiary faulting and is today subject to limited seismic (earth movement) activity (Davis, et al. 1989). Tectonic activity over the last 12,000 years has implications for human ecology as well as for archaeological research. Data compiled on earthquake occurrences in eastern Texas clearly identify natural events as well as events induced by the removal or injection of geofluids in connection with petroleum production. Because petroleum-related extraction and injection of fluids is so widespread in Texas, it is uncertain whether natural or industrial causes account for some of the recorded earthquakes centered near major oil fields. Even if none of the ambiguous events is considered, there have been recorded about 6 earthquakes in Northeastern Texas since 1847 (Davis, et al. 1989). These have reached moderate levels of intensity (from 3 to 4.7 on the Richter scale).

Geologically, evidence of Quaternary tectonics is in the form of faults and of topographic features. A fault is mapped as passing through Quaternary deposits along the Sabine River in Eastern Sabine County (Barnes 1968) and another near the confluence of Big and Little Cypress bayous in Marion County (Barnes 1964). Collins, et al. (1980) report a complex of three faults in Quaternary deposits in a Terrace of the Trinity River in Leon County. Tectonic activity affects deposition and erosion rates. Deposition is generally greater in any area that is downthrown relative to an area that is upthrown. Thus, grabens, alluvial fans, subsidence basins, and other tectonically produced environments favoring increased deposition are potentially of greater value in paleoenvironmental research. Nevertheless Holocene aged faults, such as the Meers fault in southwestern Oklahoma (Crone and Luza 1990), have not been identified and studied in Northeastern Texas.

IX. APPLICATION OF GEOCHRONOLOGICAL TECHNIQUES

Estimating the age of sediments and soils using physical-chemical techniques is a rapidly developing aspect of geochronology. The methods most commonly applied to late Quaternary soils and sediments of relevance to human ecological inquiry are radiocarbon dating of soils and fine-grained sediments, luminescent dating of fluvial and aeolian deposits composed of fine-grained quartz grains, and geomagnetism. Also in use are various spin resonance and isotopic procedures, and the use of tandem accelerator mass spectrometer (TAMS) techniques is very much in its infancy (Taylor 1987).

Any specific discussion of the application of these techniques risks being obsolete almost immediately, but general principles apply. More importantly, we are under-utilizing geochronological capabilities in Northeastern Texas and investigators should be encouraged to seek out and use appropriate techniques. Whenever possible, multiple techniques should be employed. Dating of the same event using multiple techniques in the long run contributes not only to improved chronology but to an improved basis for evaluating results based on only a single dating technique.

Tree-ring analysis is becoming more widely used in the mid and south continent areas of the United States (Stahle, et al. 1985). Wood from species as diverse as post oak, cypress, and pine is potentially datable using this technique. It is not a procedure that will provide immediate results in most cases in Northeastern Texas, but if more archaeologists will collect and have processed as many suitable samples as possible, it is likely that a substantial tree-ring chronology can be established for the region. More importantly, tree-ring analysis does provide other results even before a regional chronology is established. Intra-site or inter-site relative chronologies are one possibility; seasonality of wood use is another. Isotope data from tree-rings may also prove to be a valuable paleoenvironmental tool.

The direct dating of organic carbon in natural sediments and soils is perhaps one of the most important avenues to be pursued in the near future (Collins, et al. 1988). Results from projects such as Lubbock Lake (Haas, et al. 1986), Richland Chambers (McGregor and Bruseth 1987), Joe Pool (Peter and McGregor 1988), the Trinity River study (Ferring 1986), Aubrey Site (Ferring 1989), and Cooper Basin (Bousman, et al. 1988) are examples of the usefulness of this radiocarbon application. Normally bulk sediments are dated. One limitation with radiocarbon dating of sediments is that carbon matter is continuously leached down from the ground surface which means that younger carbon is added to older carbon at depth. Thus radiocarbon ages of buried organic layers in sediments do not necessarily represent the true age of the deposit, but rather radiocarbon ages represent the mean residence time (MRT) of the carbon in the deposit. Depending on the source and age of the contaminating carbon this can result in radiocarbon ages that are too young or sometimes too old. Care must be taken when interpreting radiocarbon dates obtained from carbon within sediments. Organic matter in soils can be divided into humic and nonhumic substances (Schnitzer 1982: 581-582). Nonhumic materials include carbohydrates, proteins, peptides, amino acids, lipids, waxes, alkanes and some organic acids. Microrganisms in the soil rapidly decompose these materials. Humic material, itself, can be divided into different fractions, i.e. humic acid, fulvic acids, and humins (Duchaufour 1982: 29-31; Schnitzer 1982: 582-583). Fulvic acid is soluble in hydrochloric acid (HCL), humic acid is soluble in a base solution of sodium hydroxide (NaOH), and humins are insoluble in these solutions. It is possible to date the bulk carbon or different fractions of humic material from single samples, but a number of studies fail to demonstrate that one humic fraction or bulk sediments yield consistently more reliable radiocarbon dates than the other fraction (Haas, et al. 1986: 480; Lowe et al 1988; Jones 1989). Recently there is a tendency among some radiocarbon labs to date bulk organic carbon because less sample pretreatment is required (Krueger personal communication, 1990; Stipp personal communication, 1990; Valestro personal communication, 1990). During a detailed comparison of sediment dating at Lubbock Lake, Haas, et al. (1986: 481) discovered that samples extracted from old exposures produced younger radiocarbon dates than samples from fresh exposures. Obviously some type of contamination occurs through exposed profile walls, and this should be considered when resampling old exposures.

Few published applications of tandem accelerator mass spectrometer (TAMS) dating exists in Texas (Bement and Turpin 1988: 32-33, Bousman 1990b), but the ability to date extremely small amounts of materials makes accelerator dating an important contribution to the arsenal of techniques. As radiocarbon laboratory turn-around times become shorter and costs decline, more and more archaeologists may choose accelerator dating methods especially for problem samples. However, samples still need to be corrected for fractionation effects, and sample context must be unquestionable with such small samples. One exciting development is direct dating of concentrated pollen grains rather than the surrounding sedimentary matrix (Brown, et al. 1989).

Luminescent dating of sediments and soils has not yet been attempted in the region. Traditional thermoluminescent dating of culturally-burned or heated materials has been used limitedly in Northeastern Texas (e.g. Perttula 1986: 484). In the same manner that heat "resets" the luminescent "clock" in heated materials ("thermoluninescence"), sunlight acts to release virtually all of the energy in a very narrow segment of the luminescent light spectrum in quartz (Smith, et al. 1990; Rhodes 1988; Huntley,

et al. 1985). In this way, silt-sized particles that have been transported by water or by wind have begun to rebuild luminescent energy in that light spectrum since last burial. Optically-stimulated luminescence, or photoluminescence as it is sometimes called, is now being tested in Texas, and it should have considerable potential for dating in Northeastern Texas. Promising results have been obtained from such samples as alluvial sands in France and England (Smith, et al. 1990:Table 1) where conditions comparable to those in Northeastern Texas prevail.

Another dating technique known to archaeologists is archaeomagnetic dating of burned earthen features (Eighmey 1980; Michels 1973; Wolfman 1982). This, too, has seen very limited application in Northeastern Texas (see discussions in McGregor and Bohlin 1987:38; Hathaway 1987). Less well known is the suitability of natural sediments for geomagnetic dating. Fine-grained sediments (silt-sized or smaller) settling out of relatively placid water will align with the ambient magnetic field and potentially provide a fossilized record of that alignment at later times (Deaver 1988; Eighmy 1988). This technique, though as yet untried in Northeastern Texas, may have considerable potential not only for estimating ages of sediments but also for evaluating post-depositional disturbances.

Most direct dating techniques have the potential of being used to do more than estimate age of samples. The many applications of tree-ring analysis is a well-known example (Dean 1969). Archaeomagnetic dating techniques can be used for site formation process studies by identifying burned rocks that have or have not been dislocated since last heating/cooling (Cheek, et al. 1980; Collins, et al. n.d.).

X. USE OF REMOTE SENSING

Remote sensing applications in archaeology and human ecology embrace numerous specific techniques, most of which are familiar to archaeologists (e.g. aerial photography and magnetometry). Generally, remote sensing is suitable for scanning either the earth's surface or subsurface. Surface-scanning techniques (usually photographic) are commonly applied in examining an area for patterns in vegetation, soils, surface geology, or topography. The objective may be to delimit cultural or natural phenomena, or both; some surface expressions actually relict subsurface conditions, such as vegetation patterns along fossil stream channels or buried cultural features (see Drass [1989] for a recent discussion and bibliography).

Techniques primarily designed to detect aspects of the subsurface include ground-penetrating radar, resistivity, magnetometry and high-intensity seismic. Technical and logistical limitations have to be taken into account when considering use of any of these procedures, but there are possible advantages in many cases. One important consideration, particularly when archaeological sites are involved, is that these are non-invasive techniques. A good example of such an application is the recent resistivity survey in Cooper Basin (Darwin, et al. 1990). In that study, buried fluvial features--stream channels and levees--were mapped without disruption of the subsurface. The resultant data can now be used to predict locations of buried sites.

Magnetometry is another potentially effective means of detecting subsurface phenomena. In the Joe Pool Reservoir project, for example, gilgai soil disturbances were prominently revealed in magnetometry mapping of site 41DL184 (Hathaway 1988). In other situations such cultural features as buried pits or burned rock concentrations are potentially discernible using magnetometers.

Deep trenching with power equipment has become a standard approach to subsurface investigations, and it can be very effective. However, there are limitations that may not be receiving adequate consideration. One is safety. Deep trenching creates a hazard to humans, livestock, and even to adjacent deposits. The costs of reducing these hazards by shoring or by stepping or sloping trench walls reduce the amount of trenching that is practical. Also, mechanical trenching generates a great deal of displaced fill in a very short period of time. If efficient means are not in place for evaluating the excavated material for its content, much information is lost. Digging backhoe trenches without screening the fill, particularly in dark colored, clayey earth, will almost certainly result in seriously deficient detection of the presence of cultural materials.

Coring is an alternative, but the very small borehole has a very low probability of recovering cultural evidence, even in dense cultural deposits. Also no profile exists for examination of such stratigraphic characteristics as dip, lensing, mottling, disturbances or facies changes that are generally not discernable in core samples.

Use of the appropriate non-invasive techniques in conjunction with limited coring and/or trenching may become the preferred strategy for investigating the subsurface. Ideally, resistivity or seismic data over a wide area would identify subsurface targets to be more closely investigated using coring or trenching. Expert technical advice is necessary on the suitability of the various remote sensing procedures for any particular application.

XI. BOTANIC PALEOENVIRONMENTAL EVIDENCE

The analysis of past plant distributions provides two types of information that are crucial to archaeological analysis. First, the temporal changes in plant taxa and plant associations (communities) provide evidence of the effect past climatic changes have on biota in an area or region. Second, the variations of plants through time along with complementary faunal information provide archaeologists with their best clues concerning the types, abundances and structure of botanic resources available to previous inhabitants of this area or region. Especially for prehistoric time frames these types of data are crucial for understanding past adaptations and exploitation patterns (Binford 1980, Kelley 1983).

In his review of plant geography Kellman (1980: 1-2) distinguishes between two broad theoretical approaches in botanic studies. The first approach is ecological where spatial or temporal plant distributions are assumed to be the result of controlling climatic and/or environmental stimuli. The second approach is floristic, and it adherents study the distributions of plants in terms of historical factors such as dispersal mechanisms, plant succession, competitive effectiveness, and ability to cross environmental barriers. The ecological approach assumes that plant distributions are in equilibrium with coeval climatic conditions and down play the importance of historical factors, while the floristic approach tends to assume that the only limiting factors are historical. Both approaches should consider the various mechanisms of the other, especially when dealing with changes in plant distributions over hundreds and thousands of years. Anyone looking at changes in plant distributions through space or time should consider the mutual importance of these two analytical approaches.

A great variety of plant materials are deposited and preserved in sediments. These materials allow the identification of plants at varying taxonomic levels from which quantitative analysis, and reconstruction of past (fossil) plant assemblages can take place. The analysis of pollen grains (palynology) is one of the most reliable techniques for reconstructing past vegetation patterns. Plants produce a super abundance of pollen as every hay-fever sufferer knows only too well. Pollen grains are the male gametophytes (sex cells) of plants. Most of the pollen produced by plants does not fulfill its intended purpose, but falls short and blankets the surrounding landscape. In environments that are undergoing deposition this pollen rain becomes trapped and because pollen is difficult to destroy, it is preserved in many depositional environments. Especially in bog, lake or stream deposits where organic deposition is great and decomposition is hindered by waterlogged sediments, pollen is often preserved. The extraction of a vertical set of samples from sediments of this sort has produced a small number of temporal pollen sequences that are used to reconstruct past vegetation changes in East Texas.

Pollen is the most common material use for botanical reconstructions. However many other types of materials are available, but these are often not collected in Texas. Nevertheless, this situation is quickly beginning to change. Diatoms and phytoliths are common alternate source for paleoenvironmental and paleoclimatic reconstructions, but these materials are rarely analyzed in Texas (Patrick 1946; Robinson 1979 and 1982; Scott-Cummings 1991; Winsborough 1991). Diatoms are unicellular algae which live in water or in soils. Diatoms are adapted to specific habitats and the occurrence of individual species is extremely indicative of the existence of these habitats (Patrick and Reimer 1966, 1975; Round 1973). Phytoliths are opal silica bodies produced by plants, especially monocotyledons such as grasses. Phytolith analysis has proceeded at a slower rate and less is known about basic phytolith taxonomy than either pollen or diatoms, but in the last few years phytolith research is beginning to address the gaps in knowledge (Piperno 1988). Tree-rings can also be used for paleoclimatic reconstructions and recent research in Texas, Oklahoma and Arkansas has produced a significant foundation for tree-ring analysis (McBryde 1983; Stahle and Hehr 1984; Stahle, et al. 1985; Stahle and Cleaveland 1988). Either living trees, logs in 19th century log-houses, or tree stumps discovered in buried floodplain deposits can be used. Trace chemicals, especially stable isotope ratios, can also be used for paleoenvironmental analysis, and a recent emphasis has begun to utilize these materials at greater and greater rates (Bousman 1990b, Huebner and Boutton in prep). Other more traditional approaches include detailed taxonomic studies of living species and their distributions (Gehlbach and Gardner 1983). This approach is known as biogeography (Kellman 1980). Extremely detailed biogeographical information can be integrated with pollen or other types of paleobotanical data, resulting in more complete understanding of the effects paleoclimatic changes have on plant community histories and past plant migrations. In addition, historic records can be used for reconstructing plant communities extant during the early historic period (Schafale and Harcombe 1983; Weniger 1984). However, before we discuss the above mentioned types of evidence for paleobotanic reconstructions it is worth considering the quantitative data base available on modern plant communities in Northeastern Texas.

Quantitative Analysis of Plant Communities

A growing number of studies on Northeast Texas forest and grassland communities are now available (Chambless and Nixon 1975; Diamond and Smiens 1985 Fountain and Risner 1988; Hocker 1956; Kroch and Nisbet 1983; Marietta and Nixon 1983

and 1984; Marks and Harcombe 1981; Nixon, Chambless and Malloy 1973; Nixon, Ehrhart, Jasper, Neck and Ward 1983; Nixon, Higgins, Blanchette and Roth 1980; Nixon, Matos and Hansen 1987; Nixon and Raines 1976; Sullivan and Nixon 1971; Wilson 1989; Wilson and Hacker 1986). These often provide a variety of quantitative data that can be used to assess the characteristics of the plant communities, however the needs for palynological analysis and other types of paleoenvironmental data are not the same as the needs for modern plant studies. These studies can offer much for future palynological analysis, but a standard type of data should be obtained, such as basal area of trees, plant density or canopy cover. Additionally species should be collapsed into taxa that are diagnostic to pollen analysis or some other form of analysis such as phytoliths. At present it remains to be demonstrated whether all of the modern plant communities discussed above can be recognized through palynology or any other method of paleoenvironmental reconstruction. Certainly differences between the Longleaf Pine Forest and the Pine-Hardwood Forest may be difficult to distinguish and the same applies for distinguishing differences between the Pine-Hardwood Forest and the Oak Woodlands. Much of the data have been collected for a preliminary assessment, but often botanists publish these data in terms of summary variables, such as importance indexes, that are not readily used for paleoenvironmental reconstructions and similar types of analysis. The formal modern plant communities will not be used in the following discussion because of the difficulty in identifying rigorously the modern plant communities from fossil data. However the names of the modern plant communities will be used informally as tentative identifications that will probably be altered with more detailed analysis.

Additionally, botanical studies can be aimed at collecting other forms of data that are crucial for understanding and documenting paleoenvironmental changes. For example studies of upland forest communities in Oklahoma have shown that tree diversity and average basal tree diameters decline from east to west as rainfall declines (Rice and Pendfound 1959). Studies of smaller scope have shown similar patterns on a microscale (Buck 1964, Crockett 1964, Marks and Harcombe 1981). In addition, detailed analysis of climatic controls on the distribution of modern plant species provides information that is critical for paleoclimatic interpretations (Hocker 1956, Rice 1962, Delcourt, et al. 1981).

Historic Reconstructions of Plant Communities

A small number of studies from Texas, Oklahoma and in the southern United States have used historic records for reconstructing the plant communities that existed during the early portion of the historic period before intensive agriculture and logging practices dramatically changed the natural composition and distribution of plant communities (Jordan 1973; Delcourt and Delcourt 1974 and 1977; Delcourt 1976; Schafale and Harcombe 1983; Jurney 1987 and 1988). Historic records vary in quality, but recently it has been discovered that the systematic recording of witness trees in early survey records from the General Land Office (GLO) have fairly consistent and dependable data on arboreal species (Bourdo 1956; Delcourt and Delcourt 1974 and 1977; Delcourt 1976; Schafale and Harcombe 1983; Jurney 1987 and 1988). Historic reconstructions are most successful when compared to modern detailed plant community studies and cross-checked in the field (Schafale and Harcombe 1983). These studies provide a firm base-line from which studies of paleobotanical changes can develop.

Biogeographical/Taxonomic Studies

Biogeographical studies often utilize discontinuous distributions of plant species for reconstructing probable routes of plant migrations and associated paleoclimatic history (Kellman 1980). One successful application of biogeography integrates distributional information with detailed taxonomic analysis of individual species, and considers these in light of know past climatic changes. Such a distributional study linked with a detailed taxonomic analysis of sugar maple sub-species (Acer saccharum floridanum and A. s. grandidentatum) provides a view of the type of information that is possible to obtain from biogeographical studies (Gehlbach and Gardner 1983). This study identifies relict sugar maple populations in protected mesic environments in western Oklahoma at Caddo Canyons (Canadians County) and the Wichita Mountains (Comanche County), and in western and central Texas at the Guadalupe Mountains in McKittrick Canyon (Culberson County), Fort Hood Army Reservation on Owl Creek Mountain (Coryell County), the Edwards Plateau Escarpment such as at Lost Maples State Park or Sabinal Canyon (Bandera, Kendall and Uvalde Counties). Large, nonrelict populations of Acer saccharum floridanum occur in Eastern Oklahoma and Texas and extend east, while in highland areas of Arizona such as the Chiricahua and Huachuca Mountains (Cochise County) and New Mexico the sub-species Acer saccharum grandidentatum occurs. Analysis of leaf morphology and flavonoids from these populations indicate that all the Texas relict sugar maple populations are associated with the eastern populations, i.e. Acer saccharum floridanum , while the population from the Wichita Mountains in western Oklahoma is composed of the western sub-species, i.e. Acer saccharum grandidentatum . The population from Caddo Canyons in Canadian County, Oklahoma appears to be a genetic mix, i.e. a hybrid population with genetic contributions from both sub-species. These data can be used to suggest that the East Texas population was the major donor population for relict sugar

maple populations over all of Texas, and that sugar maple migrations across Texas originated from the east whenever climatic conditions were favorable to the spread of sugar maples. As modern sugar maple distributions are restricted to very limited mesic habitats across most of Texas, and as large stands only occur in East Texas, it seems likely that widespread distribution of sugar maples would only occur when climatic conditions are more mesic that exists at present.

Another biogeographic study of grass species in the Plains, including the western edge of Northeastern Texas, constructed modern grass species distributions in terms of relative dominance, and attempted to reconstruct the dispersal mechanisms and environmental limiting conditions that might have led to the modern distributions (Brown and Gersmehl 1985). Following Gleason (1922) the authors suggest that grasses had three source areas from which migrations into the Plains occurred: the Western Intermontane Basins, the Southwestern Basins, and the Southeastern Coastal Plains (which includes Northeastern Texas). Detailed comparisons between grass distributions and theoretical models of dispersal and climatic variables suggests that most grass species distributions can be explained by migration from refugia populations alone (Brown and Gersmehl 1985: 393). One exception is Big Bluestem (Andropogon geradii). Its distribution appears to reflect both migration and climatic controls. Brown and Gersmehl (1985: 893) further suggest that these patterns imply that most grasses are not in total equilibrium with their environment and appear to still be migrating in delayed response (i.e. lag effect) to Holocene climatic changes. Lastly the authors suggest that this hypothetical model may be tested with fossil phytolith sequences (Brown and Gersmehl 1985: 387).

With the addition of similar taxonomic/biogeographical studies much more detailed reconstructions could be possible for past plant migrations in Texas. Biogeographic studies attain greater explanatory status when linked with other forms of paleobotanic evidence, especially when biogeographic data can be integrated with the temporal dimension such as with fossil pollen or phytolith data as suggested by Brown and Gersmehl (1985).

Fossil Pollen Studies in Eastern Texas

Few pollen studies have been conducted in Northeast Texas, and to date only one recent study from Buck Creek Marsh has provided reliable pollen data from this portion of the State (Holloway 1987a). However an important series of pollen sites occur in areas surrounding Northeast Texas (Figure 16) and a critical discussion of this research follows. In Texas the first pollen studies of Late Pleistocene and Holocene aged sediments were undertaken by J. E. Potzger and B. C. Tharp (1943, 1947) at Patschke Bog in Lee County. Later Gause and Franklin Bogs in Milam and Robertson counties were analyzed by the same individuals (Potzger and Tharp 1954). They argued that the presence of spruce (Picea) and fir (Abies) pollen in Central Texas indicated a boreal forest during the Pleistocene, and used the changes in pollen relative frequencies to suggest a four phase sequence of climate change. Their sequence began with cool-moist conditions supporting a boreal forest then shifted to a warm-dry climate as indicated by grass (Poaceae) and oak (Quercus), then changed to warm-moist conditions with chestnut (Castenea) and alder (Alnus) forests, and fluctuated back to warm-dry climate as indicated by oak and pecan/hickory (Carya). These early pollen studies were conducted before the invention of radiocarbon dating thus absolute ages for changes in the pollen relative frequencies were not possible.

Patschke, Gause and Franklin Bogs as well as the ones discussed below occur on sandy Eocene deposits, usually the Carrizo Sands Formation, that arc from east Central Texas through East Texas. This formation is an aquifer that originally had a number of artesian springs on its surface. Often stream channels erode into artesian flows and bog deposits, some are peat bogs, develop once the channel meanders are abandoned.

In 1960 Graham and Heimsch (1960) published an analysis of the South Soefje Bog in Gonzales County adjacent to Palmetto State Park, and a reanalysis of Gause Bog. Soefje Bog was the first pollen profile from Texas to be dated by radiocarbon. They were unable to verify the presence of fir and chestnut, and suggest that lower relative frequencies of other taxa (alder and spruce) make reliance on the earlier climatic interpretations of Potzger and Tharp questionable. The authors suggest (1960: 762) that pollen from the lower levels at Gause Bog imply a cooler and wetter climate, and that pollen from Holocene aged sediments represent a consistent and gradual trend to present climatic conditions. In addition, Graham and Heimsch did not identify any significant changes in the pollen record at Soefje Bog, however they did identify a slight increase in pecan/hickory in the upper meter of deposit (1960: 755). This increase in pecan/hickory was noted by Potzger and Tharp also. Importantly the authors also realized that the vegetation near South Soefje Bog in Palmetto State Park changed little during the 1950s drought (1960: 760) which Stahle and Cleaveland (1988) recognized from tree-ring records as the worst drought in the last 300 years. It is clear that the existence of this relic Big Thicket-like plant community at South Soefje Bog is made possible by the unique physiographic situation (Bogusch 1928, Parks 1935). The overriding stability of this plant community near the bog has probably acted to dampen any regional environmental signal, and small changes in pollen spectra from Soefje Bog may reflect significant environmental shifts away from the bog.

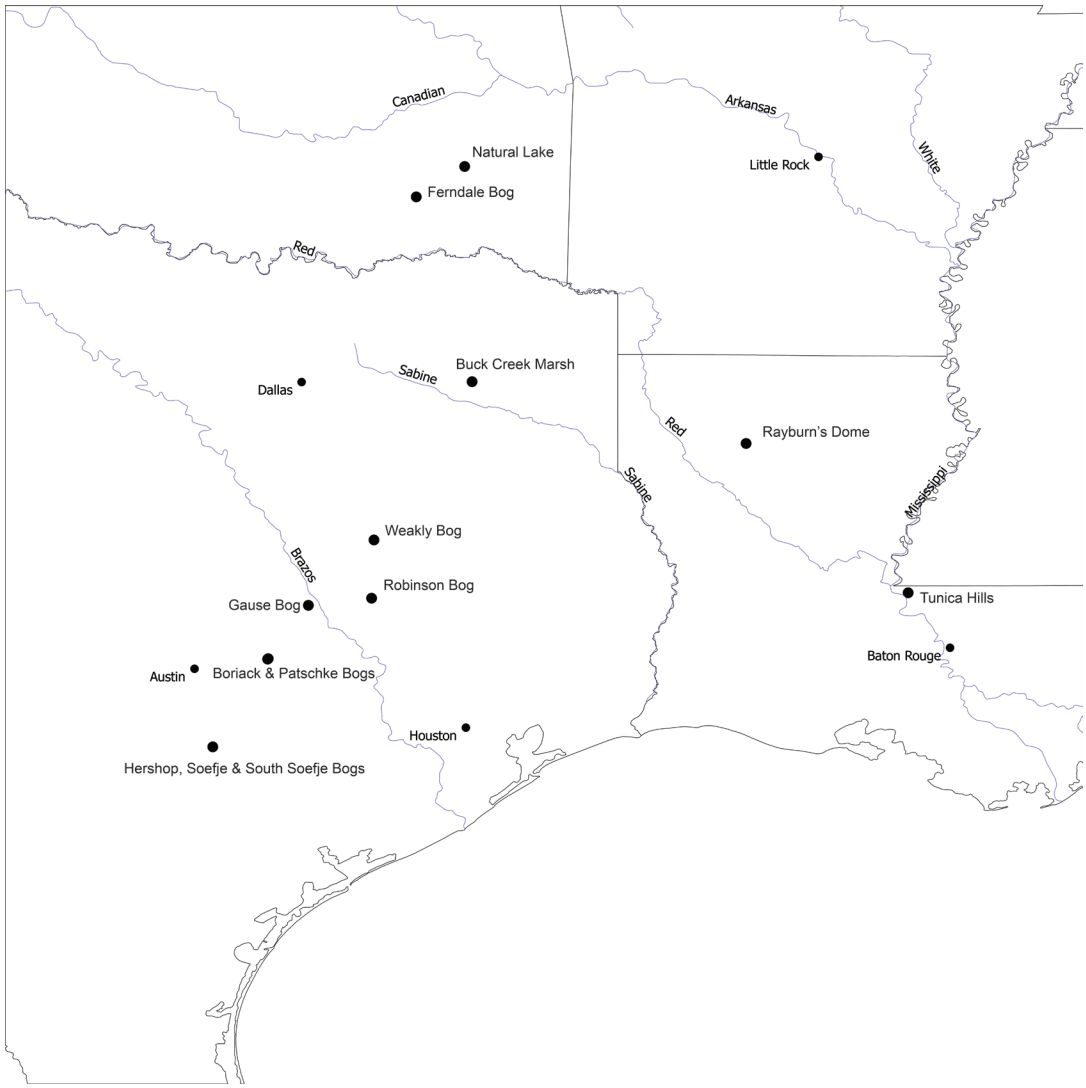

Figure 16: Distribution map of pollen sites.

In 1972 Larsen, Bryant and Patty published a pollen study of sediments from Hershop Bog. This bog is also near Palmetto State Park in Gonzales County, but it apparently is in more of an upland setting than Soefje Bog. Hershop Bog was the first well dated bog deposit with fifteen radiocarbon dates in five meters of deposit, although the dates are clustered in three portions of the profile (Figure 17). A linear regression between radiocarbon age and depth suggests that the sediments at Hershop Bog accumulated at an average rate of 1 cm every 19 years (Table 2). The analysis of Hershop Bog pollen spectra also represents the first time modern surface pollen samples were used to interpret plant community changes in this portion of Texas.

The pollen diagram of Hershop Bog shows a decline in arboreal pollen at about 10,500 B.P., and a rapid rise in grass pollen occurs after this time. Samples at 5 m and below contain the highest frequencies of oak, birch (probably Betula nigra), poplar (Populus), and elm (Ulmus). However Hershop Bog lacks evidence of maple (Acer), spruce, hazelnut (Corylus), basswood (Tilia) and dogwood (Cornus). Pollen from all these taxa occur in similar aged bog deposits further north (discussed below). Above 5 m grass reaches approximately 60 percent at 380 cm and at least 50 percent at 200 cm. These values are significantly higher than any of the surface samples (ca. 30 percent) and suggest significant increases in grassland. In the upper sediments grass declines seem to be replaced by composites (Compositae) and not arboreal species. This suggests at least two hypotheses. First, that middle Holocene grasslands were undergoing alterations, possibly disturbances due to human interference or excessive erosion that did not include their replacement by woodlands or forests. Or second, that changes in the bog itself are reflected in

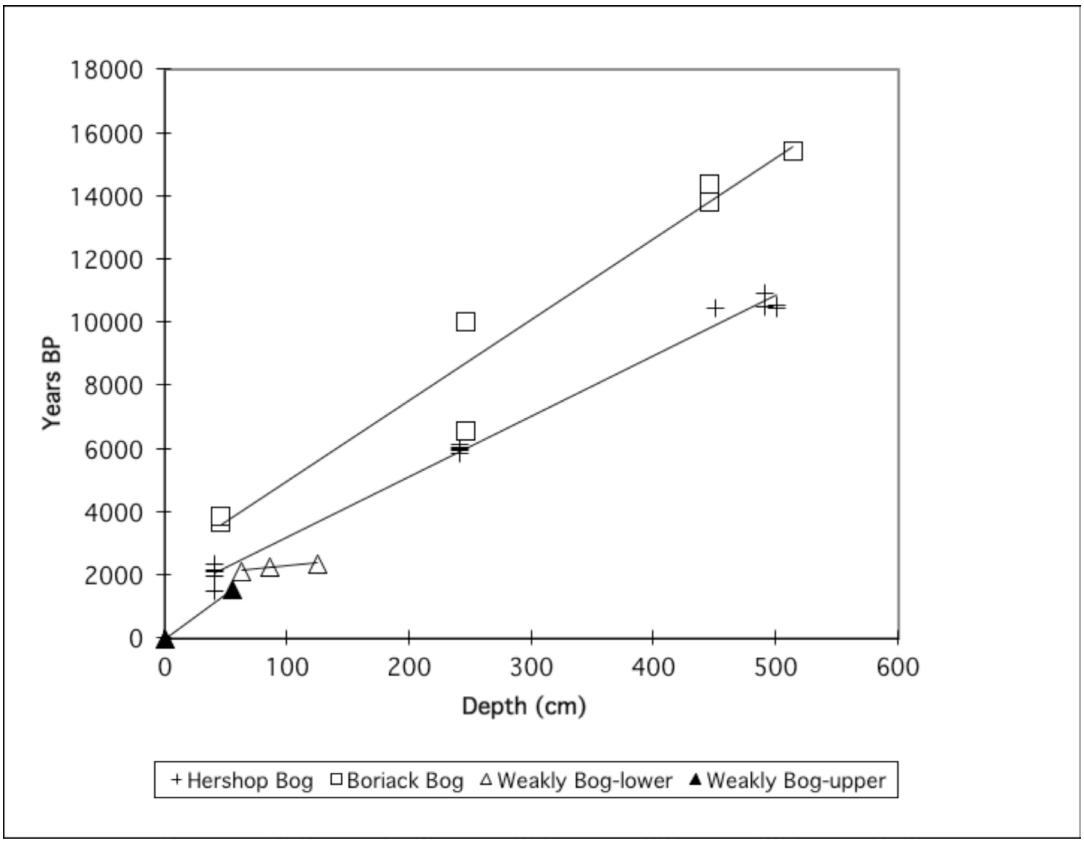

Figure 17: Linear regressions between radiocarbon sample depth and age at Boriack, Hershop and Weakly Bogs.

the variations of composit (Asteraceae) pollen frequencies (Larsen, et al. 1972: 366). In addition there is no evidence that pine occurred further west at any time during the accumulation of sediments at Hershop Bog (Larsen, et al. 1972: 365). In summation Larsen, et al. (1972: 366) suggest that at the end of the Pleistocene, vegetation changed in the uplands from a parkland to a savanna and in the floodplains from a closed canopy forest to a forest with an open canopy.

The best dated and most informative pollen sequence comes from Boriack Bog in Lee County (Bryant 1969 and 1977, Holloway and Bryant 1984). A plot of radiocarbon dates and depth suggest a regular accumulation of deposits at Boriack Bog (see Figure 17). A linear regression between radiocarbon sample depth and age indicates that Boriack Bog terminates on the surface at approximately 3000 B.P., and that the Bog appears to have accumulated at a fairly consistent rate of 1 cm of deposit every 25 years. The truncation at such an early date is attributed by Bryant (1977) to the draining of the bog and removal of peat in the 20th century. While this regression can be used to tentatively estimate the radiocarbon age of undated pollen samples, these estimates should be accepted with caution until more dates from intervening depths are available.

Bryant (1969, 1977) demonstrates that the last glacial maximum and late glacial vegetation on the southwestern edge of

Table 2: Slope, intercepts and correlation coefficients (r2) for linear regressions between radiocarbon sample depth and age at Boriack, Hershop and Weakly Bogs.

Site	Slope (yrs/cm)	Standard Error	Intercept	R^2
Boriack Bog	25.079	1.193	3007.3	0.989
Hershop Bog	19.093	0.422	1325.5	0.994
Weakly Bog-upper	32.926	4.92	-53.3	0.978
Weakly Bog-lower	3.918	0.77	1899.5	0.963

Northeast Texas consisted of spruce, poplar, birch, hazelnut, ash (Fraxinus), maple, alder, dogwood, pecan/hickory, basswood (Tilia), oak and pine (Pinus). Bryant suggests that spruce, basswood, poplar and maple were more common that the pollen spectra indicate, and oak, pine and alder were less common that the relative frequencies suggest because of differential production and transportation of pollen grains. The spruce pollen has been identified as Picea glauca and today this species occurs in areas with a mean July temperature of 21 oC (70 oF) or less (Holloway and Bryant 1984). As the modern distribution of Picea glauca extends north from North Dakota, Michigan and southern Canada, as well as isolated areas in the Rocky Mountains, this strongly suggests considerably cooler conditions before 15,000 B.P. when spruce pollen is most common at Boriack Bog.

Holocene pollen spectra at Boriack Bog shows a significant decrease in arboreal pollen of all taxa except for oak which seems to increase slightly, and a marked increase in grass and other nonarboreal pollen types. This general pattern is also documented at Hershop and Gause Bogs (Larsen, et al. 1972; Bryant 1977). In 1977 Bryant suggested that the Holocene increase in grass pollen and associated decrease in arboreal pollen corresponds with the beginning of the Altithermal, but that the termination of the Altithermal is not indicated by pollen spectra from any known site. However all these sites lack a complete sequence Late Holocene of pollen spectra. Since Bryant's pollen analysis of Boriack, Gause and South Soefje Bogs an important new study from Weakly Bog in Leon County has provided pollen data from the missing Late Holocene period (Holloway 1987b; Holloway, et al. 1987).

Weakly Bog covers the last 3000 years or so, and the bottom samples roughly match up with the younger portion of Boriack Bog. Weakly Bog does have some dating problems. Holloway, et al. (1987) suggest that a lower and an upper zone accumulated at different rates, and this is suggested by the scatterplot of radiocarbon ages and sample depths at Weakly Bog (see Figure 17). However, the linear regression between radiocarbon age and depth in the upper portion of Weakly Bog in Table 2 assumes a modern age for the surface sediment, i.e. -32 B.P. or A.D. 1982, and it ignores a "modern" age for a sample collected from 20-30 cm which is mostly likely to be contaminated by younger carbon illuviated down profile. Unfortunately the reporting of radiocarbon dates at Weakly Bog (Holloway, et al. 1987) did not mention whether these dates were corrected for fractionation effect, and radiocarbon dates must be corrected for fractionation effect before calibration to a tree-ring curve (Stuiver and Reimer 1986).

The interpretation of the pollen spectra by Holloway, et al. (1987) strongly depends on the use of pollen influx rates. Pollen influx rates are used to estimate the amount of pollen deposited in a sediment per unit of time, e.g. per year. The procedure has two steps. First pollen concentration values are calculated for each individual taxa and then these concentration values are calibrated by the span of time represented by the sample. Pollen concentration estimates are made possible by adding a known number of exotic pollen grains to a sample of known volume, and then tallying the number of exotic grains observed during a standard fossil pollen count (usually 200-500 fossil pollen grains). Pollen concentration values are calculated by the formula:

(Exotic grains counted/(Exotic grains added to sample/Sample volume))* Fossil pollen grains counted

This provides the palynologist with an estimate of the total number of fossil pollen grains deposited in the sample based on the relative recovery rate of exotic pollen grains. Pollen influx values are then calculated by dividing the pollen concentration values by the known time span of the individual sample. Influx values provide an measure of the individual contribution of pollen grains for each individual taxa that is statistically independent of the contribution of other taxa (percentages do not have this advantage). The technique demands an extremely well dated sequence where reliable sedimentation rates can be calculated. By today's standards this requires clear stratigraphic relationships between radiocarbon dates and the calibration of radiocarbon dates with tree-rings, and these are lacking at Weakly Bog. Parenthetically, palynologists should date their sequences first, calculate the sedimentation rates, and then take pollen samples of known duration that give them the temporal resolution that is required. This would also provide pollen samples of equal duration, which would make the results more comparable. Often pollen samples are taken first and then the sequence dated, and this results in pollen samples that do not have fine enough resolution for the problem at hand or, even worse, samples of varying duration where one sample represents events over a few years and adjacent samples represents events spanning hundreds of years.

Holloway, et al. (1987: 76-77) argue that the bottom of Weakly Bog, which exhibits high pollen influx values for all taxa, is dominated by oak pollen and represents dense forest that is possibly an oak-hickory forest. This is followed by a period of low pollen influx values for all taxa and continued oak dominance. The authors interpret this drop in pollen influx values as the replacement of a fairly dense oak-hickory forest by an open grassy oak savanna. Further, it is suggested that the presumed oak-hickory forest in the lower portion of Weakly Bog reflects more mesic conditions, and the oak woodlands in the upper portion of Weakly Bog represents drier conditions. This conforms to the general model of Holocene climatic change presented by Bryant and Shafer (1977), however a different interpretation is offered below.

First, the pollen influx values are high for all taxa, even grass, in the bottom portion of Weakly Bog, and then they all, including grass, decline drastically in the upper portion. Holloway, et al. (1987) believed that this dramatic drop reflected the replacement of forest by woodland. However the relative frequencies of grass and composites do not increase as they must if such a shift in plant communities actually occurred. It is suggested here that the change in pollen influx values could be due to at least two factors. First the radiocarbon dates from the bottom of Weakly Bog might be in error and the actual influx rates are in fact much lower. Geomorphological research in Alligator Creek, only a few miles downstream from Weakly Bog, suggests slightly older deposits do exist in the basin (Bousman and Fields 1988: 237-238), and it is possible that the lower sediments at Weakly Bog are dated too young. Second, it is possible that the observed change of pollen influx rates represents a very local change in depositional environment, and the site shifted from flooded to marshy or some other similar change in depositional environment. The discussion of sediments recorded in the core indicates a gradual decrease of sand and an increase in organic materials along with the sporadic occurrence of fibrous layers. Clearly a change in depositional environment is indicated. This could be assessed easily by the analysis of diatoms from these samples. Diatom studies were introduced by Patrick's (1946) study of diatoms at Patschke Bog, and a recent diatom study has provided this exact type of information for Holocene geological sites at Jewett Mine, Leon County (Winsborough 1991).

The pollen spectra from Weakly Bog show a general increase in arboreal pollen through time. The most significant patterning in the pollen spectra consist of oak and grass in the lower samples, and moving toward the top of the column pecan/hickory and then pine begins to occur in more regular frequencies. A number of typical East Texas arboreal taxa (Acer, Betula and Alnus) occur throughout, but a relict stand of pine forest occurs 35 km southeast of the bog and large stands occur east of the Trinity River where Betula and Alnus are also know to occur (Larsen, et al. 1972: 360). It is probably not wise to put a great deal of weight on the presence of these taxa as their pollen probably represents long distance wind transportation from nonlocal plant communities to the east. The temporal patterns in the pollen spectra can be used to suggest that an oak woodland is represented by samples at the bottom of the sequence, and toward the middle of the sequence hickory becomes slightly more common. This is exactly reverse to the interpretation offered by Holloway, et al. (1987), and it suggests that the climate became more moist through the Late Holocene rather than drier. Two apparently significant grass spikes occur. In this area grass is tentatively assumed to reflect drier or possibly warmer conditions although see Hall (1990) for an alternative hypothesis. The first at 51 cm is dated to 1550 B.P., and the second at 16 cm is undated although the linear regression in Table 2 produces an estimate of ca. 400-500 B.P. for this sample. The 1550 B.P. grass spike is significant because geomorphological research in the immediate area has documented a soil developing at this time in nearby floodplain deposits, and a younger soil dated to 300-600 B.P. may correspond to the younger grass spike (Bousman and Fields 1988: 195-237).

The only reliable pollen sequence from Northeast Texas comes from Buck Creek Marsh (Holloway 1987a). Unfortunately only one radiocarbon date is available from this sequence, but assuming a constant sedimentation rate as suggested by Holloway (1987a) it is possible to crudely estimate the timing of paleoenvironmental changes. One must realize that with additional radiocarbon dates these estimates are likely to change, nevertheless at this point the exercise is cautiously worth making the assumptions. The oldest sample with reliable pollen counts is at 80 cm below the surface and the age of this sample is estimated at 1775 B.P. Between 1775 B.P. and 1300 B.P. (59 cm) Buck Creek Marsh is dominated by oak, pecan-hickory and grass. Other taxa with high percentages, such as Cyperaceae, probably reflect the very local marsh environment and at present are not seen as particularly useful for distinguishing significant paleobotanical changes. During this 475 year span pine pollen begins to increase. By approximately 870 B.P. pine pollen attains its highest level and grass pollen drops dramatically in frequency. This probably represents an actual replacement of the oak woodlands by an pine-hardwood forest in East Texas. Oak and pine remain high at least until 375 B.P. except for the sample at 30 cm (estimated age is 645 B.P.) when grass peaks. It is possible that this grass peak correlates to the ca. 475 B.P. grass peak at Weakly Bog, and 300-600 B.P. soil in Lambs and Buffalo creeks at Jewett Mine. By 190 B.P. pine pollen declines and it is matched by a small rise in hickory. This may represent a brief increase of hickory in a pine-hardwood forest. However this trend does not continue in the uppermost sample (2 cm) which is dominated by willow (Salix), a marsh tree.

Other pollen studies such as Ferndale Bog and Natural Lake in Oklahoma (Albert 1981, Bryant and Holloway 1985) and Tunica Hills (Delcourt and Delcourt 1977, Givens and Givens 1987) and Rayburn Salt Dome (Kolb and Fredlund 1981) in Louisiana support a general model of a warm and/or dry middle Holocene followed by the gradual and generally consistent replacement of grasslands by various types of woodlands and forests through the Late Holocene. It appears that plant communities similar to the modern forms migrated from west to east across Texas, Oklahoma and into Louisiana.

At Ferndale Bog in Core IV it can be argued that between 160-140 cm, ca. 5200 B.P., an oak savanna with abundant grass cover existed. Between 140-70 cm, between ca. 3000-1700 B.P. an oak hickory forest occurred at Ferndale Bog. Above 70 cm, ca.

1700 B.P., pine increases and this suggests that an oak-pine-hickory forest then dominated the plant communities surrounding Ferndale Bog, although above 20 cm hickory declines. This is in general agreement with Hall's (1983: 150) interpretation of the Ferndale Bog pollen sequence. In addition the amount of total arboreal pollen increases from the bottom to the middle and top of Core IV (Albert 1981: Figure 29). Hall (1983: 151) recognized problems with Albert's calculation of influx values and the interpretation of radiocarbon dates. Albert actually calculated pollen concentration values and did not calibrated the pollen concentration values by deposition span, i.e. influx values. This is most unfortunate as Ferndale Bog is the best continuous middle through Late Holocene sequence in the entire region. Holloway and Ferring have also sampled Ferndale Bog and apparently obtained a complete pollen sequence from the Late Pleistocene through the entire Holocene. Unfortunately nothing but very preliminary results have been published (Bryant and Holloway 1985: 53-55).

A great deal of debate has developed over the dating of the alluvial deposits at Tunica Hills (see Givens and Givens 1987 and contained references). Nevertheless Late Pleistocene and Holocene plant communities have been identified (Delcourt and Delcourt 1977, Givens and Givens 1987). A transition from a cool-temperate flora consisting of white spruce, juniper, oak, and hickory to a modern warm temperate flora occurred at approximately 12,000 years B.P.

The pollen sequence from Rayburn's Salt Dome in northern Louisiana was divided into three pollen zones. A number of cores were examined but the best sequence is from core A-9. The oldest pollen zone, Zone A, is dominated by pine, hickory, oak, hophornbeam-hornbeam, and Taxaceae-Cupressaceae-Taxodiaceae, and spruce. Zone A certainly predates 19,000 B.P., and it may date to a fairly warm interstadial during the Wisconsin Glaciation or it may predate the last glacial period all together. Zone B is dominated by spruce, tamarack, alder, high and low spine composites including Artemisia, and grass. Radiocarbon dates from Zone B range from 19,200±1200 B.P. to 13,520±140 B.P. (Kolb and Fredlund 1981: 37). Zone C witnesses a dramatic increase in pine, but oak, low spine composites and grass are also present and slightly more so in the middle of Zone C. Unfortunately Zone C is undated, but Kolb and Fredlund suggest that this is probably after 5000 B.P. in the Late Holocene. One sample from a nearby core had an oak-hickory pollen assemblage that lacked spruce and pine from sediments immediately above Zone B samples (Kolb and Fredlund 1981: 38), and it is possible that this represents a pollen sample that dates to a dry middle Holocene period.

A systematic assessment of the variations in total arboreal pollen (AP) percentages from these bogs on the western edge of Northeastern Texas are possibly one of the best indications of overall vegetation change. For example the AP percentages at Boriack Bog have a large range (Figure 18), and this may indicate dramatic changes in the amount of forest cover during the accumulation of the bog deposits. It is significant that at both Boriack and Hershop Bogs total AP percentages are higher in the Late Pleistocene and decline through the early Holocene (see Figure 18). A crucial link in the pollen record is provided by Weakly Bog. At Weakly Bog the AP percentages seem to climb from the early portion of the Late Holocene through more recent times (see Figure 18). A similar comparison between Boriack Bog and South Soefje Bog indicates that the low point for arboreal pollen percentages in the middle Holocene has a short reversal at 6000 B.P (Figure 19). However the Pleistocene portion of this general pattern can be contested as the majority of the arboreal taxa at Boriack Bog consist of Alnus which may represent small trees or shrubs that live near marshes (Vines 1977: 59).

During the course of the original study of Boriack Bog Bryant (1977) questioned the status of Alnus as a true arboreal plant and conducted a second count of the Boriack Bog samples that ignored Alnus and Compositae pollen grains. Also a plotting of total arboreal pollen percentages and grass percentages from the Boriack Bog secondary counts and the primary counts from Weakly Bog strongly implies that the middle Holocene was dominated by grass pollen and other periods may have supported significant amounts of grass cover as well (Figure 20). In Figure 20 three sample averages were used in order to smooth the single sample extreme fluctuations without losing the significant short-term (3-4 sample) variations. As this procedure acts to dampen all of the fluctuations, the patterns are a conservative representation of the changes in arboreal and grass pollen. High percentages of grass pollen at approximately 16,500 B.P., 12,000 B.P., 9000 B.P., 7-4,000 B.P., 1500 B.P., and 300-500 B.P. imply that woodland or grassland plant communities existed at these times. These data suggest that grass cover was greatest in the middle Holocene, which is the period when extreme drought is documented for other portions of Texas (Holliday 1989, Meltzer and Collins 1987).

Taken as a whole, the available pollen data suggest that significant paleoenvironmental changes occur during the period of likely human habitation along the western boundary of Northeast Texas and in Northeast Texas proper. In the Late Pleistocene a forested community with boreal taxa is documented. Increases in grassland appear to occur at 17,000 B.P. and 12,000 B.P. Between 8500 B.P and 7000 B.P. the plant community changed rapidly to a grassland. During the Late Holocene the grasslands are replaced first by oak woodlands and then hickory increases in the western portion of East Texas. In East Texas proper an oak-hickory woodland or possibly forest is replaced by an pine-hardwood forest. Northeast Texas lacks a complete pollen sequence and while the combined record from Boriack and Weakly bogs has resulted in 75 pollen samples spanning the last 16,000

years (one sample every 200 or so years), it is obvious that more pollen sequences are desperately needed. An uninterrupted pollen sequence that spans the middle through Late Holocene is especially important for demonstrating the transition from Altithermal to Late Holocene plant communities.

Modern Pollen Studies

It has long been known that the number of pollen grains in a sample does not reflect directly the numerical representation of individual plants (von Post 1918, Erdtman 1943). Some plants produce great amounts of pollen that are widely dispersed by wind, while others produce very small amounts that are transported by insects and their distributions are limited. Palynologists have long relied on the analysis of modern pollen samples, collected from surface sediments or from specially built traps, to provide a link between pollen samples and plant communities. Many techniques have been developed to provide these linkages.

One of the first systematic treatments was the use of R-values (Davis 1963). The R-value of a taxon is the ratio between its relative frequency (percent) in surface pollen samples and it relative frequency in the contributing vegetation (Davis 1963: 898):

R-value = % taxon A in modern pollen ¬÷ % taxon A in surrounding vegetation

Thus R-values are easily calculated, and originally it was believed that R-values could be used to estimate the actual composition of the past plant communities. Unfortunately very serious problems have been discovered in the use of R-values (Birks and Gordon 1985: 182-204). The first major problem is that R-values calculated at different sites within a single region can vary significantly for a single taxon. Thus sets of R-values must be used in order to assess the accuracy of the estimates. Many factors could contribute to this situation. One factor is that many different species may compose a single taxa that are recognizable to pollen analysis, and differential production of pollen by different species within a single taxon and their unequal and varying composition in modern plant communities could contribute to unstable R-values. Other more complex factors could be variations in plant density and site specific pollen transportation and deposition patterns.

A second major problem with the use of R-values is an underlying assumption that all pollen deposited at a site originated from the surrounding vegetation. As transportability of pollen differs greatly between taxa so must the "pollen catchment area" of the different taxa for a specific site. In other words heavy pollen that is transported by insects or poorly transported by wind will originate from only nearby plants, but light pollen such as pine that is easily transported by wind will be contributed from plants many miles away from the sample site. Bradshaw and Webb (1985) show how the selection of different sized source areas can affect quantitative estimates of pollen/vegetation relationships.

A third problem is a result of the differential preservation of pollen. Holloway (1981, 1989) has shown that cycles of freeze/thaw and especially wet/dry can rapidly lead to the decomposition of pollen grains, and that some pollen grains from some taxa

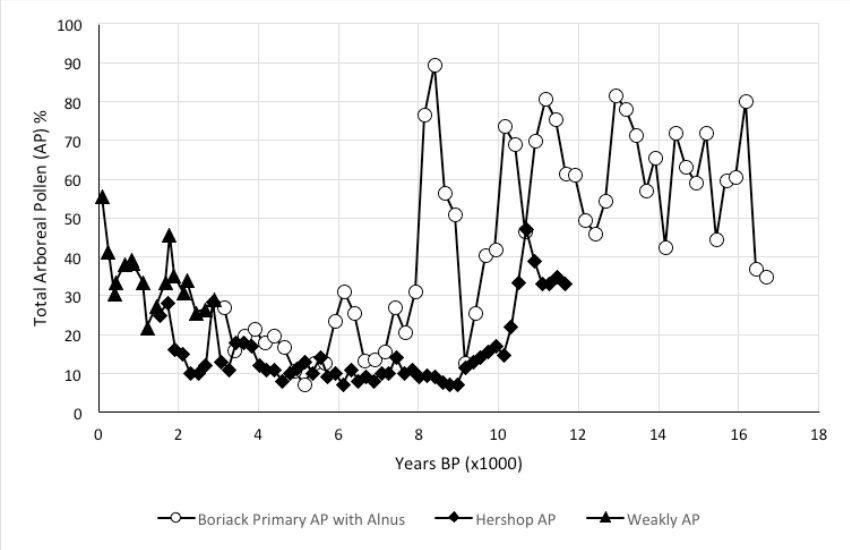

Figure 18: Total arboreal pollen percentages from Weakly, Boriack and Hershop Bogs (data from Larsen, et al. 1972; Bryant 1977; and Holloway 1987a).

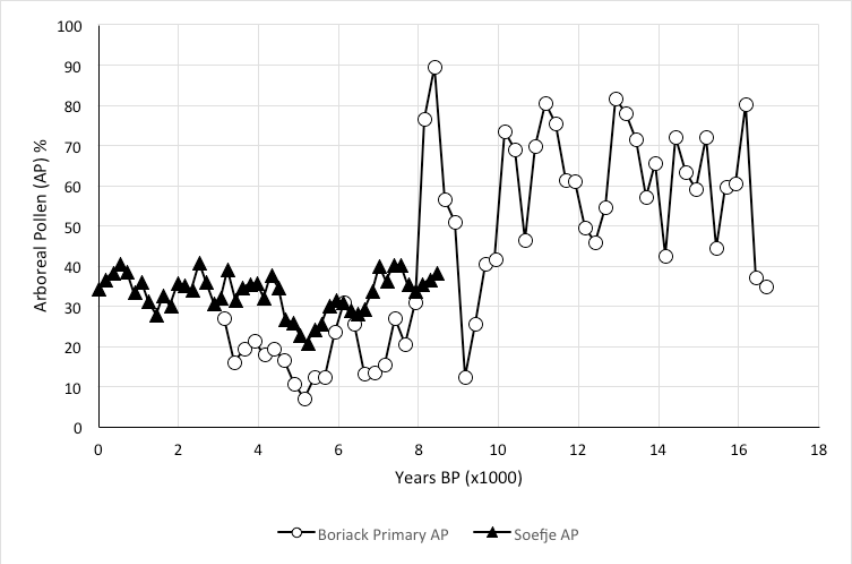

Figure 19: Total arboreal pollen percentages from Boriack and South Soefje Bogs (data from Graham and Heimsch1960 and Bryant 1977).

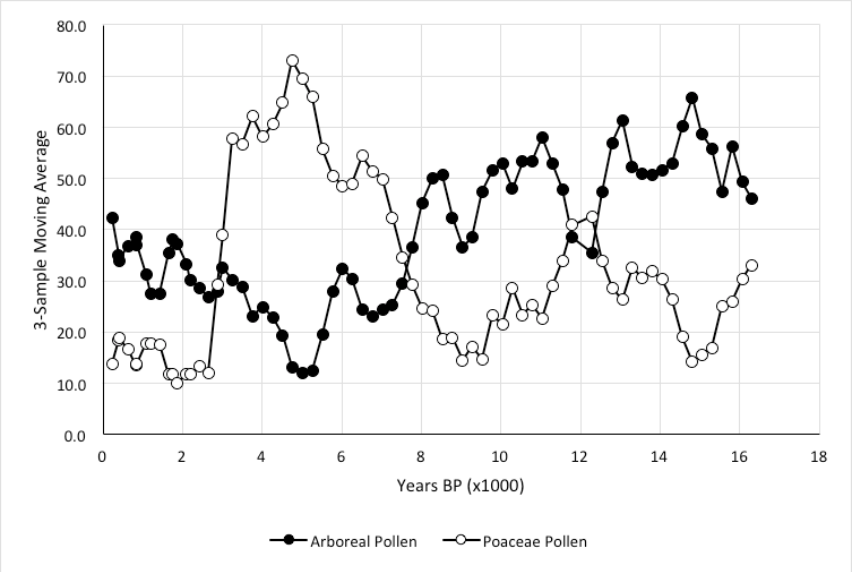

Figure 20: Three sample moving averages of arboreal pollen percentages and matching grass pollen percentages from Weakly Bog primary counts and secondary counts (minus Alnus and Compositae) from Boriack Bog.

are more susceptible than other taxa. If possible a modern pollen rain study should attempt to control for this bias.

A fourth problem stems from the type of site or sediment that is sampled for pollen. Often modern surface pollen samples are taken from depositional contexts that are different from the fossil pollen collection sites. For example modern surface pollen samples might be taken from slopes surrounding a pond but rarely from the surface of the pond itself or from the most recent sediments at the bottom of the pond. Fall (1987) has investigated how different depositional environments influence the composition of pollen spectra and how depositional processes distort the representation of pollen spectra. She argues that surface samples composed of pollen transported by wind accurately reflect the surrounding vegetation, but pollen grains transported by water in alluvial systems are deposited as sedimentary particles and do not reflect local vegetation patterns in an unbiased manner. Depositional environment must be considered when interpreting pollen data.

A fifth problem results from the use of relative frequencies of taxa in pollen spectra and vegetation communities. It is assumed that as the relative frequency of a taxa in the pollen spectra increases then its relative frequency in the contributing vegetation community will also increase in equal proportion. However this is not the case. Birks and Gordon (1985: 188-189) show that a simple linear correspondence between pollen spectra and surrounding vegetation does not hold in all cases. These serious problems limited the reliability of R-values, and alternative must be sought.

In the Southeast the relative frequencies of tree biomass, as measured by tree basal area, has been compared to relative frequencies of 156 surface pollen samples (P. Delcourt, et al. 1983). As the western boundary of this study includes portions of East Texas, it provides modern pollen/vegetation relationships that could be used for future East Texas pollen studies. Plus this study provides one model of how such studies can be designed. Linear regressions and associated correlation coefficients between a tree species biomass relative frequency and its proportional representation in modern pollen spectra provide a more accurate estimation of modern vegetation/pollen relationships than traditional R-values. Ten taxa (Betula, Carya, Celtis, Cupressaceae-Taxodiaceae, Fraxinus, Juglans, Pinus, Quercus, Salix and Ulmus) had significant correlation coefficients, while another nine taxa (Acer, Fagus, Ilex, Liquidambar, Liriodendron, Magnolia, Nyssa, Platanus, and Tsuga) did not. One minor problem with this study is that plant biomass was used as the independent variable and pollen percentages as the dependent variable in the linear regressions and correlations, but for prediction purposes these variables should be reversed with pollen percentages used as the predictor of plant biomass. Nevertheless, the results from this study can be used to more accurately estimate actual plant composition from pollen data for fossil pollen assemblages from East Texas.

Additionally a study from Central Texas provides data that is also potential useful for estimating actual vegetation cover from fossil pollen spectra (Shaw, et al. 1980). This analysis demonstrated that the relative frequency of arboreal pollen is related to arboreal canopy cover, nonarboreal pollen was significantly correlated to herbaceous canopy cover, and that the relative frequency of Quercus pollen is related to Quercus canopy cover. In addition pine and oak are over represented, and juniper and grass pollen are underrepresented in relation to their actual composition in the surrounding plant communities. Even though these data were collected on the Edwards Plateau, it is perhaps enlightening to apply the results of this study to pollen data from Boriack and Weakly bogs. According to Shaw, et al. (1980) the linear regression between arboreal pollen and arboreal canopy cover is:

arboreal pollen % = 16.9 + (0.88 x arboreal canopy cover %)
In order to estimate arboreal canopy cover the formula must be algebraically converted:
arboreal canopy cover % = (arboreal pollen % - 16.9) ÷ 0.88

When this conversion is applied to the arboreal pollen percentages from Boriack Bog (secondary counts) and Weakly Bog the results are striking (Figure 21). Until more accurate estimates are gathered from a wider variety of modern plant communities, which support the estimates from Boriack and Weakly Bogs, these estimates cannot be relied upon with strong conviction. In other words, with better estimates the scale of canopy cover can be expected to change. Nevertheless, it is doubtful if dramatically different estimates would be produced with future modern pollen studies. It is interesting to recall the basic cutoff levels of forest canopy cover that Diamond, et al. (1987: 205) use for the definition between forest, woodlands and grasslands. Forest have more than 60 percent canopy cover, woodlands are less than 60 percent and more than 25 percent, and grasslands have 25 percent or less. These estimates suggest that the southwest corner of Northeast Texas supported forests for only two brief periods during the Late Pleistocene before documented human occupation of the region. Most of the plant communities in the Late Pleistocene were woodlands, but the western edges of the woodlands fluctuated in density during this period. In the early Holocene these woodland communities not only changed in composition, as discussed above, but also changed dramatically in density so that by 7000 B.P. little arboreal cover remained on the western edge of Northeast Texas and it is likely that much of Northeast Texas was covered by prairie and grasslands in the middle Holocene. After 4500 B.P. it appears that canopy cover increased from the mid Holocene low. A strict adherence to the 25 percent cutoff between grasslands and woodlands would suggest that woodlands did not reappear until the last few hundred years, but it is more likely that most of the Late Holocene samples do represent woodlands. Parenthetically, if such a scenario did occur then additional evidence such a faunal remains and geological data should support such broad environmental patterns. Studies of bison distribution provide just such supporting evidence. Dillehay (1974: 185) suggests that bison were absence or at least present in low numbers in the Southern Plains during the middle Holocene, McDonald (1981: 251-257) argues that bison were much more frequent in the Northern Plains than the Southern Plains during this same period, and Guthrie (1990: 286) suggests that the decrease in radiocarbon dated bison between 7000 and 4000 years B.P is due to climatic change. If these arguments are correct then it implies that climatic change forced bison north and not east during the stressful conditions of the middle Holocene. In regards to this argument it is pertinent that the effect of

drought on botanical communities in the 1930s decreased in intensity from south to north in the Great Plains (Coupland 1958: 331). The absence of alluvial sediments that date to the middle Holocene over much of Texas including Jewett Mine and Lake Creek Reservoir, except in unusual depositional contexts such as the alluvial fan along the south valley margin at Cooper Lake, implies widespread nondeposition or erosion during this period (Mandel 1987; Bousman and Fields 1988; Bousman et al 1988). Additionally at Jewett Mine buried soils have been dated to ca. 3000 BP, 1500 BP and 300-600 BP (Bousman and Fields 1988). This suggests that floodplain surface stability (possible associated with channel entrenchment, cf. Hall 1990) may correlate with increased grass cover and a reduction of forests.

As Northeast Texas is at the ecotone between the southern forest and grasslands to the west, a comprehensive modern pollen study is needed that will take this ecotonal position into account. The modern vegetation includes forests, woodlands and grasslands, and a study must provide the calibrations between modern vegetation and pollen samples. The Central Texas modern pollen rain study (Shaw, et al. 1980) demonstrates one approach that might be useful for analyzing forested and unforested vegetation communities. Most pollen studies conducted in Northeast Texas have collected modern pollen samples (Bryant 1977, Scott-Cummings 1991), but they are usually extremely limited in spatial scope and research design. A future study should incorporated a number of elements into its research design.

Ideally, the scale should be broad and range from at least the Ouachita Mountains in Oklahoma to the Coastal Plain in the south, and from the grasslands in the west to the forests in the east. By covering an area this large a broad range of climatic (temperature and rainfall) conditions and presumably vegetation relationships will be incorporated.

Secondly the selection of surface pollen samples should correspond to well-studied vegetation communities that have not been recently disturbed and have quantified vegetation composition measurements, canopy estimates and/or other pertinent measurements that will be useful for palynological analysis. This is more difficult than the forest study discussed above (P. Delcourt, et al. 1983), because arboreal and nonarboreal species must be included in a quantitative assessment of the plant community. Often botanists use different methods to measure arboreal and nonarboreal species, but clearly overstory and understory plants must be considered in an integrated fashion.

Thirdly, modern studies should be linked with modern climatic patterns. On a grand scale the 357 meter deep and 3.5 million year continuous Funza core from the high plain near Bogota, Columbia has shown the clear influence climate has on pollen spectra (Hooghiemstra 1984). The modern pollen studies by Delcourt, et al. (1983) and Shaw, et al. (1980) failed to complete this step, but it is crucial if systematic and reliable estimates of associated climatic changes are to be obtained. A number of studies have successfully estimated climatic variations from pollen data (Cole and Bryson 1968; Webb and Bryson 1972; Bryson and Kutzbach 1974; Webb and Clark 1977; Huesser, et al. 1980; Huesser and Streeter 1980; Bernado 1981; Adam and West 1983; Hooghiemstra 1984; Guiot 1987; Guiot, et al. 1989), and they used a variety of statistical methods known in pollen studies as transfer functions (Birks and Birks 1980, Birks and Gordon 1985: 252-259). In general transfer functions use quantitate modern botanical surveys or modern pollen rain studies to search for distributions in these data that appear to be controlled by climatic patterns. Usually standard statistical techniques such as multiple linear regression or canonical correlation analysis are used to define plant/climate relationships and estimate the climatic conditions that likely existed for individual pollen samples. The use of transfer functions could provide more accurate estimates of past climates in Texas than has been attempted in previous pollen studies, however such a undertaking implies that all past plant communities represented by fossil pollen spectra are sampled by modern botanical surveys and/or modern pollen rain studies. Further such studies assume that the past plant communities did not suffer dramatically in terms of lag effect. Lag responses to climatic changes may be less serious for some groups of plants than others, e.g. grasses versus trees, but see Brown and Gersmehl (1985) for a conflicting view.

Fourthly, a single lab should probably do all the analysis with modern pollen rain. This is suggested to insure comparability and consistency for the overall study. In addition both small and large archaeological projects could and should contribute to the completion of this study. The most logical manner for both of these suggestions to be incorporated into such a study is to fund the fieldwork portion of the study where samples are taken and modern plant communities documented. The fieldwork would not be an expensive effort. Then establish an escrow or similar account into which both small and large archaeological projects can contribute. When the account attains enough funds to allow the laboratory processing of a reasonable number of previously collected pollen samples, then the pollen laboratory could begin to process a set of samples. By using such a strategy, over a few years the modern pollen rain study could be finished, and all archaeological projects, not just the largest and best funded, could contribute to the completion of this study.

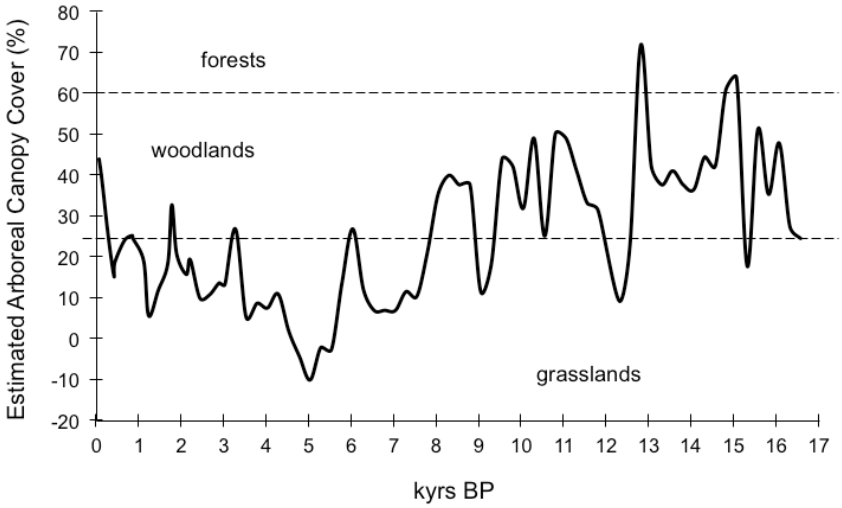

Figure 21: Estimated canopy cover through time at Boriack (secondary counts) and Weakly Bogs (data from Bryant 1977 and Holloway 1987a). Arboreal canopy cover cut off levels between forest (>60%), woodland (60-26%) and grassland (≤25% plotted according to Diamond, et al. (1987).

Pollen Sample Preparation and Counting

This is not a discussion of the nitty-gritty aspects of sample preparation and quantification techniques, however a very short discussion about these procedures is justified. This discussion is intended to address different philosophical viewpoints concerning the preparation of pollen samples, and it is intended to help archaeologists and other non-palynologists become aware, in a very general sense, of the ways palynologists approach the processing of samples. In order to accomplish this task two extreme viewpoints are offered and the reader should be aware that individual palynologists may not represent such extreme points of view. One point of view argues that every sample must be processed in exactly the same manner. Deviation away from a standard method will produce incomparable data and inconsistent results. As many palynologists use strong acids or other chemicals that are highly corrosive, poorly preserved pollen grains will not survive some preparation processes. Thus samples with poor preservation can be identified more easily and eliminated from consideration. In recent years another group of palynologists have begun to experiment with the methods and chemicals used to process pollen samples. This group argues that the preparation techniques, themselves, destroy pollen grains and that less destructive preparation methods and chemicals should be employed. Some palynologists would further suggest that each sample should be processed by whatever method and chemicals are most likely to liberate the pollen grains that were originally present in a particular sample with as little damage to those pollen grains as possible. Poorly preserved samples can be assessed during the counts and not eliminated by the extraction process.

During counting it is particularly important to note samples with low total counts (<200 grains), count indeterminate pollen grains, and calculated pollen concentration values. Low counts can be a direct indication of post-depositional destruction of pollen grains. Indeterminate pollen grains are those that are too poorly preserved for accurate identification, and their relative occurrence is an indication of destruction. Pollen concentration values are achieved by "spiking" a pollen sample of given size with a known amount of totally foreign pollen, and using its observed frequency to estimate the frequency of natural pollen taxa within the sample. Low concentration values provide another indication of poor preservation.

It is particularly difficult for the non-palynologist to assess the relative benefits and liabilities of these two extreme processing strategies. Logical arguments can be constructed for both approaches, and indeterminate pollen numbers as well as concentration values provide an index of preservation. Nevertheless archaeologists or researchers who enlist the collaboration of palynologists should be aware of the philosophies in order to be in a position to ask reasonable questions and to better understand the approach of a particular palynologist.

Fossil Diatom and Phytolith Studies

Considerable less research has focused on the analysis of diatoms and phytoliths, and for this reason both will be discussed together in this section. Diatoms, single cell algae, can float in water (planktonic), live on pond or stream bottoms (benthonic),

attach to plants (epiphytic) or live in soils (aerophilious). The single diatom cell is surrounded by a hard, box-like structure, known as a frustule, made of silica. It is unique combinations of size, shape and surface patterning of the frustule that allows identification often to the species level. R. Patrick (1938) conducted one of the earliest diatoms studies in archaeology at Blackwater Draw in eastern New Mexico. Later J. E. Potzger and B. C. Tharp sent Patrick samples from Patschke Bog and this resulted in the first integrated diatom and pollen analysis from Texas. Unfortunately, diatoms preservation was limited to the uppermost samples. It is only recently that diatom studies in Holocene sediments from East Texas has been renewed (Winsborough 1991), but this study is still to be integrated with the analysis of pollen. Diatoms can provide important evidence on the depth and chemistry of bodies of water. As discussed in the pollen section, this type of data can be crucial in determining depositional environments such as bogs, and provide evidence that can collaborate or refute interpretations based on pollen analysis alone.

Phytoliths form in stems, leaves and flowers. Silica in solution in ground water precipitates along cell walls creating phytoliths. While a fair amount of morphological overlap exists between a number of taxa, and phytolith taxonomic studies of many plants have not been conducted; other plants create distinguishable and known forms. Phytolith analysis is the developing stages still (Pearsall 1989; Piperno 1988), and practicing analysts have not agreed on a standard set of processing and counting procedures. Nevertheless, phytoliths can provide more detail on the distribution of certain taxa, especially grasses, than is currently possible with pollen analysis.

The grasses are especially diagnostic (Twiss, et al. 1969; Brown 1984), and can be divided into three main classes: Festucoids (the Festuceae, Hordeae, Aveneae and Agrostideae tribes), Panicoids (the Andropogoneae, Paniceae, Maydeae, Isachneae and Oryzeae tribes) and Chloridoids (the Chlorideae, Eragrosteae and Sporoboleae tribes). The Chloridoid phytoliths were found to be produced primarily by grasses occurring in the short grass prairie, and are mainly C4 grasses. Panicoid phytoliths are produced by grasses from the tall grass prairie, and Festucoid phytoliths are characteristic of grasses that grow in moist habits. Both the Panicoids and Festucoids are mainly C3 grasses. C3 and C4 grasses differ in terms of photosynthetic pathways and this significant will be discussed more fully below in the section on stable isotope analysis.

One phytolith study is now in progress in Northeast Texas at Jewett Mine (Scott-Cummings 1991), and the preliminary results are encouraging as shifts between Chloridoid and Panicoid grass phytoliths are clearly indicated although the research is still too preliminary to provide additional details. The Jewett phytolith research will soon be published, however research in South Texas has demonstrated a clear dominance of Chloridoid grass phytoliths during the middle Holocene (Robinson 1979, 1982). Further north along the prairie/forest boundary soil scientist have used the gross abundance of phytoliths as an indicator of prairie plant communities (Witty and Knox 1964; Wilding and Drees 1968). In Virginia at the Fifty Site in the Shenandoah Valley, Carbone (1977) demonstrated a shift from forest to grassland and back to forest in the last 12,000 years. Additionally varying relative frequencies of Chloridoid, Panicoid and Festucoid phytoliths have been used to reconstruct available moisture and past vegetation at archaeological sites in the Northern Plains (Lewis 1981). Finally Brown and Gersmehl (1985) have suggested that phytolith analysis could be used to test hypotheses concerning the migration of grasses from relict populations. Thus phytoliths have the potential to provide crucial data on the nature and types of grasses and grasslands that may have existed in Northeast Texas during the past.

Charcoal and Macrobotanical Analysis

The most commonly recovered plant material from archaeological sites in Northeast Texas is charcoal. It is generally assumed that most charcoal recovered from archaeological sites was collected by the prehistoric inhabitants for fire wood. Only a few archaeological projects conducted in Texas and Oklahoma have identified macrobotanical remains and generally the emphasis has been on the analysis of ethnobotanical remains from the point of view of paleo-ethnobotany and paleoeconomies (Holloway 1990, Crane in prep, Adair 1984). Recently in one case wood identifications have been used to infer past environments (Holloway 1990). Wood identifications are based on the distinctive structure of the wood, and features used in identification include vessels, rays, parenchyma in the xylem and growth rings. It is assumed that changes in the frequency of different types of wood charcoal reflect changing availability of wood rather than human selection or preferences.

In Africa recent analysis of the size and distribution of the structural features of charcoal within a single species, known as Ecologically Diagnostic Xylem Analysis (EDXA), has demonstrated that wood structure is climatically controlled (Scholtz 1986, Tusenius 1989). Scholtz (1986) uses the concepts of conductivity, i.e. relative flow rates, and vulnerability, i.e. the ability of plants to withstand water stress, as proxy indicators of climate (Carlquist 1977; Zimmerman 1982). Vessels are especially diagnostic, and appear to decrease in size and increase in number with reduced moisture availability. This approach promises to circumvent the confounding problem that human selection has on the use of charcoal frequencies for paleoclimatic interpretations, but applications in North America are lacking.

Tree Ring Studies

The use of tree rings for climatological analysis in Northeast Texas is still in a period of growth and development (Stahle and Hehr 1984; Stahle, et al. 1985a; Stahle, et al. 1985b; Stahle and Cleaveland 1988; Cleaveland 1989), however considerable research has been devoted to the use of tree rings for climatic reconstructions (Fritts 1976; Hughes, et al. 1982). Stahle and Hehr (1984) demonstrate that post oak (Quercus stellata) is one of the most sensitive species in Texas, and tree-ring thicknesses have a positive correlation with rainfall and a negative correlation with temperature. Stahle and Cleaveland (1988) have used tree-ring analysis of post oaks to estimate the Palmer Drought Severity Index from 1698 to 1980 for north central Texas (Figure 22).

The Palmer Drought Severity Index is based on both temperature and rainfall, and values of -3.0 or less are considered as extreme or severe drought. Five year moving averages of these estimates show short (18-20 year) quasi-cyclical variations in droughts over the last 300 years, and it appears that longer cycles are not evidenced by these estimates. Based on these estimates the well recorded drought of the 1950s was the most severe drought recorded by the tree-ring analysis, although a longer drought period apparently occurred about 1860, and another at approximately 1775. These data suggest that the modern climatic patterns recorded during the historic period are reflective of climatic patterns over the last few hundred years, and that severe drought periods can be expected every 100 years or so. It can be assumed that biotic responses to severe droughts at irregular intervals was a normal condition, and it can be expected that successional changes stimulated by such short-term drought fluctuations as evidenced by the tree-ring records will not be visible in pollen samples with intervals that span 75-100 years. It is unfortunate that the tree-ring record does not show any evidence of long-term climatic change over periods greater than 100 years or more, but analysis now underway in northern Louisiana with bald cypress may produce significantly longer sequences that will allow a longer view of climatic change with tree rings (Stahle personal communication 1990).

XII. STABLE ISOTOPES

More and more archaeologists, geologists and paleoclimatologists are beginning to use stable isotopes, especially those of carbon, nitrogen oxygen and hydrogen, for documenting past environments, climatic changes, and animal dietary patterns. Texas occupies a unique position in stable isotope analysis because Redfish Bay near Corpus Christi is where stable carbon isotope analysis of diet was first suggested by P. L. Parker in 1964. Unfortunately since 1964 very few research projects in Texas have utilized stable isotope ratios for paleoenvironmental or dietary analysis, however some data are beginning to emerge (Land, et al. 1980, Stafford 1984, Haas, et al. 1986, Meltzer and Collins 1987, Turpin 1988, Bousman 1990a, Bousman and Quigg 1990, Huebner and Boutton 1990). Worldwide interest is growing on the use of stable isotope ratios, however, and this interest is originating from three quarters: biologists interested in modern ecology, archaeologists concerned with reconstructing paleodiets of prehistoric humans, and radiocarbon specialists and geochemists interested in reconstructing paleoenvironments and paleoclimates. The latter application will be the major focus of this section, but much of the knowledge gained from the study of human paleodiets and modern ecological studies are crucial for a more complete understanding of the applications. It is perhaps easiest to introduce the subject by discussing isotopes of individual elements, i.e. carbon, oxygen, nitrogen and hydrogen, and at the appropriate place in the individual sections discuss the general processes that control isotope ratios. This discussion does not assume that the reader has any knowledge of physics or chemistry besides the existence of atoms which are composed of neutrons, electrons and protons. Some sections may not be necessary for all readers and the discussion is organized so that introductory sections can be skipped, scanned or read, as needed.

What is an isotope?

Everything in nature is composed of atoms of individual elements, and all atoms are composed of three types of particles known as protons, neutrons and electrons. Protons and neutrons are the largest and heaviest particles in an atom and they comprise the nucleus of an atom which is surrounded by one or more electrons that orbit the nucleus. The electrons are very small and light in weight, and they rotate around the nucleus similar to the way the moon orbits the earth (Figure 23). Protons have a positive electrical charge and electrons have a negative charge, so they attract each other; but neutrons have no charge. The number of protons determines the type of element. For example carbon has six protons, nitrogen has seven, oxygen has eight and hydrogen has only one. Usually atoms have an overall neutral charge, and the number of electrons matches the number of protons. When an atom loses or gains an electron, then the atom attains a positive or negative charge, respectively, and these are known as ions of an element. Thus isotopes of a single element are not determined by either protons or electrons. The only difference between isotopes of a single element is the number of neutrons in the nucleus of its atom. As a neutron is slightly heavier than a proton and much, much heavier than an electron, the number of neutrons in the nucleus can significantly affect the weight of the atom. The different weights of isotopes are very important since the weight of the atom influences how it is used in chemical reactions. Heavy isotopes (with more neutrons) are not used as readily as light ones. Nature does not like to work any harder than it must.

Chemists have a special notation for different isotopes of the same element which indicates the number of neutrons and protons in an isotope. For example carbon, always has 6 protons, and two of its stable isotopes that are of interest to us have 6 and 7 neutrons. These are identified as 12C and 13C, respectively. The superscript number immediately preceding the element symbol is known as the mass number, and refers to the number of neutrons and protons. Thus the mass number serves to identify the specific isotope of that element and for the most part its weight. In the following discussion stable isotopes of four elements are presented, and these are carbon (C), nitrogen (N), oxygen (O), and hydrogen (H).

Carbon isotopes

Three carbon isotopes are most commonly used in isotopic analysis: 12C, 13C, and 14C. Each carbon atom has six protons. 12C has six neutrons, 13C has seven neutrons, and 14C has eight neutrons. As is well known through the use of radiocarbon dating, 14C is an unstable radioactive isotope with a half-life of approximately 5700 years. It is created by cosmic ray bombardment of 14N in the atmosphere where the molecule loses a proton and adds a neutron so that the atomic number (14) remains the same. 14C changes back to 14N through the process of radioactive ß- particle decay (Taylor 1987: 1-2) where a neutron turns into a proton and produces an electron and an electron antineutrino ( ), . The other two carbon isotopes are stable, and thus allow for the study of their distribution in nature without the complication of radioactive decay.

Most researchers agree that changes in 12C/13C ratios in terrestrial ecosystems are most strongly influenced by plant photosynthesis. Three types of photosynthesis are known presently to occur: C3, C4 and CAM (the subscripted number

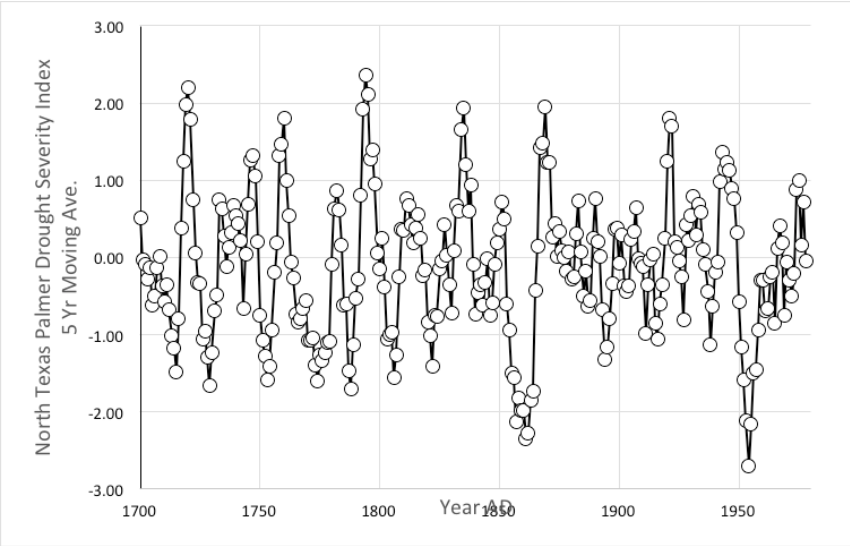

Figure 22: North Texas 5-year moving averages of PDSI (Palmer Drought Severity Index) estimated from tree-rings (data from Stahle and Cleaveland 1988).

that follows an element symbol refers to molecule numbers and should not be confused with superscripted mass numbers of different isotopes). C3 and C4 plants are distinguished by the chemical composition of the energy molecules produced by the photosynthetic pathway used by each type of plant. The terms C3 and C4 originate from products of the photosynthetic pathways. C3 plants include all trees and woody shrubs and some of the grasses, and they use a photosynthetic pathway that produces a three-carbon molecule. This pathway is called the Calvin-Benson pathway and it is named after its discoverers. C4 plants consist mostly of the remaining grasses (also known as Krantz grasses, named after a unique anatomical structure in leaves) and a small variety of other plants. These plants use a different photosynthetic pathway called the Hatch-Slack pathway, with a four-carbon molecule produced during the process. It is also named after its discoverers. It is significant that grasses are both C3 species and C4 species.

During the production of these three or four carbon molecules a plant may use either of the two stable carbon isotopes: 12C or 13C. As noted above these two isotopes of carbon are stable, do not change, and they are readily available in the atmosphere. Also these two stable carbon isotopes, as all isotopes, have slightly different weights, and because of their weight differences the chemical reactions and physical process in the two photosynthetic pathways use 12C and 13C in slightly different ratios. This is because lighter isotopes have higher vibrational frequencies and thus form weaker bonds and are more reactive in chemical processes than heavier isotopes. (Vibrational frequencies are inversely related to the square root of an element's mass, i.e., v = 1/m2; thus the vibration frequencies of 12C and 13C are approximately equal to 0.083 and 0.077, respectively). The most important difference between the two photosynthetic pathways is that the C4 photosynthetic pathway has the same basic steps as the C3 pathway, but also the C4 pathway has additional steps which allow it to more efficiently use all the available carbon. This does two things. First, C4 plants are usually more resistant to water stress, but less capable of withstanding cold temperatures, especially minimum temperatures during the growing season (Vogel, et al. 1978). This means that C3/C4 plant ratios reflect climatic parameters. Second, the heavier isotope, 13C, occurs in greater relative abundance in C4 plants than it does in C3 plants. Thus the ratios of the two stable carbon isotopes in C3 and C4 plants can be accurately measured with very sensitive instruments such as mass spectrometers. Carbon isotope ratios in materials that form on land thus provide a measurement of C4 plants versus C3 plants in the overall biota (Stuiver 1975; Flexor and Volkoff 1977; Vogel 1978a; Krishnamurthy, et al. 1982; Cerling 1984; Dzurec, et al. 1985; Cerling and Hay 1986; Guillet, et al. 1988; Haas, et al. 1986; DeLune 1986; Nakai and Koyama 1987; Schwartz, et al. 1986; Volkoff and Cerri 1987; Natelhoffer and Fry 1988; Goodfriend 1988; Cerling, et al. 1989).

One complicating factor to this situation, is the existence of a third group of plants, CAM plants, that have the ability to switch back and forth between C3 and C4 pathways in response to climatic changes. If this occurs in significant amounts and degrees, CAM plants could blur the clear C3/C4 signals. CAM plants are mostly succulents and cacti, and these do not occur in large numbers in East Texas, plus a study of two of the most common CAM plants in Texas, prickly pear (Opuntia spp.)

and lecheguilla (Agave lecheguilla), suggests that these plants would normally use a C4 pathway (Eickmeier and Bender 1976; Marino and DeNiro 1987).

The measurement of carbon isotope ratios is calibrated to the 13C/12C ratio in a special piece of marine belemnite limestone from the Pee Dee Formation in South Carolina. As this marine limestone, known as the PDB standard, has an enormous amount of 13C in relation to 12C, most materials from terrestrial sources such as living plants have much less 13C. Thus most materials are called "light". This results in measurements of terrestrial materials often attaining a negative number. The measurement is represented by the notation "δ13C", i.e. delta 13C, and is expressed in parts per mil or "‰". The isotopes of oxygen and nitrogen are represented in similar notation as well. The formula for calculating δ13C values is:

$$\delta 13C = [(13C/12C)sample/(13C/12C)standard-1]*1000$$

The preindustrial atmospheric δ13C value is estimated at -6.0 ‰, but C3 plants have much less 13C and their δ13C value is approximately -27 ‰. C4 and CAM plants have more 13C and their average δ13C value is near -13 ‰. In other words C4 and CAM plant δ13C values are higher, less negative, but "heavier" which reflects more 13C than is present in C3 plants (Figure 24). In materials that represent an accumulation between both types of plants, such as the organic fraction in soils, the δ13C value should range between -27 ‰ and -13 ‰, and given no further chemical changes, the value should reflect the relative biomass contribution of C3 and C4 plants to this material.

Unfortunately, additional chemical changes that alter the isotope ratios, known as fractionation effects, do occur in most materials such as soils, calcium carbonate nodules or bone, and this complicates the picture but not hopelessly. In fact the assimilation of carbon isotopes from the atmosphere into plants through the process of photosynthesis is the first major fractionation step. Thus C4 plants fractionate the atmospheric source of carbon isotopes to a lesser extent than C3 plants. Additional fractionation steps occur as carbon isotopes pass from plants into animals, soils and other materials, and the degree of fractionation change varies by material, however all stable isotopes, including oxygen and nitrogen, undergo fractionation due to unequal weights and it is this process that allows stable isotope analysis. At this point is is easiest to discuss the application of stable carbon isotope analysis by material.

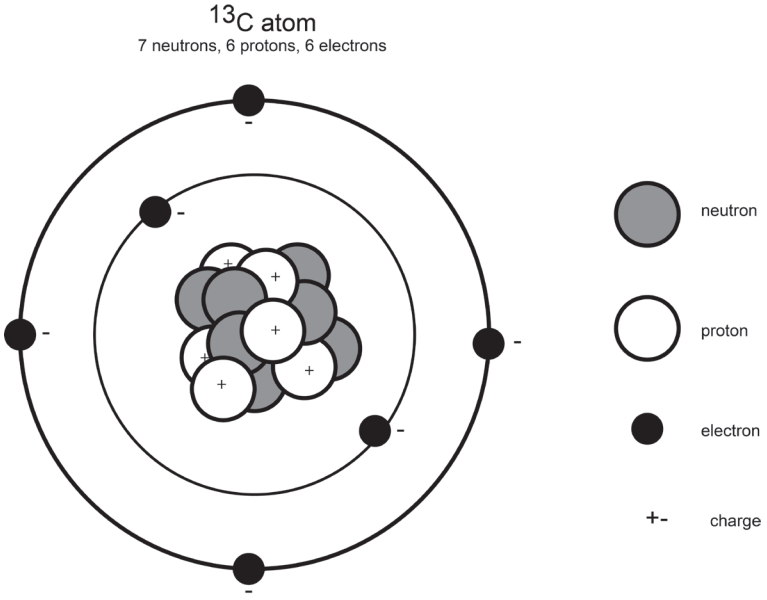

Figure 23: Carbon atom structure with protons, neutrons and electrons.

Soil Humates and Carbon Isotopes

Carbon isotope measurements on bulk soil or sediment humates have been used for assessing botanic changes between C3 and C4/CAM plants (Stuiver 1975; Flexor and Volkoff 1977; Krishnamurthy, et al. 1982; Cerling 1984; Dzurec, et al. 1985;

Cerling and Hay 1986; Guillet, et al. 1988; Haas, et al. 1986; Nakai and Koyama 1987; Schwartz, et al. 1987; Volkoff and Cerri 1987; Natelhoffer and Fry 1988; Cerling, et al. 1989). Data from Dzurec, et al. (1985), and Natelhoffer and Fry (1988) can be used to suggest that a +3.5 ‰ to +3.0 ‰ fractionation shift in δ13C values occurs because of microbial decomposition of organic material in the soils. For the following discussions a 3.5 ‰ fractionation shift is used, but this tentative value may require adjustment with further research results. Thus bulk soil humate δ13C values can be adjusted for fractionation effect and the relative contribution of C3 versus C4/CAM plants calculated through the formula:

Estimated percent of C3 Plant Biomass = ((δ13C - 3.5) + 13)/ (-0.14)

This formula assumes that the average δ13C value for C3 plants is -27.0 ‰ and the average δ13C value for C4/CAM plants is -13.0 ‰. Additionally the soil humate model assumes that carbon isotopes in bulk soil humate are fractionated by +3.5 ‰. It should be noted that there is disagreement among various researchers on the actual δ13C values for C3 and C4/CAM plants, and the degree of fractionation. As more accurate estimates become available especially for the local setting, the formulas used for estimation should be altered to reflect more reliable data. Nevertheless, it is doubtful that these figures will change by a significant amount and the estimates presented below are probably fairly accurate.

For the last few years the radiocarbon dating strategy for archaeological investigations at Jewett Mine has included the dating of bulk humic material from buried soils and alluvial sediments (Fields 1987: 277-278; Fields, et al. 1988: 13-67; Fields 1990a: 111-113, 340). Most of these humate dates were corrected for fractionation effect and stable carbon isotopes measured. It may be helpful to state that radiocarbon dating is based on the measurement of 14C/12C ratios. The method assumes a consistent amount of 12C, and that the amount of 14C varies only with time. As the discussion above indicates, the amount of 12C also varies in nature, and the way of nullifying this effect on radiocarbon dates is by adjusting the raw radiocarbon date by the 13C/12C ratio measured in the material. Radiocarbon dates are corrected to a δ13C value of -25.0 ‰, and thus to C3 plants. Fractionation correction of radiocarbon dates becomes particularly important for materials other than tree charcoal such as C4 or CAM plants, animals that eat these plants, or organic carbon in sediments derived from C4 or CAM plants since the 13C/12C ratios can significantly change the resulting age (Bousman 1990b).

The graph below shows the estimated C3 plant biomass percentages for bulk humate samples from Jewett Mine, Leon County, Texas plotted by general local physiographic contexts which are well known to be sensitive to plant community patterns, i.e. bottomland and upland (Figure 25). It should be mentioned that radiocarbon dates run on sediments are not accurate ages of the sediments, but the assays represent the mean residence time (MRT) of the organic carbon of the sediments. Stable carbon isotope ratios also represent MRT values (Hillaire-Marcel, et al. 1989), but the direct dating of the carbon allows a reasonably accurate temporal placement of these averaged δ13C values.

The C3 plant estimates are based on the formula presented above and even a quick inspection of Figure 25 shows that many of the estimates in the Late Holocene upland samples exceed 100 percent. This could be due to at least three problems that will be discussed below. The bottomland estimates indicate low C3 plant percentages for the two early Holocene samples, for the 3500 B.P. sample, and also for the 1800 B.P. sample. No upland sediment dates are available for the early or middle Holocene. Until data are available for the middle Holocene it is not possible to guage the accuracy of the straight line drawn between the 6500 B.P. sample and the 3500 B.P. sample. Between 3500 B.P. and 3000 B.P. C3 plants increase by approximately 20 percent. In both the bottomland and upland C3 plant contribution to bulk soil humates appears to drop dramatically between 3000 B.P. and 1800/1500 B.P. Interestingly this is approximately the same date as an increase in grass at nearby Weakly Bog (Holloway, et al. 1987: 74), and the implication is that at least some of the grasses are C4 species. After 1500 B.P. a general increase occurs in both the uplands and bottomlands, but the more detailed record in the uplands suggests that a number of fluctuations may have occurred or more spatial variation exists. Some of these may correspond to fluctuations in the Weakly Bog pollen spectra.

As noted above the C3 plant estimates above 100 percent constitute a problem which could be due to at least three possibilities. First the average δ13C values for C3 and C4 may not be correct for the specific plants in this portion of Texas. These values are derived from world wide estimates and until more specific regional data are available, their accuracy can not be assessed. Secondly, it is possible that the formula is incorrect and that a linear change in humate δ13C values does not correspond to an equal change in the contributing plant biomass δ13C values or that the amount of fractionation due to microbial decomposition is incorrect. The resolution of this problem will require controlled sample collection where plant biomass and matching bulk soil humate δ13C values are measured and calibrated.

The third problem is that stable isotope studies of closed canopy forests have shown that air and foliage can be extremely negative in their δ13C values, and this has been explained as due to the recycling of carbon dioxide (C02) in these forests (Vogel

1978a, van der Merwe and Medina 1989). If plants are forced to use the same air and these plants deplete the air of 13C, then the air will be more negative in terms of its δ13C value. The degree of this effect is related to the amount of carbon dioxide emission from the forest floor from plant respiration, and the change can be as great as 5-6 ‰ (van der Merwe and Medina 1989: 1093). Thus it appears that forest canopies can so significantly limit the flow of air between the forest floor and the open atmosphere that it alters the atmospheric δ13C value in the forest which is the starting point for all carbon isotope fractionation in the forest. Carbon isotope studies in German and Amazonian forests can be used to 'view' the effect (Figure 26), but too much variability exists between forest for these data to be applied to East Texas isotopes. The resolution of this problem will require a careful sampling of modern air, leaf litter, and soil from local forests.

Returning back to Figure 25, now it seems likely that the samples with estimates over 100 percent could represent forested environments with closed canopies. This is assessed in Figure 27 where the δ13C values from Jewett upland radiocarbon dates are plotted with the percent of arboreal pollen from nearby Weakly Bog. This scatterplot indicates that as arboreal pollen percentages increase then the δ13C values decrease, and if one drops the other is likely to rise. The reader should realize that the carbon isotope samples and pollen samples are not matched samples, and were taken from different areas and distinctly different depositional environments. Nevertheless the patterns suggest that canopies might have restricted air circulation enough to influence stable isotopes in past forests at Jewett Mine. This provides some support for the argument that these two lines of evidence are linked and reflect the same biotic changes at roughly the same times. Clearly more research is needed on this topic and the integration of pollen analysis and stable isotope analysis is likely to provide significant and exciting breakthroughs in paleoenvironmental reconstructions (Hillaire-Marcel, et al. 1989).

As an additional gauge of the usefulness of using carbon isotopes in bulk humate radiocarbon samples four sequences have been plotted from three areas of Texas, including Jewett Mine in Leon and Freestone Counties, Hidalgo-Willacy Counties Drainage Ditch Project in far south Texas, and Justiceberg in the southern Plains (Figure 28). These sequences show a complex set of patterns, but they all show some of their lowest δ13C values indicating the greatest amount of C3 plants between 2400-3000 B.P. This may correlate to the mesic interval identified in the Lower Pecos (Bryant and Holloway 1985, Patton and Dibble

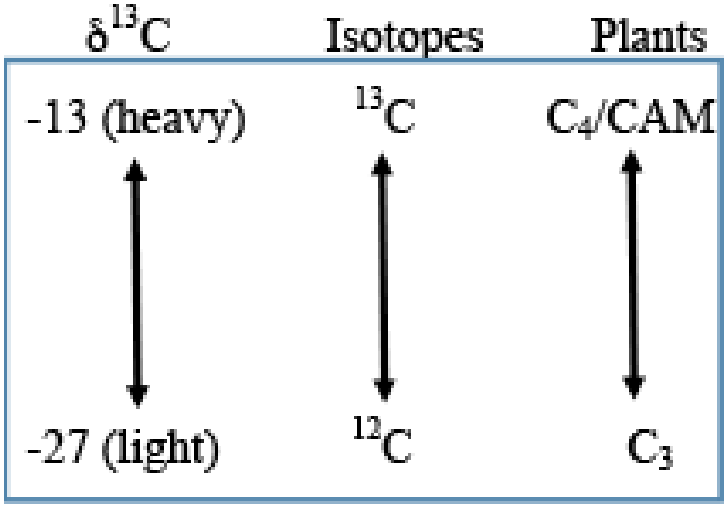

Figure 24: Illustration of relationships between carbon isotope measurements, isotopes and plants.

1982), and may indicate a very wide spread climatic event. Interestingly the Jewett upland samples consistently have the most negative δ13C values and thus the greatest relative frequency of C3 plants. The range of δ13C values represented between 2400 B.P. and 1300 B.P. is approximately 6 ‰, and this probably represents a 40 percent decline in the relative contribution of C3 plants through time. A second drop in δ13C values is recorded at approximately 500 B.P. and this may represent another widespread climatic event.

Bone and Carbon Isotopes

Since 1977 when John Vogel and Nikolaas van der Merwe presented the first dietary analysis in archaeology using stable carbon isotope ratios in prehistoric human bone from New York State, an explosion of applications using isotopes in bone has occurred (see van der Merwe 1982, DeNiro 1987, Price 1989 for general references). In comparison to other materials, more is known about stable carbon isotopes, diets and fractionation effects in bone. Plus stable isotopes from other elements such as oxygen and nitrogen in bone (see below), now are known to yield additional types of information . However, it is most logical to proceed with the discussion of carbon isotopes in bone and later explore the other isotopes.

The basic concept is that carbon isotopes are introduced into an animal's body, including humans, through their food. As carbon is a constituent of bone and as the source of carbon is from the diet, the isotopic composition of an animal's diet will be registered in its bone. If the diet is different, at least in terms of the mix of C3 and C4 plants, then this can be assessed by the measurement of carbon isotopes in the collagen fraction of bone. The notation and scale of measurement (δ13C) is exactly the same as for bulk soil humates.

Bone is constructed of organic and inorganic materials. The inorganic components constitute approximately 70 percent of the dry weight, the organic components make up 20 percent, while water bound to the organic and inorganic constituents accounts for most of the remaining 10 percent. The inorganic fraction is also known as apatite, and the organic fraction is mostly composed of collagen. The pathways for carbon inclusion into collagen and apatite are apparently different (Krueger and Sullivan 1984, Sillen, et al. 1989).

Krueger and Sullivan (1984) argue that in collagen and apatite from herbivore bones the primary source of carbon is from ingested plant food carbohydrates. However, because of different metabolic processes stable carbon isotopes are fractionated to different degrees in collagen and apatite. For herbivore collagen is on the average 5 ‰ higher than the diet eaten, and apatite is 12 ‰ higher than the diet. Unfortunately, the carbon isotope pathways for collagen and apatite, and the specific metabolic processes are poorly understood. Additionally research has shown that after the animal's death and if buried, apatite has a tendency to acquire carbon isotopes from ground water (Land, et al. 1980, Schoeninger and DeNiro 1982, Stafford 1984). This process of changing chemically or physically after burial is called diagenesis, and it makes the results of carbon isotope analysis of apatite (including radiocarbon dating) less reliable than analysis of the organic fraction of bone.

No stable isotope analysis of herbivore bone is available from East Texas, but limited analyses have been undertaken in West Texas and southern New Mexico (Speth 1983, Stafford 1984, Meltzer and Collins 1987). At Lubbock Lake buffalo (Bison sp.) bone δ13C values from collagen can be used to estimate local changes in buffalo diet and presumably surrounding vegetation (Stafford 1984: 90-120, Meltzer and Collins 1987: 22-23). Buffalo are known to be grazers (i.e. grass eaters), and it is presumed that changes in buffalo stable carbon isotopes reflect changes in the C3/C4 grass composition in the surrounding grasslands. Grazers, such as buffalo, represent some of the best animal species for the analysis of stable isotopes because of their rather narrow dietary preferences, i.e. grasses, and the ease of interpreting the ratios between C3 and C4 grass ratios. Numerous studies exist on C3 and C4 grasses in North America and worldwide, and it is well known that C4 grasses are better adapted to warmer climates, especially warm growing seasons than are C3 grasses (Teeri and Stowe 1976, Vogel, et al. 1978, Tieszen, et al. 1979, Boutton, et al. 1980). Thus it is assumed that changes in carbon isotope ratios in the organic fraction of buffalo bone reflect changes in actual grass composition in the Southern Plains which is itself controlled by changing climatic conditions (Figure 29). In East Texas where grazers such as buffalo are rare, other animal species can be selected that will provide a reasonable yardstick of changing biota. The problem is that the great majority of browse available is composed of C3 species so in woodlands it might be better to select generalized feeders over specific feeders such as browsers. This has been done in southern Africa with ostriches which are voracious and indiscriminate feeders (von Schirnding, et al. 1982; Bousman, et al. 1989). Instead of ostrich bone which is rare in archaeological sites, ostrich eggshell is used for stable isotope analysis. Similarly common and generalized feeders such as rabbits or hares could be used for East Texas.

For carnivores additional fractionation effects are know to complicate the picture (Krueger and Sullivan 1984, van der Merwe 1986). Lipids (fat) in herbivore flesh are 1‰ less than the diet of the herbivore, while herbivore protein (meat) is 5 ‰ higher than the diet. In carnivores, ingested meat protein is the greatest contributor to carnivore collagen, while ingested lipids appear to contribute most of the carbon to carnivore apatite (Krueger and Sullivan 1984). δ13C values from carnivore collagen do not appear to indicate a fractionation from its prey's protein, but carnivore apatite fractionates by approximately +9 ‰ from the lipid level of -1‰ from the original herbivores diet δ13C value, or in other words by +8 ‰ from the prey's diet. Few studies use carnivore bones for stable isotopes analysis and this is presumably because carnivore bones are not as common in archaeological or paleontological sites as herbivore bones.

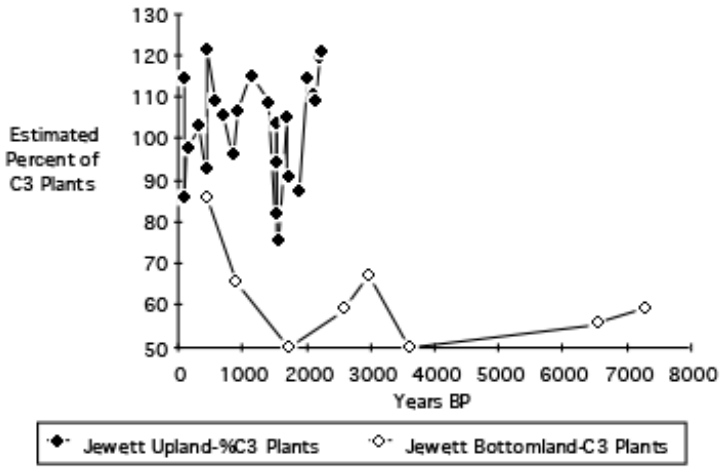

Figure 25: C3 plant composition estimates for radiocarbon dated bulk humate samples from Jewett Mine, Leon County (data from Fields 1987; Fields, et al. 1989; Fields 1990a; Fields 1990b).

The ignorance concerning carbon isotope pathways and metabolic processes is not dramatically important when considering animals that have a single source of food such as herbivores or carnivores, but recently major complications were discovered for mixed feeders, i.e. omnivores, such as humans. The reason is that humans and other omnivores eat significant amounts of both meat and plant foods. Krueger and Sullivan (1984) argue that humans incorporate carbon directly from meat protein into collagen, which is itself a protein. They go on to suggest that most of the carbon in apatite is acquired firstly from plant carbohydrates, then secondly from meat lipids, and lastly only small amounts from meat protein. It would be convenient if this were the case, but circumstantial evidence suggests that significant amounts of carbon isotopes in human collagen are obtained in fact from both meat and plant foods (Vogel and van der Merwe 1977; Klepinger and Mintel 1986). At this point in time the relative contribution of plants and meat derived carbon isotopes to human collagen is unknown (Sillen, et al. 1989). It is also unknown how the relative contribution of carbon isotopes from each source changes as one or the other food source is altered within the diet.

Nevertheless, it is clear that carbon isotopes in human collagen are fractionated by +5 ‰ above either the plant foods ingested directly by humans or the plant foods ingested by herbivore prey animals eaten by humans. If the primary source of carbon isotopes is through prey animals, then biotic changes should be registered in human carbon isotope ratios. This proposition assumes that prey animal diets reflect biotic patterns. Thus if δ13C values from human remains mirror changes in the botanical environment, one can take the extreme point of view that the major carbon pathway is from plant to herbivore to human, and that an unknown portion of the isotopic signal in human collagen is due simply to environmental changes that are transferred trophically from plants through herbivores to humans with little or no significant shift of human diet necessary. However if human and environmental patterns differ, then one must assume that this reflects a true human dietary difference that cannot be explained as simply a botanical change that is indirectly registered in human isotopes. In order to assess the significance of human δ13C values a measure of environmental change as registered by δ13C values is necessary, and carbon isotopes from bulk soil radiocarbon dated samples are the best and most easily acquired source.

An example is provided in order to illustrate the approach. First a preliminary and very limited example is now available from South Texas (Figure 30). These data were obtained from test excavations on the Hidalgo and Willacy Counties Drainage Ditch (Bousman 1990a). The two radiocarbon dates on human remains are from 41WY50 and 41WY113, while the humate samples were obtained from 41HG128, 41WY112 and 41WY113. The increasing slope of the soil humate δ13C values shows a consistent increase in C4 plants in the South Texas landscape (this is a widespread trend recorded in bulk soil humates in Texas at such places as Jewett Mine, Hidalgo and Willacy Counties Drainage Ditch, and Justiceberg), however the slope between the two human collagen δ13C values is opposite to this environmental trend. This suggests that environmental change does not account for the difference in the human δ13C values, and that dietary differences might be reflected in these values. It is of more than passing interest that 41WY50 is at the coast and that 41WY113 is 30 km inland. If additional data support these very preliminary measurements then it is possible that a coastal and inland dietary difference could be indicated by these measurements.

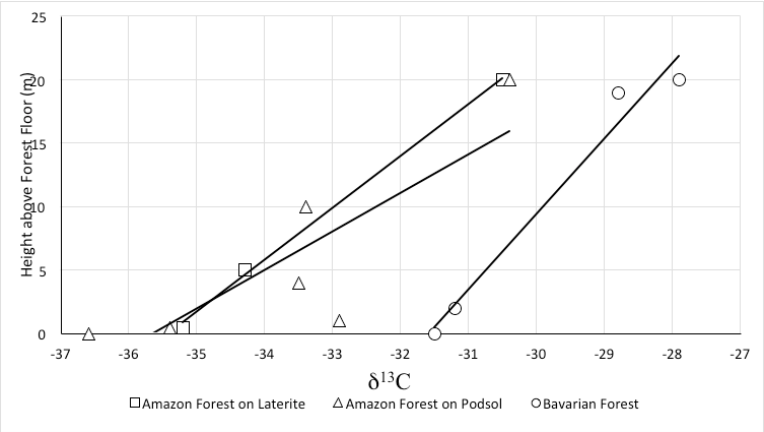

Figure 26: Carbon isotope effects under closed canopy forests (data from Vogel 1978a and van der Merwe and Medina 1989).

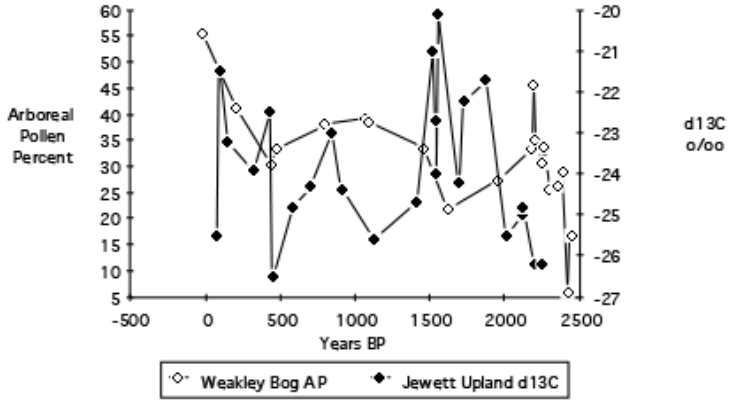

Figure 27: Percent of arboreal pollen at Weakly Bog and δ13C values of bulk sediments from Jewett Mine in Leon County, Texas.

Besides bone other faunal materials such as snail shells could prove suitable for carbon isotope analysis. Detailed studies of isotope ratios in modern and fossil shells by Abell (1982 and 1985), Abell and Nyamweru (1988), and Goodfriend (1988, 1990) might provide another approach for isotope analysis in East Texas.

Nitrogen Isotopes

Two stable nitrogen isotopes are used in paleoenvironmental and dietary analysis: 15N and 14N. The 15N/14N ratios are calculated by the formula:

δ15N= [(15N/14N)sample/(15N/14N)standard-1]x1000

This formula indicates that as the amount of 15N increases in the sample then the resulting δ15N value will be higher (i.e. heavier). The standard for 15N/14N ratio measurements is air, and it is given an arbitrary value of 0 ‰.

In terrestrial botanic communities 15N/14N ratios can be used to divide plants into two two groups: legumes and all other plants (Virginia and Delwiche 1982). Legumes have slightly less 15N and their corresponding δ15N values are consistently lower. The difference is not due to isotopic fractionation by plants, such as occurs with carbon isotopes by photosynthesis, but rather it is due to the ability of legumes to extract or to fix nitrogen from two sources: gaseous N2 from the atmosphere, as well as nitrate and ammonium ions from the soil. Other plants, nonlegumes, can only fix nitrogen from soil nitrate and ammonium.

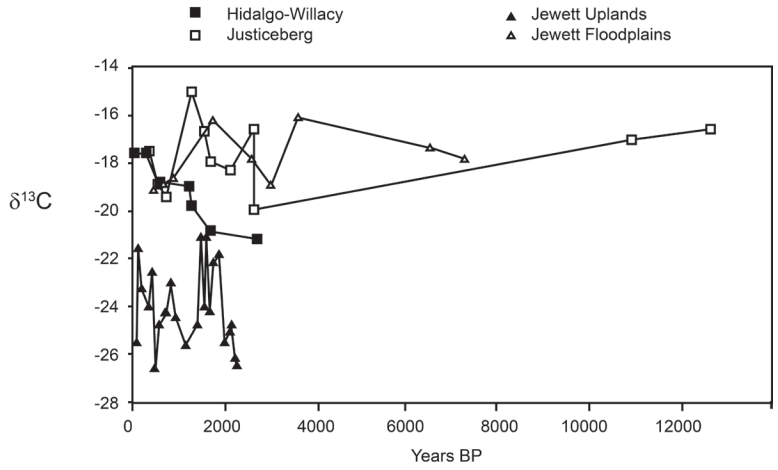

Figure 28: Four δ13C sequences from northeast, south and west Texas.

Atmospheric δ15N values average 0 ‰, while nitrate and ammonium have higher δ15N values (Letolle 1980). As atmospheric N2 has lower δ15N values than soil nitrogen, this difference is transferred to plants with very little change in the 15N/14N ratios. On average, legumes have δ15N values near 1 ‰ and δ15N values of nonlegume plants are close to 9 ‰ (DeNiro 1987). Initially 15N/14N ratios from scrapings taken from the interiors of prehistoric ceramic vessels or 15N/14N ratios from human bone were used in paleodietary studies to measure the introduction of beans as agricultural products through North America (DeNiro and Epstein 1981; Farnsworth et. al. 1985), but a number of new studies have discovered complications to this approach (DeNiro and Epstein 1981; Schoeninger, et al. 1983; DeNiro and Hastorf 1983; Heaton, et al. 1986; Heaton 1987; Sealy, et al. 1987).

The first complication is the enrichment of 15N as nitrogen isotopes pass from primary producer (plants) to consumer (animals). This effect increases δ15N values by approximately 3 ‰ for each trophic level, and it occurs in both terrestrial and marine food webs (DeNiro and Epstein 1981; Schoeninger, et al. 1983).

Additional complications consist of environmental effects on δ15N values in ecological systems (Heaton, et al. 1986; Heaton 1987; Sealy, et al. 1987). Two environmental effects are known: aridity and salinity. Heaton, et al. (1986) and Sealy, et al. (1987) have shown that stable nitrogen isotope ratios in human and mammal bone collagen are negatively correlated with mean annual rainfall, while Heaton (1987) has demonstrated that δ15N values in plants are also negatively correlated with mean annual rainfall. Even though the higher δ15N values in plants would be passed on to animals, the rate of nitrogen fractionation correlated to aridity is greater in animals than in plants. Higher δ15N values in animals appears to be a metabolic response to water stress, but this response has not been demonstrated for plants. In fact, Shearer et al.(1978) have shown that δ15N values in total soil nitrogen is strongly correlated with aridity, and this suggests that the nitrogen isotopic ratios of soils are transferred to plants and animals, and it is possible that no nitrogen fractionation by plants due to water stress occurs. The mechanisms that control soil 15N amounts are unknown.

Research as shown also that plant δ15N values are elevated near coasts (Virginia and Delwiche 1982, Heaton 1987). As δ15N values of ocean water is generally higher than terrestrial sources, it seems likely that sea-spray could introduce nitrates with high δ15N values and that this would influence 15N/14N ratios of plants growing near coasts. In addition, Heaton (1987) has demonstrated that plants growing at inland saline environments, for example near a salt dome, also have high δ15N values. It is known that salt can influence a number of metabolic, physical and chemical processes and reactions, and one or a combination of these apparently accounts for the elevated δ15N values of plants near saline environments.

Given a good sequence of well dated bone, it might be possible to construct a water stress curve using δ15N values. This has been done with the bones of modern animals (Heaton, et al. 1986), but a well-documented prehistoric example is lacking. To date few limited examples of stable nitrogen isotope analysis are available for Texas (Bousman 1990a), and the results are too restricted and preliminary to be useful. In northeast Texas stable nitrogen isotope analysis has been conducted on a series of human remains from the Hurricane Hill site at Cooper Lake, but these have not been published (Perttula, personal communication). Future research could address the questions on fractionation of nitrogen isotopes by plants in different environmental situations and more useful relationships with environmental parameters could lead to more accurate estimates of paleoenvironmental conditions.

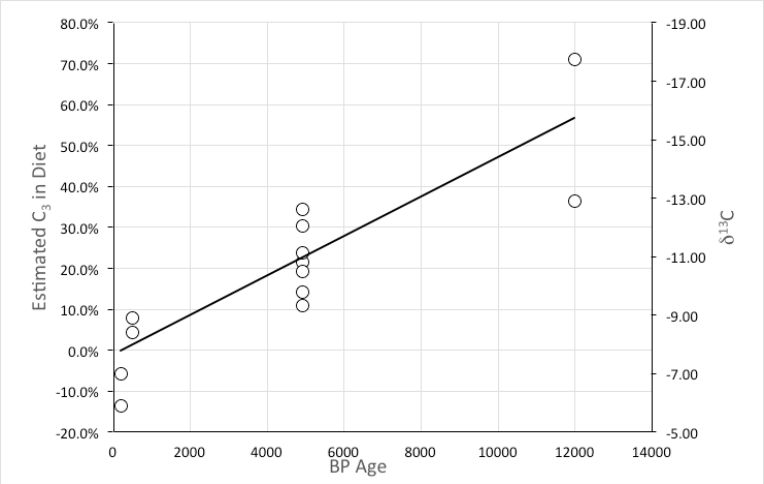

Figure 29: Estimated C3 plants ingested by Bison from Lubbock Lake (Stafford 1984: Table 2).

Oxygen Isotopes

In Texas almost no paleoenvironmental research has undertaken the analysis of stable oxygen isotopes, however Land, et al. (1980) have conducted a study of oxygen isotopes from the inorganic (apatite) fraction of modern deer bone. The δ18O ratio is used in paleoenvironmental studies, and two stable isotopes of oxygen, 16O and 18O, are employed. The δ18O ratio is calculated by the formula:

δ18O= [(18O/16O)sample/(18O/16O)standard-1]x1000

This formula reflects higher δ18O values with increasing amounts of 18O and lower δ18O values with increasing amounts of 16O.

In 1947 Harold Urey first theorized that fractionation of oxygen isotopes should be temperature dependent and δ18O values in marine shell could be used to estimate ocean water temperatures that existed during the formation of the shell. Temperature/oxygen isotope relationships were demonstrated in rain water by Epstein and Mayeda in 1953, and Emiliani (1955) first successfully argued that several complete glacial/interglacial temperature cycles were preserved in the oxygen isotopic record from fossil shells recovered in a core taken in the Caribbean Ocean. In a landmark paper Dansgaard (1964: 436-468) demonstrated that δ18O values in annual precipitation were related to mean annual surface air temperature. Numerous researchers have built on this knowledge and developed regional relationships (see Gat 1981, Siegenthaler and Oeschger 1980, Yurtsever and Gat 1981). Using δ18O values measured on precipitation from over 100 stations throughout the world between 1968-1983 (International Atomic Energy Agency 1973, 1975, 1979, 1986) shows that weighted annual average δ18O values of rain water can predict mean annual air temperatures (Figure 31). The coefficient of determination is r2 = 0.523., and it should be noted that this regression is not a strong as that presented by Libby (1983) because we use mean annual temperatures compared to weighted mean annual δ18O values in precipitation, while Libby uses only monthly temperatures with matching precipitation δ18O values. Thus dry months are not included in Libby's temperature calculation. The resulting formula is:

mean annual temperature (oF) = 73.962 - (0.208±.703)x - (0.336±.088)x2-(0.01±.003)x3

Oxygen Isotopes and Bone

Land, et al. (1980) indicate that δ18O values in deer bone apatite can be used to estimate evaporation rates. Initially the authors believed that the most significant relationship would be between δ18Ovalues and surface air temperature. However, analysis between these variables did not show a strong relationship with mean annual surface air temperature, while comparisons between δ18O values and evaporation rates did.

Water evaporates when the vapor pressure of the air is lower than the water surface where evaporation takes place (Trewartha, 1968). Evaporation continues until the vapor pressure of air reaches equilibrium with this evaporation surface, then at that point

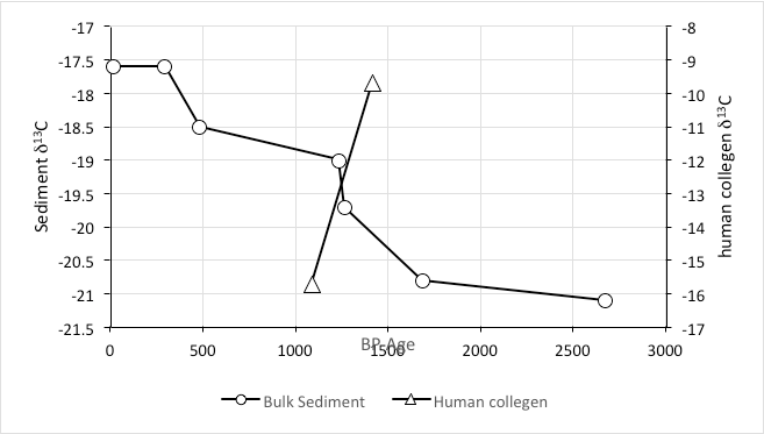

Figure 30: Bulk soil humate and human bone collagen stable carbon isotope ratios from Willacy County, Texas (Bousman 1990).

the air reaches its saturation level. Evaporation is dependent on temperature, relative humidity of air, and wind (Bomar 1983: 181). As temperature and wind increase and as humidity decreases so does the rate of evaporation. The two stable oxygen isotopes, 16O and 18O, evaporate at different rates (Faure 1986). As 16O is lighter, it has higher vibrational frequencies and forms weaker bonds, thus it evaporates more easily than 18O. As evaporation intensifies more and more 16O is removed. This causes the remaining water to become isotopically heavier as it is composed increasingly of 18O and depleted of 16O. When animals drink surface water or eat plants with moisture, they incorporate these isotopes into their bones, and the isotopic ratios of the surface water are preserved in the inorganic fraction (apatite) of the bone. As with the other stable isotopes, detailed knowledge of the processes by which these isotopes are incorporated into bone are lacking.

Land, et al. (1980) demonstrate that a linear regression between deer bone apatite δ18O values and local evaporation rates were strongly correlated (r2 = 0.827) as a plot of these data indicate (Figure 32). Using the data from Land, et al. (1980) evaporation rate can be estimated from deer apatite δ18O values by the formula:

Estimated Evaporation Rate = 27.226 (deer apatite δ18O value) + 122.33

New research has refocused on stable oxygen isotopes in deer bone (Luz, et al. 1990). They have analyzed δ18O in deer bone phosphate and found a fairly strong relationship (r2 = 0.836) between the δ18O values and annual temperature (Figure 33). The relationship is modelled by the formula:

Annual Temperature oF = 2.8408(δ18O) + 4.6243

In addition, Luz, et al. (1984) published a study that analyzed the relationship between δ18O values in rain water and δ18O values in phosphates from human teeth (Figure 34). This study demonstrated that a linear relationship (r2 = 0.94) could be used to estimate the δ18O value in rain water and the formula is:

δ18O rain water = (δ18O human teeth phosphate - 22.7)/0.78

This study is important because it implies that isotopic analysis on human remains could provide estimates of the actual paleoenvironmental conditions under which specific individuals lived. Oxygen isotopes in other organic materials such as snail shell (Yapp 1979; Magaritz and Hellier 1980; Magaritz and Heller 1981; Abell 1982 and 1985; Lecolle 1985), mammal bone (Shemesh 1983; Longinelli 1984), or wood (Long 1982; Wigley 1982; Libby 1983) can provide similar avenues for paleoclimatic estimations. Although complications such as the influence of compression wood on oxygen isotopes are to be expected (Luckman and Gray 1990).

Oxygen Isotopes in Carbonates

Recently a series of studies have focused on the analysis of stable oxygen isotopes in calcium carbonate deposits (Cerling et al. 1977; Cerling 1984; Cerling and Hay 1986; McKenzie and Eberli 1987). Cerling (1984) argues that oxygen isotopic composition of soil carbonates and meteoric water are correlated strongly at continental locations that receive less than 1000 mm (39.4 inches) of rain annually. Data from Cerling (1984: Table 1) can be used to provide an linear regression that tentatively models this relationship (Figure 34) and the resulting formula is:

$\delta 18O$ rain water = -1.361 + 0.955±0.054 * $\delta 18O$ soil carbonates, r2 = 0.969

However, when a site is on limestone bedrock the soil carbonates acquire oxygen isotopes from both meteoric water and the limestone, and this produces spurious results (Salomons and Mook 1976; Magaritz and Amiel 1980; Dever et al. 1983; Rabenhorst et al 1984). Other applications for stable oxygen isotopes include measurements on radiocarbon dated water from Pleistocene or Holocene aged aquifers (Heaton et al. 1986). Interestingly such aquifers exist, especially within the Eocene bedrocks that extend through Northeast Texas.

Hydrogen Isotopes

Hydrogen has two isotopes 1H and 2H. 2H is known as deuterium. The ratios between these two isotopes are represented as D/H ratios, and the dD is calculated by the formula:

dD = [(D/H)sample/(D/H)standard-1]x1000

Dansgaard (1964) showed that D/H ratios in ground water are related to the temperature during precipitation for the same reasons as oxygen. In fact water molecules can be composed of four combinations of the two oxygen and two hydrogen stable isotopes: D218O, D216O, H218O, and H216O, and the fractionation of these four water molecules can more strongly favor the lighter H216O water. Because deuterium, 2H, is much heavier than hydrogen, 1H, the degree of fractionation is much greater than for other isotopes, such as 18O and 16O, where the weight difference is much less. Using dD values measured on precipitation from over 100 stations throughout the world between 1968-1983 (International Atomic Energy Agency 1973, 1975, 1979, 1986) shows that weighted annual average dD values of rain water can predict mean annual air temperatures (Figure 35). The coefficient of determination is r2 = 0.586, and the formula is:

Temperature oF = 76.301 + 0.264±.051(dD rain) - 0.001±.0004 (dD)2

D/H Ratios in Plant Cellulose

Epstein et al. (1976) have argued that almost all stable hydrogen isotopes in plant cellulose are derived from groundwater, which is itself derived from rainfall. Hydrogen is incorporated into plant cellulose during photosynthesis when it binds with carbon or oxygen. A further step creates cellulose nitrate by replacing oxygen bound hydrogen with nitrates, thus leaving only carbon bound hydrogen in cellulose. This luckily appears to eliminate the exchange of hydrogen bound with oxygen in cellulose with hydrogen in water introduced later. Thus the D/H ratio in terrestrial plant cellulose reflects the D/H ratio in ground water at the time of cellulose formation (Figure 36). The relationship between D/H ratios in plant cellulose and ground water is modeled by the formula:

ground water dD = 19.965 + 0.99±0.044 * dD plant cellulose nitrate

In addition, Marino and DeNiro (1987) demonstrate that a variety of cooking processes including carbonization, do not influence the D/H ratios in plant cellulose. This implies that D/H ratios might be measurable in wood charcoal and past temperatures could be calculated.

Summary

A series of stable isotope studies are available that indicate useful data can be gathered on Late Pleistocene and Holocene climates and environments. Generally these data are not collected or if collected not analyzed. Future research can begin to collect and analyze these types of data, and build a comprehensive data base from which past environments and climates can be

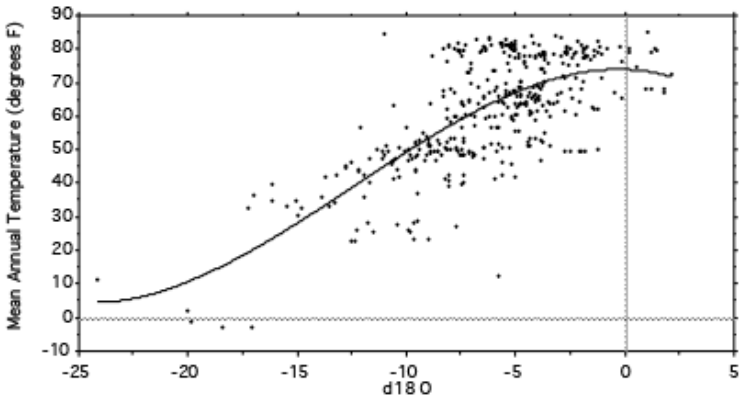

Figure 31: Third order polynomial estimating mean annual temperature (oF) from d18O in precipitation.

reconstructed. Carbon isotope measurements should be obtained always in order to correct radiocarbon dates for fractionation effects, especially for sediment or bone samples. The resulting paleoenvironmental data are an added benefit. Other stable isotopes require specific analysis, but in general the costs per sample are low and many radiocarbon dating labs offer the analyses as a service. Continued research on the "taphonomic" aspects of stable isotopes, or in other words, how isotopes are deposited in bone, soils or other materials, will make a wider variety of materials obtainable from the prehistoric record yield useful paleoenvironmental data. The reader should be aware that many of the climate/isotope relationships presented as formulas above are tentative, and these can be expected to change as more data are amassed and fractionation processes understood in greater detail. Nevertheless, the prospects are good that continued research will discover additional relationships between isotopes from materials often preserved on archaeological sites and climate. Archeologists should keep an open although critical mind toward new isotopic research as new materials are discovered that can provide paleoenvironmental data.

Besides establishing the various environment-isotope relationships, and greater understanding of fractionation, stable isotope analysis has other problems and difficulties. One problem is related to sampling. In many of the applications discussed above each sample was individually dated. These measurements are combined with a number of other individual samples to provide a fragmentary view of isotopic changes, but we remain ignorant of the temporal gaps between samples. Archeologists should be aware that significant fluctuations can occur between these data points in gaps. Except in rare cases it will not be possible to obtain a continuous set of samples from a single site analogous to a pollen profile or a tree ring record. Thus caution should be exercised when assessing individual isotope readings plotted by radiocarbon age because of the possibility of missing patterns.

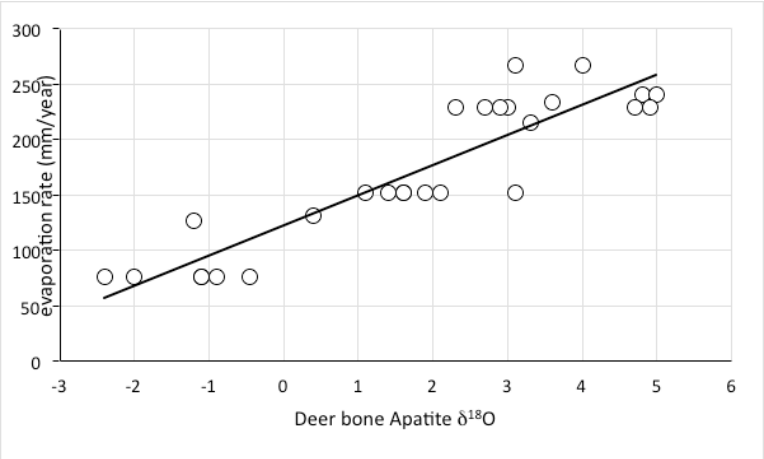

Figure 32: Linear regression between evaporation rates and stable oxygen isotope ratios from deer bone (data from Land, et al. 1980).

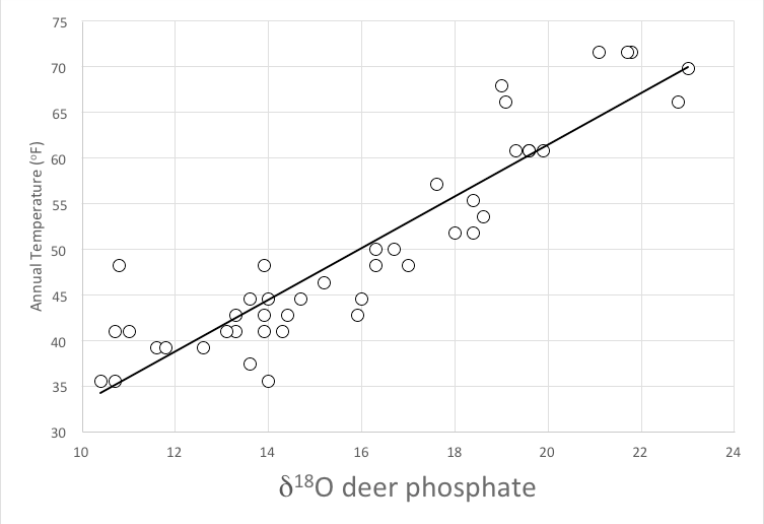

Figure 33: Linear regression between annual temperature and stable oxygen isotope ratios from deer bone phosphate (data from Luz, et al. 1990).

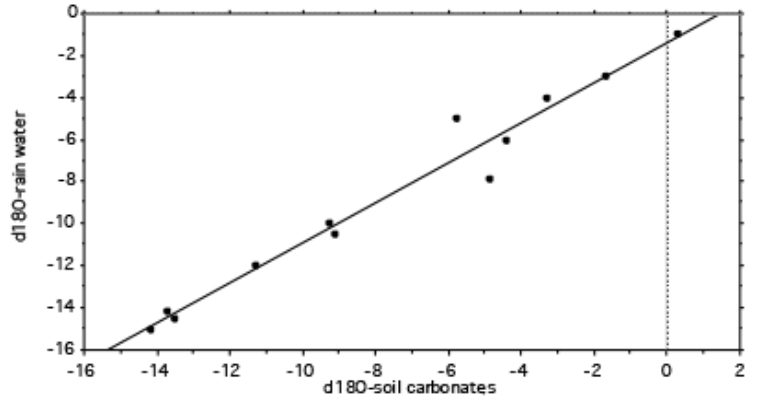

Figure 34: Linear regression between d18O in soil carbonates and d18O in local rain water.

XIII. COMPUTER SIMULATIONS OF PAST CLIMATES

In recent years the development of complex computer models that simulate weather and climate have begun to be employed in paleoenvironmental studies. These computer simulations are useful heuristically on a number of levels. First they allow for a more complete understanding of the workings of climate through experimental control of the variables. In addition, computer models allow changes in the parameters that are believed to control climate and the effects of these changes can be assessed. Thirdly, computer models can produce interactions between variables that might not have been considered before, and these new interactions provide new insights into climatic conditions at specific periods. Finally, tests of simulated conditions can be devised with proxy measurements of climate such as pollen or isotopes. Thus the "correctness" of these models can be assessed.

It is important to note that annual and seasonal solar radiation budgets have changed significantly during the Late Pleistocene and Holocene (Berger 1978; Hopkins 1981 in Kutzbach 1981; Milankovitch 1930). Computer simulations of past climates based on different solar radiation conditions offer extremely informative, challenging, and testable climatic models (see Schneider 1987 for general discussion; and Gates 1976; Kutzbach 1981; Kutzbach and Guetter 1984 and 1986; Manabe and Hahn 1977; Williams 1974; COHMAP Project Members 1988 for more detailed studies).

Most of climatic simulations are based on changes in the solar radiation budget due to variations in three of Earth's orbital parameters (Figure 37). These are orbital eccentricity, axial tilt or obliquity, and axial precession (see Imbrie and Imbrie 1979 for a readable history of these discoveries). It has long been known that Earth's orbit regularly varies from an elongated oval or elliptical orbit to a more circular orbit. The elongation and contraction of Earth's orbit, known as eccentricity, has a cycle period of 100,000 years. When the orbit is more circular solar radiation is more equitable between the seasons, but when the orbit is elongated then solar radiation varies more seasonally.

Earth also changes the angle of its rotational axis. When the angle is greater then summers receive more solar radiation and winters receive less solar radiation than if the angle of tilt is less. It is known that the angle changes from 21.5 degrees to 24.5 degrees and back to 21.5 degrees every 41,000 years.

The third variable is axial precession. Earth is like a spinning top, and as it spins the poles rotate in a circular motion. This wobble is a slow and continuous process that causes the seasons to actually change their positions on Earth's orbit so that at one time summer occurs when Earth is closest to the sun, and at another time summer occurs when Earth is farthest away from the sun. This wobble is known as axial precession or precession of the equinoxes, and it has a 22,000 year periodicity.

The interaction of these three orbital parameters with different rates of change are now thought to account for the major climatic variations observed in the Pleistocene and Holocene (Hays, et al. 1976; Imbrie and Imbrie 1979; Kutzbach 1981; Berger, et al. 1984). A number of computer simulations have been published for the last glacial maximum (Gates 1976; Kutzbach and Guetter 1986; Manabe and Hahn 1977; Williams 1974), and all show significant decreases in temperature in North America. This glaciation was stimulated by all three factors: 1) reduction in obliquity reduced summer temperatures, 2) an increase in axial tilt, made the seasons more extreme, and perihelion (the point on Earth's orbit when it is closest to the sun) occurred during the Northern Hemisphere's winter, which made summers cooler (Berger 1978). These factors acted in concert with the negative feedback mechanism of increased reflection of solar radiation by snow to reduce the amount of summer snow melt. It is reduced melting of snow in the summer that leads to the growth of glaciers rather than the accumulation of greater amounts of snow in the winter.

Kutzbach and Guetter (1986) presented a series of climatic simulations calculated every 3000 years from 18 thousand years ago (18kya) to present day so that simulations are available for 18kya, 15kya, 12kya, 9kya, 6kya, 3kya and 0kya. Kutzbach and Guetter (1986) suggest that for the Holocene at 9000 B.P., orbital parameters differed most from modern conditions. When compared to today, at 9000 B.P axial tilt was 0.38 degrees greater, orbit eccentricity was slightly more elongated, but most importantly perihelion was during the Northern Hemisphere's summer (30 July) while today it is in the winter (3 January). Given these differences summer would have received more solar energy and winter less at 9000 B.P. than today. The annual radiation budget at 9000 B.P. does not differ significantly from today's, but simulations (these models divide the Earth into large grids for calculation), using both a low resolution general circulation model with large grids and the high resolution National Center for Atmospheric Research-Community Climatic Model (NCAR-CCM) with smaller grids, create a seasonal climate at 9000 B.P. that was less equitable than today with hotter summers and cooler winters in the Northern Hemisphere (Kutzbach 1981; Kutzbach and Guetter 1984 and 1986; COHMAP Project Members 1988).

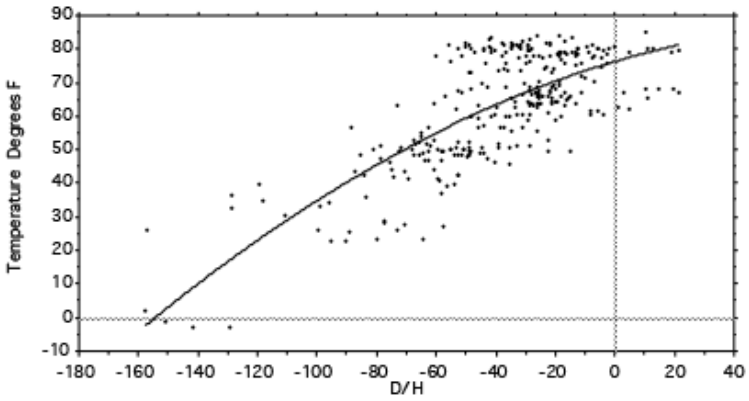

Figure 35: Second order polynomial estimating mean annual temperature (oF) from dD in precipitation.

COHMAP Temperature and Precipitation Simulations

John Kutzbach and a group of collaborators on the Cooperative Holocene Mapping (COHMAP) Project have run new simulations on the high resolution NCAR-CCM model for each 3000 year point from 18,000 BP until present. The new simulations have longer run times (450 days versus 150 days) and more accurate global ice distributions for individual temporal points (COHMAP Project Members 1988). The longer run times and new ice distributions in accordance with CLIMAP Project Members (1981) produce more precise climatic estimates. The NCAR-CCM model covers the world with grids that are 4.4o latitude and 7.5o longitude.

Three grids were selected to provide estimates for East Texas (Figure 38). These three grids extend from 24.4o latitude (slightly south of Brownsville) north to 37.8o latitude (just north of Springfield, Missouri), and from 90o longitude (New Orleans) west to 97.5o longitude (near Waco, Texas). This is a large heterogeneous area, however the NCAR-CCM model is of global scale so that isolation of small areas is not possible, and greater spatial resolution would sacrifice the reliability of the predictions. Dr. Kutzbach has generously made available these unpublished simulated data for Texas, and these simulations are presented here as hypotheses to be tested by future paleoenvironmental research in Texas. As untested hypotheses these simulations are intended to stimulate ideas and dialogue on Late Pleistocene and Holocene climatic change and paleoenvironments.

The simulated annual temperature indicates that the climate was coldest from 18kya to 15kya, and it began to warm between 15kya and 12kya (Figure 39). The estimates for 18kya and 15kya are approximately 9 oF lower than the modern annual temperature. After 12kya the rate of warming increases, and the point of maximum temperature is roughly 58 oF at 3kya. Annual precipitation simulations are 45-47 inches at 18kya and 15kya. Simulated precipitation then proceeds to climb steadily to 69-70 inches at 3kya. After 3kya it drops dramatically. For East Texas these precipitation estimates appear to be high and temperature estimates appear to be too low, also considering the synthesis of pollen data (above) a middle Holocene warm dry event was expected. However it must be remembered that the area covered by these simulations extends much further north and east making an accurate match between known modern climatic conditions and the simulated estimations less secure. Because the simulations differed from many preconceived ideas about Pleistocene and Holocene climates, the simulations for West Texas are also presented (Figure 40). The West Texas grids cover all of West Texas, eastern New Mexico, western Oklahoma, southeast Colorado and southwest Kansas. Interestingly, these simulations do show a middle Holocene, 6kya, rise in temperature associated with a drop in precipitation. However, simulated conditions today are worse with temperatures at the same levels as at 6kya, and precipitation much lower. Few paleoenvironmental researchers would be willing to accept that conditions are worse today than during the middle Holocene drought (Altithermal). Also precipitation is estimated at much higher levels for 0kya than is known to exist.

Possibly a more instructive procedure for utilizing the simulations is to plot the differences from the simulated 0kya values for different times. For example this procedure would subtract the precipitation simulated for 0kya from the precipitation simulated for 18kya and every other time period. This allows an assessment of how simulated climatic variables have changed in relation to the present climate even if the real climate is warmer and drier than the simulated values. Additionally it is worthwhile to plot the simulations for January (winter) and July (summer) in a similar manner. In this way seasonal changes in simulated climate can be seen, and their possible impact on human, plant and animal distributions assessed.

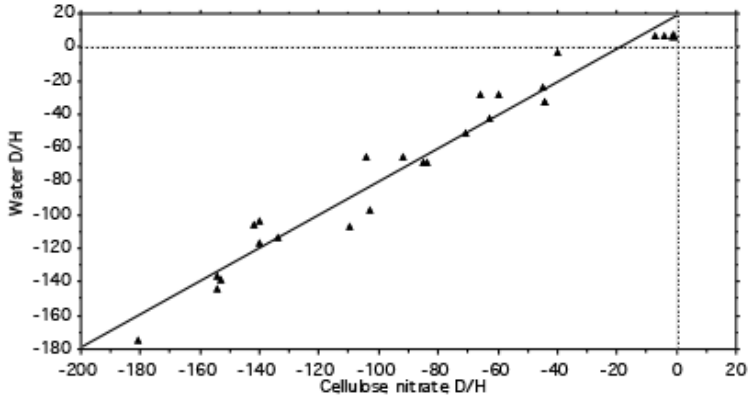

Figure 36: Linear regression between the D/H ratio in wood cellulose nitrate and associated water (data from Epstein, et al. 1976: Table 4).

Temperature simulations for East Texas (Figure 41) show that through the Late Pleistocene there is a constant and steady rise in summer temperature so that by 9kya summers are a degree or so warmer than modern temperatures. Winters at 15kya and 18kya are over 9 oF lower than modern temperatures. Between 15kya and 12kya winter temperatures begin to rise but only reach modern winter temperatures at 3kya. One point worth noting is the apparent greater temperature variability between summer and winter temperatures from 9kya to 18kya when compared to the most recent three simulations. Also at these times summers are considerably warmer than annual temperature estimates.

Simulations for West Texas (Figure 42) show the lowest temperatures at 18kya and 15kya with little change in winter temperatures but a large increase in summer temperatures in this period. Summer temperatures become hotter than modern at 9kya and remain hot until some time after 6kya. Winter temperatures and annual temperatures reach their highest level at 6kya and then decline. These data could be used to suggest that the existence of an early-middle Holocene dry period (i.e. the Altithermal) was a response to changing incoming solar radiation due to variations in the orbital parameters discussed above.

In order to plot summer and winter precipitation on the same scale as annual precipitation the seasonal values must be multiplied to the levels expected if that amount of rainfall was received for an entire year and not just one month. As noted above precipitation simulations from East Texas suggest that annual rainfall is at its lowest level at 18kya. Annual rainfall then increases at a rapid rate until 9kya, when it levels off until 3kya, and then drops between 0-3kya. Significant changes in winter and summer precipitation simulations provide a challenge for testing with independent paleoenvironmental data (Figure 43).

These simulations suggest that between 12kya and 18kya winter rainfall was higher than modern levels, and at the same time summer rainfall was significantly lower than modern levels. This situation changes dramatically between 12kya and 9kya, when summer rainfall rapidly increases to a level well above modern simulations. Simulations of winter rainfall drops between 12kya and 9kya, and generally never exceeds modern levels in any significantly degree after that time. The implications of a cool Late Pleistocene with low rainfalls and greater contributions by winter rain has yet to be considered in terms of past plant communities. Also the effects of a cool Late Pleistocene climate changing to a warm early Holocene climate with summers wetter and hotter, and winters drier than those of todays must be assessed as well (cf. Holliday 1987).

Seasonal precipitation simulations for West Texas (Figure 44) indicate a similar winter-summer rainfall dichotomy between the Pleistocene and Holocene. One significant difference between Holocene simulated precipitation for East and West Texas is the dramatic drop in summer rainfall at 6kya. At the least, this would seem to support Meltzer and Collins' (1987) and Holiday's (1989) data for the Altithermal in the Southern Plains. A major concern for paleoenvironmental studies is how far east did the effects of the Altithermal reach? The simulations for East Texas seem to imply that this region did not suffer from its impact, and Bryant (1977) has suggested the same conclusion based on the pollen analysis from Boriack Bog. However the model presented in the summary of the pollen data (above) suggests that the Altithermal did impact East Texas plant community structure and composition.

These reconstructions provide an independent estimate of changing climate that can be tested by proxy paleoenvironmental data such as sediments, pollen, phytoliths, stable isotopes, large mammalian fauna, microfauna, diatoms, and molluscan fauna. Unfortunately, these simulations have low spatial resolution, but they are based on known atmospheric processes and known

variations in solar radiation. As noted by Kutzbach and Guetter (1986: 1727) these simulations are based on atmospheric circulation models, but they are not coupled to ocean circulation models. This is a major drawback as such interactive ocean-atmosphere models are likely to provide much more accurate climatic simulations. Certainly integration of these simulations with ocean derived paleoenvironmental data (cf. Brunner 1982; Jasper and Gagosian 1990) will provide as crucial of a test as land based data, and possibly indicate interactions between oceanic and terrestrial past climates. Lastly the simulations cannot predict short-term fluctuations such as might be stimulated by major volcanic events (Bryson 1989) or by rapid surges in glacial meltwaters at the end of the Pleistocene (Emiliani, et al. 1975, Jones and Ruddiman 1982), but they are capable of simulating the major climatic patterns for the Late Pleistocene and Holocene as as such they provide extremely stimulating assessments of late Quaternary climates in Texas.

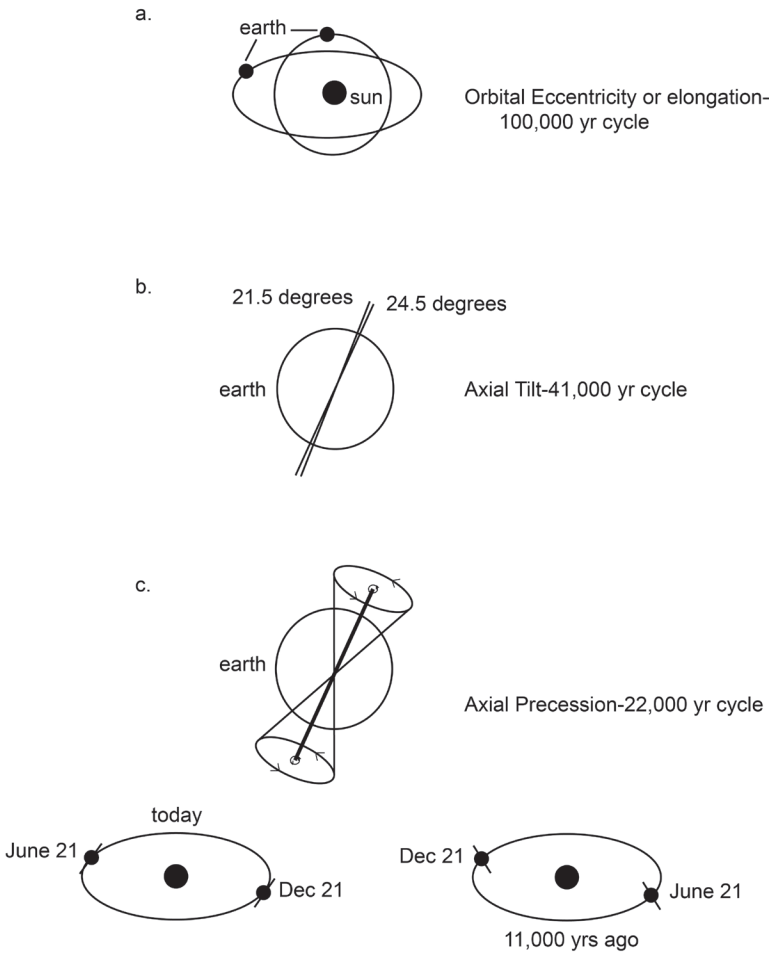

Figure 37: Orbital parameters used in COHMAP climatic simulations.

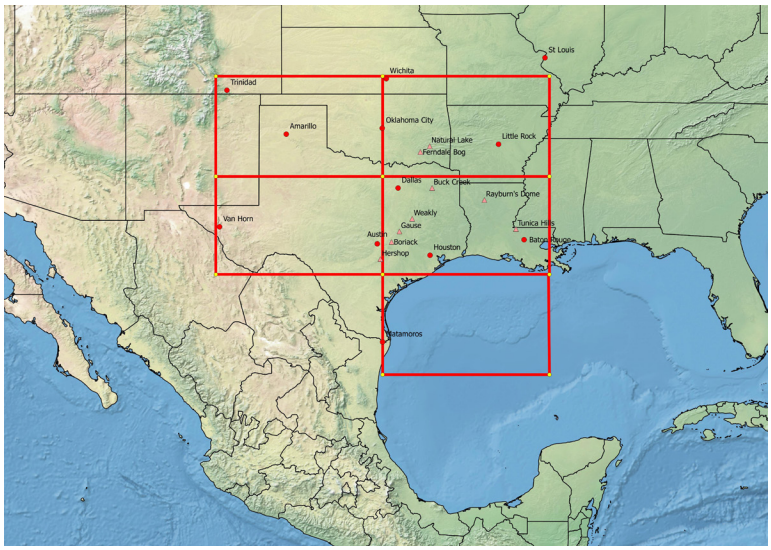

Figure 38: Map of simulation grids over Texas.

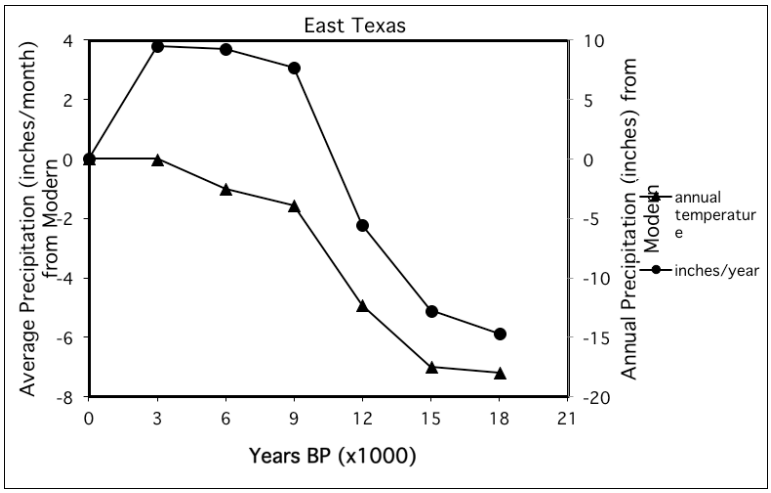

Figure 39: COHMAP Project high resolution NCAR-CCM model simulated annual temperature and annual precipitation for East Texas.

XIV. FORMATIONAL PROCESSES OF THE ARCHAEOLOGICAL RECORD OF NORTHEASTERN TEXAS: IMPLICATIONS, QUESTIONS, AND PROBLEMS FOR FUTURE INVESTIGATIONS.

The diverse natural settings in Northeastern Texas of today as well as those which have existed in the past fundamentally influence the nature of the archaeological and cultural-ecological record. At present, the archaeological record is most complete for the recent past and most evidence for Archaic and Paleoindian is derived from isolated finds of diagnostic artifacts or from culturally-mixed contexts. Similarly, the best ecological evidence is from the Late Holocene. A very high priority in Northeastern Texas must be to locate and document high quality occurrences of data on Archaic and Paleoindian lifeways and on Late Pleistocene and early to middle Holocene environmental conditions. The paleogeographic framework for seeking out these data sets is far from established, but much of the necessary data needed to build the framework is extant. It needs to be evaluated and synthesized as a prelude to further fieldwork.

The geologic dynamic is both foe and friend. As foe, geologic processes destroy sites through erosion and, along with soil processes, alter the evidence that remains in other sites through chemical and physical attack on site contents (Ferring in prep). These are not random forces. Erosion is widespread in uplands and unevenly present in lowlands; groundwater, soil acidity, compaction, and other adverse conditions are found in different combinations and in various expressions over the landscape. The differential loss and preservation of archaeological evidence is a familiar fact of archaeological inquiry. Its converse--the beneficial aspects of geologic process --is less familiar.

Much in geologic process is governed by conditions that are both reasonably well understood and highly pertinent to human activities. Investigation of prehistoric human ecology can only benefit by fuller use of these relationships. Site distributions mapped for an area must be evaluated to determine whether significant numbers or particular subsets of the population have been lost to geologic destruction, or exist but have been obscured in the subsurface. It seems probable that in the region in general early sites are underrepresented by virtue of both of these conditions; on the other hand, systematic search for geologic deposits of Late Pleistocene or early Holocene age has the potential to gradually improve the representativeness of our samples.

Individual sites of whatever time period may vary internally in terms of the effects of site formational processes and survival conditions. Geologic and pedogenic evidence may be critical in assessing site integrity. Careful and thorough evaluation of these conditions by someone trained in earth sciences needs to be a part of archaeological surveys and site assessments.

It appears for Northeastern Texas that much of the archaeological record is buried in valley fill (Rainey 1974; Mandel 1987 and in prep; Mandel, et al. 1987; Bousman, et al. 1988; Bousman and Fields 1988; Ferring 1986, 1989, in prep). However in the areas of thickest Eocene sands, there are also considerable colluvial areas with buried site potential (Heinrich 1986; Perttula, et al. 1986; Fields and Heinrich 1987a and 1987b; Fields, et al. 1988; Bousman 1990c; Fields 1990a and b). Additionally there is evidence that, at least west of 95th meridian, Late Holocene cycles of valley filling and cutting have been driven by climatic changes (Hall 1990). A major question is whether similar cycles are evidenced for earlier times or other areas. Certainly the general lack of Middle Holocene deposits throughout much of Eastern Texas (Mandel, et al. 1987; Bousman and Fields 1988) except in unique circumstances (Bryant 1977; Bousman, et al. 1988; Mandel in prep), and the identification of a significant shift in plant communities at the same time in the Middle Holocene (see above) may represent a very likely candidate for other depositional/erosional cycles that are driven by climatic changes. The nature of human adaptations would be subject to change under climatic oscillations and in response to the actions of streams; also, such cycles have major implications for survival of archaeological evidence. Major episodes of valley cutting first destroy sites in the areas cut but they also create low-lying areas where any sites formed may subsequently become deeply buried in the next valley filling episode.

There is also the unresolved question of site formation processes in the deep, unconsolidated sands of presumably Eocene age. Fossil soils and intact features at depth in these sands strongly indicate active deposition during the Holocene, although until the nature of such deposition is more convincingly understood, Holocene deposition will remain at issue.

There are hints that tectonic activity may have occurred during culturally-relevant times in Northeastern Texas. If so, changes in the gradient of streams, formation or destruction of lakes, landslides, formation of alluvial fans, shifts in water table levels, and other physical changes may have affected not only past human adaptations, but the preservation and nature of the archaeological record.

Archaeologists have focused on sites of relatively high visibility in Northeastern Texas. These include sites with mounds and other visible features as well as sites with large concentrations of cultural material at the surface. In some cases, the latter are the result of multiple components residing on a single, long-stable surface or a deflation surface. Less conspicuous sites with discreet components are needed to improve the quality of data on individual components. Targeting areas of geologic deposition

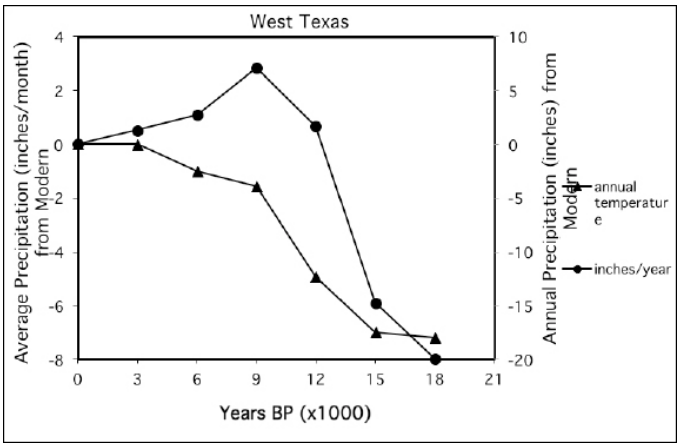

Figure 40: COHMAP Project high resolution NCAR-CCM model simulated annual temperature and annual precipitation for West Texas.

of relevant ages needs to become a foremost research strategy.

Environmental data from non-site areas are needed for most of the prehistoric past in most of Northeastern Texas. Systematic searches for sediment traps of long duration and with good conditions for preservation of biotic materials are needed. Fossil channels, flood basins and oxbows in stream valleys as well as bogs and ponds should be cored whenever there is an opportunity. To increase the number of such opportunities, cultural-resource permit projects should include identification and assessment of such localities. The same is true for fossil soils in non-site areas.

A high priority needs to be placed on the discovery and investigation of prograded deposits such as valley ridges and point bars. These afford good stratigraphic separation and potentially long sequences of low energy deposits relatively near the present surface.

In summary, the collection and analysis of comprehensive ecological data (geomorphological, pedogenic and biotic) should become a carefully planned part of all archaeological research in Northeastern Texas. This is not to say that ecological inquiry should displace more traditional data recovery efforts, but that the two should be fully integrated with an emphasis on data quality. To achieve this, all of the appropriate specialists must be a part of the total planning process. The tendency for such studies as Quaternary geomorphology to be afterthoughts or independent studies having little or no integration with other aspects of projects is wasteful and can no longer be justified.

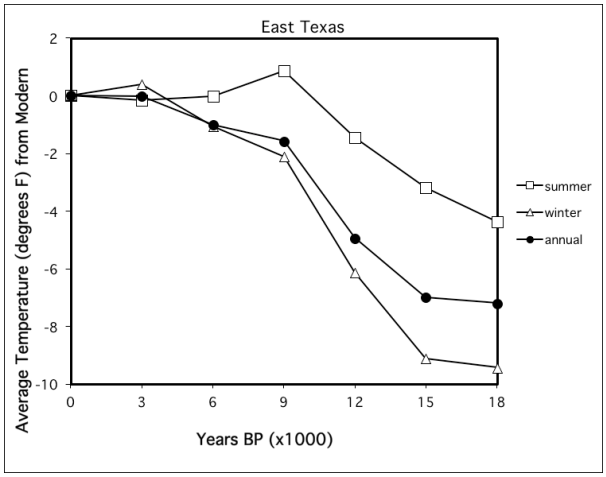

Figure 41: COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer temperature for East Texas. Variations reflect differences from modern levels.

XVI. ENVIRONMENTAL CHANGE AND HUMAN ECOLOGY IN NORTHEASTERN TEXAS

For the sake of discussion, the premise is taken that much of what we seek to know about the natural environmental dimension of human ecology in Northeastern Texas over the last 12 or so millennia is controlled or influenced by climatic conditions. Climate, then, is the independent variable--though not perfectly so--with floral, faunal, pedogenic, and geomorphic systems responding in complex but basically dependent ways to climatic change. Human response to these conditions is also dependent to the extent that the natural environment affords opportunities and sets limits; the actual cultural ecological patterns that emerge also reflect independent factors of cultural history, political conditions, belief systems, and the like. Turning to just the environmental side of the culture ecology equation, we attempt here a brief synthesis for the region, highlight areas of strength and weakness in our present knowledge base, and suggest some directions for future inquiry.

Over the last 12,000 or so years climates have changed dramatically in Northeastern Texas. Late Pleistocene climates were certainly cooler, and it seems clear that more moisture was available for plant growth during this time as well. Forest communities in the region support a number of taxa that are characteristic of forest communities that exist today at more northerly latitudes or higher elevations. It is likely that although cooler, Late Pleistocene climates may have been more equable. Terminal Pleistocene climates appear, on the other hand, to have been complex with numerous and rapid fluctuating conditions that apparently stimulated rapid deforestation and reforestation. This is a worldwide phenomenon and it is likely linked to the melting of glaciers and a complex series of events that accompanied the rapid influx of fresh water into the world's oceans, especially the Gulf of Mexico and the North Atlantic. During the early Holocene climatic conditions appear to be warming, less moisture is available for plant growth, and a consistent trend toward less forest cover in Northeast Texas is indicated. The middle Holocene is marked by a dry and warm-to-hot period that may have had a brief respite at ca. 6000 B.P. Paleobotanic data can be used to suggest that grasslands became much more widespread and replaced forest communities at this time, especially along the western edge of Northeastern Texas. The Late Holocene witnesses the gradual reforestation of the eastern portion of Texas. Short brief intervals with greater grass cover occur at ca. 1500 B.P. and 500 B.P. The evidence is unclear whether these short grassy intervals represent slightly drier or slightly wetter periods, nevertheless, generally through the Late Holocene the trend toward reforestation can be taken to imply better conditions for forest growth than existed during the middle Holocene. As plant communities can demonstrate a lag effect in responding to beneficial climatic conditions, it is unclear if the slow reforestation documented best at Weakly Bog represents a lag effect to a rapidly improved climate or a matching response to slowly improving climatic conditions.

A coherent faunal record of the last 12,000 years does not exist for Northeastern Texas. There are a few assemblages of Late Pleistocene fossils, and animal bone has been recovered from some archaeological sites, mostly dating from the Late Holocene (Slaughter and Hoover 1963). The Pleistocene assemblages are neither precisely dated nor from well stratified sequences (Rainey 1974). Additional faunal data are needed for the region, especially for the Early Holocene. The bog pollen data discussed earlier in this report raises an important question in regard to the concept of "disharmonious" faunal assemblages as originally defined by Hibbard (1960). By disharmonious fauna, paleontologists mean that species seem to occur together at times in the Pleistocene that today occupy very different ranges (Slaughter 1975, Lundelius et al 1983, Semken 1983). The implication of this concept is that certain ecological extremes which define habitat limits, such as high or low temperatures, did not occur because climate was more equable in the Pleistocene as compared to climates known from the Holocene (Graham and Lundelius 1984, Semken 1988). If the very short term swings in the bog pollen record between 16,000 and 9,000 years ago reflect climatic swings, it is possible that faunal collections that represent a few thousand years and appear to contain diverse, co-existing fauna may, in fact, be mixes of fauna from two or more brief and contrasting climatic episodes. This underscores the need for very tight chronological controls on all classes of paleoenvironmental data, including fauna (Stafford and Semken 1990).

Much of the upland areas in Northeastern Texas manifest relatively low order but persistent physical change over the culturally-relevant past. The presence of ancient soils and mature landforms attest convincingly to this, but perhaps we have been too easily convinced. Uplands in the northwest corner of our area have been subaerial since the waning of the Cretaceous (greater than 65 million years) and most of the rest of the area has been terrestrial since late in the Paleogene (greater than 40 million years).

Landscape evolution over tens of millions of years is certainly going to appear dominant over the relatively minor changes wrought in the last 12 thousand or so years. But in human ecological terms, those most recent and minor changes are significant, maybe even dramatic. We do have mature landforms, but nature's work is not finished. High ground is weathering to produce colluvial slopes and contribute detritus to the fluvial environments. Upland soils, though ancient, are not static, and they inch downward to alter more substrata as erosion takes off the topmost part of the profile. As noted, there is evidence that at times and

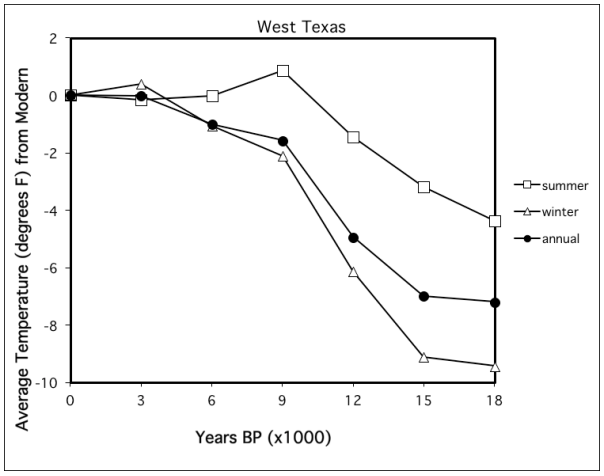

Figure 42: COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer temperature for West Texas. Variations reflect differences from modern levels.

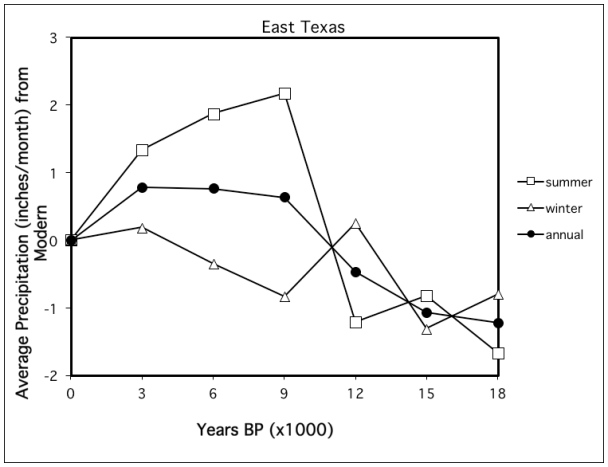

Figure 43: COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer rainfall for East Texas. Variations reflect differences from modern levels.

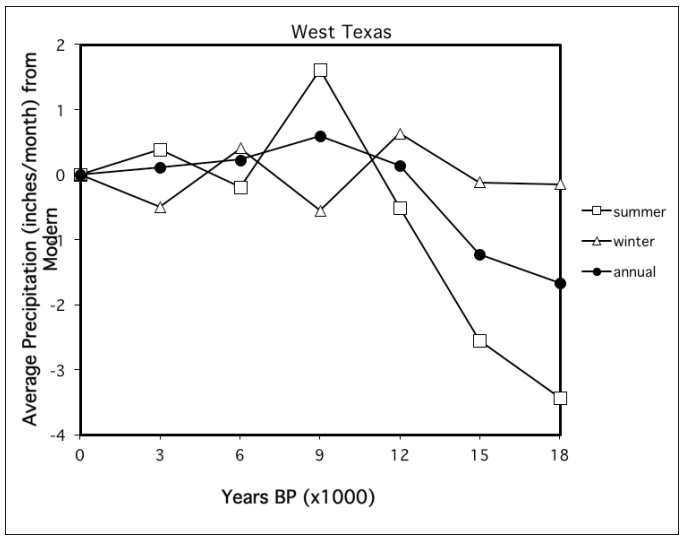

Figure 44: COHMAP Project high resolution NCAR-CCM model simulated annual, winter and summer rainfall for West Texas. Variations reflect differences from modern levels.

places, erosion has been excessive and the upper soil horizons have been lost and later reformed. These edaphic events are not well dated, but the not uncommon occurrence of late Paleoindian and early Archaic diagnostic artifacts resting on the contact between truncated B-horizons and overlying soils may be evidence that widespread erosion either predates the human presence or is partly contemporaneous with it. In either case, it is important to our understanding of the archaeological record and to past human ecology. Efforts are needed to fully investigate this soil-geomorphic question. There are clear trends in the climatic models and provocative cycles in the pollen and isotope curves. It is tempting to suggest that as solar heating and seasonal contrasts increased in the period 18,000 to 10,000 years ago, adverse effects on vegetative cover and greater incidence of heavy rainfall resulted in patchy but widespread soil stripping in Northeastern Texas. Due to the lag in response of biotic communities to climatic change and the slow recovery to lost soil cover, conditions favoring substantial localized erosion may have persisted in the area through the early and into the middle Holocene. In Late Holocene times, there appears to have been an improvement of these conditions, and more stable cover established. Extensive early to middle Holocene valley fill deposits as well as significant downwasting in the Eocene sand areas are consistent with this suggestion. Late Holocene Copan (and Navarro) type soils would most likely develop in areas of good ground cover where seasonally heavy rains caused flooding but little erosion.

The lowlands of Northeastern Texas during the last 12-13 millennia have undergone substantial change, brought about primarily by fluvial processes. Extensive terraces and massive fluvial deposits, some composed of coarse material, have generally been thought of as remote ("Pleistocene") in age. Deweyville and comparable fluvial features are getting younger as we apply direct dating procedures and look closely for included archaeological manifestations, all indicating more dynamic change than we have traditionally perceived for the time of human presence in Northeastern Texas. The comparatively minor climatic change that triggered the valley trenching over wide areas of the southern great plains ca. A.D. 1000 underscores the capacity for change that exists in those natural systems critical to human ecology. More systematic correlation, dating, and interpretation of these data are high priority research needs.

Not dependent upon climatic variation are tectonic forces which, if we look closely, may be found to be more characteristic of the Late Quaternary in Northeastern Texas than generally thought. Subsidence, faulting, and the like are capable of locally altering the environment significantly. Alluvial fans, natural lakes and other stream gradient changes, ponds, and salt water seeps are among the ecological consequences of tectonics. In the long run, sediment traps afforded by some of these conditions should host valuable paleoenvironmental information.

A limited synthesis of paleoenvironmental change has been present above. However the data are scarce and incomplete, and before a reasonable and reliable picture of past paleoecology can be constructed much more raw information must be gathered, and from a variety of sources. Major gaps exist in the present record and understanding of past environmental changes in Northeast Texas, such as faunal changes, and their virtual omission in the above discussions should not be taken as a gauge of their importance toward understanding past environments and paleoecology. Rather their apparent omission should send up a flag earmarking a major gap that desperately needs to be filled in rapid order.

In addition to the gathering of new and varied data sets, more dialogue is needed on what environmental and climatic changes occurred and why these changes happened. In Northeastern Texas, and Texas in general, too little effort has been expended on the causes of environmental change. The models and theories of Kutzbach (1981), Bryson (1977, 1989), Emiliani, et al. (1975) and others need to be discussed at length, argued over, new ideas presented and then tested with field observations. It is not enough to present new ideas and theories (cf. Gunn and Brown 1982), but a considerable effort must be expended on the "ground truthing" of these ideas. Nor is it sufficient to present models of environmental change without providing some concept of how the causal variables create such conditions (cf. Bryant and Shafer 1977). In retrospect it appears that a more complete understanding of past environmental changes can best proceed in a constructive manner by constant critical evaluation of ideas, models and data, along with the accumulation of new and varied sources of raw data (cf. Hall 1990). The slow buildup of more data, such as new pollen sequences, and the introduction of new types of data, such as stable isotopes, can by critical evaluation, provide the stimulus for new insights on how past environments and climates changed in Northeast Texas. These models can then be used by archaeologists to better understand the nature of prehistoric human behavior.

REFERENCES CITED

Abell, Paul I.
1982 Paleoclimates at Lake Turkana, Kenya, from Stable Oxygen Isotope Ratios in Gastropod Shells. *Nature* 297: 321-323.

1985 Oxygen Isotope Ratios in Modern African Gastropod Shells: A Data Base for Paleoclimatology. *Chemical Geology* (Isotope Geoscience Section) 58: 183-193.

Abell, Paul I. and Celia K. Nyamweru
1988 Paleoenvironments in the Chalbi Basin of Kenya. *Chemical Geology* (Isotope Geoscience Section) 72: 283-291.

Adair, Mary J.
1984 Plant remains from Drumming Sauna (34WN29). In *Hunters of the Forest Edge: Culture, Time and Process in the Little Caney Basin (1980, 1981, and 1982 field seasons)*. Kenneth C. Reid and Joe Alan Artz (eds.) University of Tulsa Laboratory of Archaeology, Contributions in Archaeology 14.

Adam, D. P. and G. J. West
1983 Temperature and Precipitation Estimates through the Last Glacial Cycle from Clear Lake, California, Pollen Data. *Science* 219: 168-170.

Albert, L. E.
1981 Ferndale Bog and Natural Lake: Five Thousand Years of Environmental Change in Southeast Oklahoma. Oklahoma Archaeological Survey, Studies in Oklahoma's Past, No. 7.

Alford, John J. and Joseph C. Holmes
1985 Meander Scars as Evidence of Major Climatic Change in Southwest Louisiana. *Annals of the Association of American Geographers* 75: 395-403.

Allen, J. R. L.
1965 A Review of the Origin and Characteristics of Recent Alluvial Sediments. *Sedimentology* 5: 89- 191.

Anderson, K. M.
1971 Archaeological Resources of Lake Palestine, Texas. Department of Anthropology, Southern Methodist University, Dallas. National Park Service, Contract No. 14-10-7:931-937

Autin, W. J., J. I. Snead, R. T. Saucier, S. F. Burns, and B. J. Miller
1990 Current Approach to Quaternary Research in the Lower Mississippi Valley. In *Field Guide to the Mississippi Alluvial Valley, Northeast Arkansas and Southeast Missouri*, edited by M. J. Guccione and E. M. Rutledge. Friends of the Pleistocene, South Central Cell. Fayetteville, Arkansas.

Banks, L.
1984 Lithic Resources and Quarries. In *Prehistory of Oklahoma*, ed. by R.E. Bell, pp. 65-96. Academic Press. New York.

1990 *From Mountain Peaks to Alligator Stomachs: A Review of Lithic Sources in the Trans-Mississippi South, the Southern Plains, and Adjacent Southwest.* Oklahoma Anthropological Society, Memoir 4. Norman.

Barnes, V. E.
1964 Geologic Atlas of Texas, Tyler Sheet. Bureau of Economic Geology. The University of Texas at Austin.

1966 Geologic Atlas of Texas, Texarkana Sheet. Bureau of Economic Geology. The University of Texas at Austin.

1967 Geologic Atlas of Texas, Sherman Sheet. Bureau of Economic Geology. The University of Texas at Austin.

1968 Geologic Atlas of Texas, Palestine Sheet. Bureau of Economic Geology. The University of Texas at Austin.

1970 Geologic Atlas of Texas, Waco Sheet. Bureau of Economic Geology. The University of Texas at Austin.

1987 Geologic Atlas of Texas, Dallas Sheet. Bureau of Economic Geology. The University of Texas at Austin.

Bement, Leland C. and Solveig A. Turpin
1988 Archaeological Investigations in Seminole Sink. In Seminole Sink: Excavation of a Vertical Shaft Tomb, Val Verde County, Texas. *Plains Anthropologist*, Memoir 22, 33-122, Part 2: 19-36.

Berger, A. L.
1978 Long Term Variations of Caloric Insolation Resulting from the Earth's Orbital Elements. *Quaternary Research* 9: 139-167.

Berger, A. L. , J. Imbrie, J. Hays, G. Kukla and B. Saltzman (eds.)
1984 *Milankovitch and Climate*, Part 1 and 2. D. Reidel Publishing Company.

Bernado, J. C.
1981 Quantitative Estimates of Temperature Changes over the Last 2700 Years in Michigan based on Pollen Data. *Quaternary Research* 15: 143-159.

Binford, Lewis R.
1980 Willow Smoke and Dog's Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* 45: 4-20.

Birkeland, P. W.
1984 *Soils and geomorphology.* Oxford University Press.

Birks, H. J. B. and H. H. Birks
1980 *Quaternary Palaeoecology.* London: Edward Arnold.

Birks, H. J. B. and A. D. Gordon
1985 *Numerical Methods in Quaternary Pollen Analysis.* London: Academic Press.

Blum, M. D. and S. Valastro
1989 Response of the Pedernales River of Central Texas to Late Holocene Climatic Change. *Annals of the Association of American Geographers* 79(3): 435-456.

Bogusch, E. R.
1928 Composition and Seasonal Aspects of the Gonzales County Marsh Associes. Unpublished M. A. Thesis, University of Texas-Austin.

Bomar, G. W.
1983 *Texas Weather*. University of Texas Press, Austin.

Boardman, J. and D. A. Robinson
1985 Soil Erosion, Climatic Vagary and Agricultural Change on the Downs around Lewes and Brighton, Autumn 1982. *Applied Geography* 5: 243-258.

Bourdo, E. A., Jr.
1956 A Review of the General Land Office Survey and of its use in Quantitative Studies of Former Trees. *Ecology* 37: 754-768.

Bousman, C. Britt
1990a Paleoenvironments and Human Diets. In *Prehistoric Archaeology and Paleoenvironments in South Texas: Results of Phase II Test Excavations in Hidalgo and Willacy Counties,* by C. B. Bousman, S. A. Tomka and G. L. Bailey. Prewitt and Associates, Inc., Reports of Investigations, No. 76, Draft Report, p. 145-169.

1990b Appendix D: Radiocarbon Dates. In *Prehistoric archaeology and paleoenvironments in south Texas: results of Phase II test excavations in Hidalgo and Willacy Counties*, by C. B. Bousman, S. A. Tomka and G. L. Bailey. Prewitt and Associates, Inc., Reports of Investigations, No. 76, Draft Report.

1990c Geomorphic Investigations, 41LN29A and 41LN106. In *Excavations at the Charles Cox, Lambs Creek Knoll and Buffalo Branch sites, Jewett Mine Project, Leon and Freestone Counties, Texas*, Ross C. Fields (ed.), Reports of Investigations, No. 70, p. 65-93.

Bousman, C. B., M. B. Collins, and T. K.Perttula
1988 Quaternary Geomorphology at Cooper Basin: A Framework for Archaeological Inquiry, Delta and Hopkins Counties, Texas. Reports of Investigations, No. 55. Austin: Prewitt and Associates, Inc.

Bousman, C. Britt and Ross C. Fields
1988 Results of the Geoarchaeological Investigations. In *Archaeological Survey of the 1989-1993 Permit Area, Jewett Mine Project, Freestone and Leon Counties, Texas*. Reports of Investigations, No. 63. Austin: Prewitt and Associates, Inc.

Bousman, C. Britt, L. Scott, N. J. Shackleton and J. C. Vogel
1989 Pollen, Stable Isotopes and Paleoenvironmental Reconstructions in Africa. Paper presented at 54th Annual Meeting, Society for American Archaeology, Atlanta.

Bousman, C. Britt and Michael Quigg
1990 Stable Carbon Isotopes from Human Remains in Trans-Pecos Texas: A Reconsideration. Paper presented at 55th Annual Meeting, Society for American Archaeology, Las Vegas.

Boutton, Thomas W., A. Tyrone Harrison and Bruce N. Smith
1980 Distribution of Biomass Species Differing in Photosynthetic Pathway along an Altitudianal Transect in Southeastern Wyoming Grassland. *Oecologia* 45: 287-298.

Bradshaw, R. H. W. and T. Webb III
1985 Relationships Between Contemporary Pollen and Vegetation Data in Wisconsin and Michigan, U. S. A. *Ecology* 66: 721-737.

Brice, J. C.
1974 Evolution of Meander Loops. *Geological Society of America Bulletin* 85: 581-586.

Brown, Dwight A.
1984 Prospects and Limits of a Phytolith Key for Grasses in the Central United States. *Journal of Archaeological Science* 11: 345-368.

Brown, Dwight A. and Philip J. Gersmehl
1985 Migration Models for Grasses in the American Midcontinent. *Annals of the Association of American Geographers* 75: 383-394.

Brown, K. M.
1976 Fused Volcanic Glass from the Manning Formation. *Bulletin of the Texas Archaeological Society* 47:189-207.

Brown, T. A., D. E. Nelson, R. W. Mathewes, J. S. Vogel and J. R. Southon
1989 Radiocarbon Dating of Pollen by Accelerator Mass Spectrometry. *Quaternary Research* 32: 205-212.

Brown, T. M., K. L. Killen, H. Simons, and V. Wulfkuhle
1982 Resource Protection Planning Process for Texas. Texas Historical Commission. Austin.

Brunner, Charlotte A.
1982 Paleoceanography of Surface Waters in the Gulf of Mexico during the Late Quaternary. *Quaternary Research* 17: 105-119.

Bruseth, J. E., J. T. Bagot, K. M. Banks, and M. A. McKinley
1977 Archaeological Research at Lake Fork Reservoir: Site Inventory and Assessment. Research Report 87. Archaeology Research Program, Southern Methodist University, Dallas.

Bruseth, J. E., L. M. Raab, and D. E. McGregor
1987 Late Holocene Paleoecology of the Prairie Margin of Texas. In *Introduction to the Richland Creek Archaeological Project,* edited by J.E. Bruseth and R.W. Moir. Richland Creek Technical Series, Vol. I, pp.29-47. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University. Dallas.

Bryan, W. A. and M. B. Collins
1989 Inventory and Assessment of Cultural Resources above the 1551.5 Foot Contour Line, Stacy Reservoir Recreation Areas, Concho, Coleman, and Runnels Counties, Texas. Reports of Investigations No 57. Prewitt and Associates, Inc. Austin.

Bryant, V. M., Jr.
1969 Late Full-Glacial and Post-Glacial Pollen Analysis of Texas Sediments. Unpublished Ph.D. dissertation, The University of Texas, Austin.

1977 A 16,000 Year Pollen Record of Vegetational Change in Central Texas. *Palynology* 1: 143-155.

1989 Botanical Remains in Archaeological Sites. In *Interdisciplinary workshop on the physical-chemical-biological processes affecting archaeological sites*, compiled by C.C. Mathewson. pp. 85-115. Department of the Army, U.S. Army Corps of Engineers, Washington.

Bryant, V. M., Jr. and R. G. Holloway
1985 A Late-Quaternary Paleoenvironmental Record of Texas: An Overview of the Pollen Evidence. In *Pollen Records of Late-Quaternary North American Sediments,* edited by Bryant, V. M., Jr. and R. G. Holloway. Dallas: American Association of Stratigraphic Palynologists Foundation.

Bryant, V. M., Jr. and H. J. Shafer
1977 The Late Quaternary Paleoenvironment of Texas: A Model for the Archaeologist. *Bulletin of the Texas Archaeological Society* 48: 1-25.

Bryson, R. A.
1989 Late Quaternary Volcanic Modulation of Milankovitch Climate Forcing. *Theoretical and Applied Climatology* 39: 115-125.

Bryson, R. A. and J. E. Kutzbach
1974 On the Analysis of Pollen-Climate Canonical Transfer Functions. *Quaternary Research* 4: 162-174.

Bryson, R. A. and T. J. Murray
1977 *Climates of Hunger, Mankind and the World's Changing Weather.* The University of Wisconsin Press: Madison.

Buck, P.
1964 Relationships of the Woody Vegetation of the Wichita Mountains Wildlife Refuge to Geological Formations and Soil Types. *Ecology* 45: 336-344.

Buol, S. W., F. D. Hole, and R. J. McCracken.
1989 *Soil Genesis and Classification.* Iowa State University Press, Ames.

Butzer, K. W.
1982 *Archaeology as Human Ecology*. New York: Cambridge University Press.

Carbone, Victor A.
1977 Phytoliths as Paleoecological Indicators. *Annals of the New York Academy of Science* 288: 194-205.

Carlquist, S.
1977 Ecological Factors in Wood Evolution: A Floristic Approach. *American Journal of Botany* 64: 887-896.

Carlston, C. W.
1965 The Relation of Free Meander Geometry to Stream Discharge and its Geomorphic Implications. *American Journal of Science* 263: 862-885.

Catt, John A.
1986 *Soils and Quaternary Geology: A Handbook for Field Scientists*. Oxford University Press.

Cerling, Thure E.
1984 The Stable Isotopic Composition of Modern Soil Carbonate and its Relationship to Climate. *Earth and Planetary Science Letters* 71: 229-240.

Cerling, Thure E. and Richard L. Hay
1986 An Isotopic Study of Paleosol Carbonates from Olduvai Gorge. *Quaternary Research* 25: 63-78.

Cerling, Thure E., Richard L. Hay and J. R. O'Neil
1977 Isotopic Evidence for Dramatic Climatic Changes in East Africa during the Pleistocene. *Nature* 267: 137-138.

Cerling, Thure E., J. Quade, Y. Wang and J. R. Bowman
1989 Carbon Isotopes in Soils and Palaeosols as Ecology and Palaeoecology Indicators. *Nature* 341: 138-139.

Chambless, L. F. and E. S. Nixon
1975 Woody Vegetation-Soil Relationships in a Bottomland Forest of East Texas. *The Texas Journal of Science* 26: 407-415.

Cheek, C. D., S. Bearden, W. Young, and C. B. Bousman
1980 Archaeological Investigations at the Graham Site, 34At90: 1975, 1977, and 1978. Research Report No. 23. Archaeological Research Associates. Tulsa.

Clarke, D.
1978 *Analytical Archaeology.* Columbia University Press, New York.

Cleaveland, M. K.
1989 Dendroclimatic Research, Delta and Hopkins Counties, Texas. In *Archaeological investigations at Cooper Lake: 1987 Season*, R. W. Moir, D. E. McGregor and D. H. Jurney (eds.). Draft report, Archaeology Research Program, ISEM. Dallas: Southern Methodist University.

CLIMAP Project Members
1981 Seasonal Reconstructions of the Earth's Surface at the Last Glacial Maximum. Geological Society of America, Map Chart Series, MC-36.

Coffman, J. L., C. A. vonHake, and C. W. Stover
1982 Earthquake History of the United States. *U.S. Geological Survey Publication* 41(1). Washington, D.C.

COHMAP Project Members
1988 Climatic Changes of the last 18,000 Years: Observations and Model Simulations. *Science* 241: 1043-1052.

Cole, H. S. and R. A. Bryson
1968 The Application of Eigenvector Techniques to the Climatic Interpretation of Pollen Diagrams: An Initial Study. Bog D Pond, Itasca. Center for Climatic Research, University of Wisconsin.

Collins, E. W., D. K. Hobday, and C. W. Kreitler
1980 Quaternary Faulting in East Texas. Geological Circular 80-1. Bureau of Economic Geology, The University of Texas at Austin.

Collins, M. B.
1975 Sources of Bias in Processual Data: An Appraisal. In, *Sampling in Archaeology*, edited by J.W. Mueller, pp. 26-32. University of Arizona Press Tucson.

1981 The Use of Petroleum by Late Archaic and Early Woodland Peoples of Jefferson County, Kentucky. *Journal of Field Archaeology* 8(1):55-64.

1988 Fluvial Geoarchaeology of Walnut and Mountain Creek Valleys. In *Late Holocene Prehistory of the Mountain Creek Drainage, Joe Pool Lake Archaeological Project, Volume I*, ed. by D.E. Peter and D.E. McGregor, pp. 259-275. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University, Dallas.

Collins, M. B., G. D. Hall, and C. B. Bousman
1988 Archaeological Applications of Geochronological Techniques in Southern Texas. *La Tierra* 16(1): 14-27

Collins, M. B., J. T. Abbott, M. D. Blum, C. B.Bousman, A. A.Fox, M. D. Freeman, J. M. Jackson, E. L. Lundelius, Jr., D. L. Miller, R. C.Neck, J. M.Quigg, J. Seay, and S. A.Tomka
n.d. Research Design for the Cultural Resources at Stacy Reservoir, Coleman, Concho, and Runnels Counties, Texas. Unpublished manuscript on file, Prewitt and Associates, Inc. Austin.

Coupland, Robert T.
1958 The Effects of Fluctuations in Weather upon the Grasslands of the Great Plains. *The Botanical Review* 24: 5: 273-317.

Crane, Cathy J.
in prep Archaeobotanical Remains. In *Archaeological investigations at Cooper Lake: 1987 Season*, Randall W. Moir, Daniel E. McGregor and David H. Jurney (eds.). Draft Report submitted to U. S. Army, Corps of Engineers by Archaeology Research Program, Southern Methodist University.

Creel, D. G.
1986 Assessing the Importance of Acorns in Archaic Subsistence: The Distribution of Prehistoric Burned Rock Middens in West Central Texas. Unpublished PhD dissertation, University of Arizona.

Crockett, J. J.
1964 Influence of Soils and Parent Materials on Grasslands of the Wichita Mountains Wildlife Refuge, Oklahoma. *Ecology* 45: 326-335.

Crone, Anthony J. and Kenneth V. Luza
1990 Style and Timing of Holocene Surface Faulting on the Meers Fault, Southwestern Oklahoma. *Geological Society of America Bulletin* 102: 1-17.

Dansgaard, W.
1964 Stable Isotopes in Precipitation. *Tellus* 16: 436-468.

Darwin, R. L., C. R. Ferring, and B. R. Ellwood
1990 Geoelectric Stratigraphy and Subsurface Evaluation of Quaternary Stream Sediments at the Cooper Basin, NE Texas. *Geoarchaeology* 5: 53-79.

Davis, J. O.
1989 Archaeological Paleoenvironments of the Southwestern Division, U.S. Army Corps of Engineers. Arkansas Archaeological Survey. Fayetteville.

Davis, M. B.
1963 On the Theory of Pollen Analysis. *American Journal of Science* 261: 897-912.

Davis, S. D., W. D. Pennington, and S. M. Carlson
1989 A Compendium of Earthquake Activity in Texas. Geological Circular 89-3. Bureau of Economic Geology, The University of Texas at Austin.

Dean, J.
1969 Chronological Analysis of Tsegi Phase Sites in Northeastern Arizona. Papers of the Laboratory of Tree Ring Research No. 3. Tucson.

Deaver, W. L.
1988 Identifying Contemporary Archaeological Events through Comparison of Archaeomagnetic Directions. In *The 1982-1984 Excavations at Las Colinas, The Site and its Features*, pp. 73-119. By D.A. Gregory, W.L. Deaver, S.K. Fish, R. Gardiner, R.W. Layhe, F.L. Nials, and L.S. Teague. Archaeological Series 162, Vol. 2. Cultural Resource Management Division, Arizona State Museum, University of Arizona. Tucson.

Delcourt, H. R
1976 Presettlement Vegetation of the North of Red River Land District, Louisiana. *Castanea* 41: 122-139.

Delcourt, H. R. and P. A. Delcourt
1974 Primeval Magnolia-Hlly-Beech Climax in Louisiana. *Ecology* 55: 638-644.

1977 Presettlement Magnolia-Beech Climax of the Gulf Coastal Plain: Quantitative Evidence from the Apalachicola River Bluffs, North Central Florida. *Ecology* 58: 1085-1093.

Delcourt, H. R., D. C. West and P. A. Delcourt
1981 Forest of the Southeastern United States: Quantitative Maps for Aboveground Woody Biomass, Carbon, and Dominance of Major Tree Taxa. *Ecology* 62: 879-887.

Delcourt, P. A. and H. R. Delcourt
1977 The Tunica Hills, Louisiana-Mississippi: Late Glacial Locality for Spruce and Deciduous Forest Species. *Quaternary Research* 7: 218-237.

Delcourt, P. A., H. R. Delcourt and J. L. Davidson
1983 Mapping and Calibration of Modern Pollen-Vegetation Relationships in the Southeastern United States. *Review of Palaeobotany and Palynology* 39: 1-45.

DeLaune, R. D.
1986 The Use of δ13C Signature of C-3 and C-4 Plants in Determining Past Depositional Environments in Rapidly Accreting Marshes of the Mississippi River Deltaic Plain, Louisiana, U.S.A. *Chemical Geology* 59: 315-320.

DeNiro, M.
1987 Stable Isotopy and Archaeology. *American Scientist* 75: 182-191.

DeNiro, M. J. and S. Epstein
1981 Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45: 341-351.

DeNiro, M. J. and C. A. Hastorf
1985 Alteration of 15N/14N and 13C/12C Ratios of Plant Matter During the Initial Stages of Diagenesis: Studies Utilizing Archaeological Specimens from Peru. *Geochimica et Cosmochimica Acta* 49: 97-115.

Dever, L, R. durand, J.Ch. Fontes and P. Vachier
1983 Etude Pédogénétique et Isotopique de Néoformations de Calcite dans un sol sur Craie-Caractéristiques et Origines. *Geochimica et Cosmochimica Acta* 47: 2079-2090.

Diamond, D. D., D. H. Riskind and S. L. Orzell
1987 A Framework for Plant Community Classification and Conservation in Texas. *The Texas Journal of Science* 39: 203-221.

Diamond, D. D. and F. E. Smeins
1984 Remnant Grassland Vegetation and Ecological Affinities of the Upper Coastal Prairie of Texas. *The Southwestern Naturalist* 29: 3: 321-334.

1985 Composition, Classification and Species Response Patterns of Remnant Tallgrass Prairies in Texas. *The American Midland Naturalist* 113: 2: 294-308.

Dillehay, Tom D.
1974 Late Quaternary Bison Population Changes on the Southern Plains. *Plains Anthropologist* 19: 180-196.

Doehner, Karen and Richard E. Larson
1978 Archaeological Research at Proposed Cooper Lake, Northeast Texas 1974-1975. Dallas: Archaeological Research Program, Southern Methodist University.

Doering, J. A.
1963 Correlation of the Sulphur River Formation. *Journal of Graduate Research Center* 31(3):149-151. Southern Methodist University, Dallas.

Drass, R. R.
1989 The Applications of Remote Sensing to Archaeology. *Bulletin of the Oklahoma Anthropological Society* 38:79-97.

Duchaufour, P.
1982 *Pedology, Pedogenesis and Classification*, translated by T. R. Paton. London: George Allen & Unwin.

Duffield, L. F.
1970 Vertisols and their Implications for Archaeological Research. *American Anthropologist* 72:1055-1063.

Dzurec, R. S., T. W. Boutton, M. M. Caldwell and B. N. Smith
1985 Carbon Isotope Ratios of Soil Organic Matter and their use in Assessing Community Composition changes in Curlew Valley, Utah. *Oecologia* 66: 17-24.

Eickmeier, W. G. and M. M. Bender
1976 Carbon Isotope Ratios of Crassulacean Acid Metabolism Species in Relation to Climate and Phytosociology. *Oecologia* 25: 341-347.

Eighmy, J. L.
1980 *Archeomagnetism: A Handbook for the Archaeologist*. Cultural Resource Management Series, Heritage Conservation and Recreation Service, U.S. Department of the Interior.

1988 Dating Hohokam Canals by the Archaeomagnetic Method. Paper Read, 53 Annual Meeting, Society for American Archaeology, Phoenix, Arizona.

Emiliani, C.
1955 Pleistocene Temperatures. *Journal of Geology* 63:538-578.

Emiliani, C, S. Gartner, B. Lidz, K. Eldridge, D. K. Elvey, T. -C. Huang, J. J. Stipp and M. F. Swanson
1975 Paleoclimatological Analysis of Late Quaternary Cores from the Northeastern Gulf of Mexico. *Science* 189: 1083-1088.

Epstein, Samuel and T. Mayeda
1953 Variation of O18 Content of Waters from Natural Sources. *Geochimica et Cosmochimica Acta* 4: 213-224.

Epstein, Samuel and Crayton J. Yapp
1976 Climatic Implications of the D/H Ratio of Hydrogen in C-H Groups in Tree Cellulose. *Earth and Planetary Science Letters* 30: 252-261.

Epstein, Samuel, Crayton J. Yapp and John H. Hall
1976 The Determination of the D/H Ratio of Nonexchangeable Hydrogen in Cellulose Extracted from Aquatic and Land Plants. *Earth and Planetary Science Letters* 30: 241-251.

Erdtman, G.
1943 *An Introduction to Pollen Analysis.* Waltham, Massachusetts: Chronica Botanica.

Fall, P. L.
1987 Pollen Taphonomy in a Canyon Stream. *Quaternary Research* 28: 393-406.

Farnsworth, P., J. E. Brady, M. J. DeNiro and R. MacNeish
1985 A Re-evaluation of the Isotopic and Archaeological Reconstructions of Diet in the Tehuacan valley. *American Antiquity* 50: 102-116.

Faure, G.
1986 *Principles of Isotope Geology.* John Wiley & Sons, New York.

Fenneman, N. M.
1938 *Physiography of Eastern United States*. McGraw- Hill. New York.

Ferring, C.R.
1986 Late Quaternary Geology and Environments of the Upper Trinity basin. pp. 32-112. In *An Assessment of the Cultural Resources in the Trinity River Basin, Dallas, Tarrant, and Denton Counties, Texas*. Institute of Applied Sciences, North Texas State University, Denton.

1989 The Aubrey Clovis Site: A Paleoindian Locality in the Upper Trinity River basin, Texas. *Current Research in the Pleistocene* 6:9-10.

in prep Geoarchaeological Investigations at Cooper Lake. In *Archaeological Investigations at Cooper Lake: 1987 Season*, R. W. Moir, D. E. McGregor and D. H. Jurney (eds.), Archaeology Research Program, Dallas: Southern Methodist University.

Fields, Ross C.
1987 Excavations at the Alley Road Site (41LN149B) and the Harris Hole Site (41LN30), Jewett Mine Project, Leon County, Texas. Reports of Investigations, Number 61. Austin, Prewitt and Associates, Inc.

1990a Excavations at the Charles Cox, Lambs Creek Knoll, and Buffalo Branch sites, Jewett Mine Project, Leon and Freestone Counties, Texas. Reports of Investigations, No. 70. Austin: Prewitt and Associates, Inc.

1990b Geomorphic Investigations, 41LN311. In *Excavations at the Charles Cox, Lambs Creek Knoll and Buffalo Branch sites, Jewett Mine Project, Leon and Freestone Counties, Texas*, Ross C. Fields (ed.), Reports of Investigations, No. 70, p. 321-333. Austin: Prewitt and Associates, Inc.

Fields, Ross C., C. Britt Bousman and Sylvia J. Kooren
1988 National Register Assessments of Six Prehistoric Sites at the Jewett Mine, Leon County, Texas. Reports of Investigations, No. 67. Austin: Prewitt and Associates, Inc.

Fields, Ross C. and Paul V. Heinrich
1987a Geoarchaeology of the Alley Road Site, 41LN 149B. In *Excavations at the Alley Road Site (41LN149B) and the Harris Hole Site (41LN30), Jewett Mine Project, Leon County Texas* , R. C. Fields (ed). Reports of Investigations, No. 67, pp 63-83. Austin: Prewitt and Associates, Inc.

1987b Geoarchaeology of the Harris Hole Site, 41LN30. In *Excavations at the Alley Road Site (41LN149B) and the Harris Hole Site (41LN30), Jewett Mine Project, Leon County Texas* , R. C. Fields (ed). Reports of Investigations, No. 67, pp 255-276. Austin: Prewitt and Associates, Inc.

Fields, R. C., S. V. Lisk, J. M. Jackson, M. D. Freeman and G. L. Bailey
1986 National Register Assessments of Archeological and Historical Resources at the Jewett Mine, Leon County, Texas. Reports of Investigations, Number 48. Austin, Prewitt and Associates, Inc.

Fisher, W. L.
1965 Rock and Mineral Resources of East Texas. Report of Investigations 54. Bureau of Economic Geology, University of Texas. Austin.

Flexor, J. M. and B. Volkoff
1977 Distribution de l'sotope Stable 13C dans la Matiére Organqui d'un sol Ferrallitique de l'état de Bahia (Brésil). *Comptes Rendus de Seances de l'Academia des Sciences, Series D*. 234: 307-314.

Fountain, M. S. and W. H. Risner
1988 Woody Vegetation of a Natural Pine-Hardwood Woodland in San Augustine County, Texas. *The Texas Journal of Science* 40: 347-352.

Fritts, H. C.
1976 Tree-Rings and Climate. London: Academic Press.

Gagliano, S. M.
1967 *Occupation Sequence at Avery Island.* Louisiana State Universiy Press, Coastal Studies Series No. 22. Baton Rouge.

Gat, J. R.
1981 The Isotopes of Hydrogen and Oxygen in Precipitation. In *Handbook of Environmental Isotope Geochemistry,* P. Fritz and J. Ch. Fontes (eds.), Vol. 1A, Elsevier, Amsterdam, p. 24-27.

Gates, W. L.
1976 The Numerical Simulation of Ice-Age Climate with a Global General Circulation Model. *Journal of the Atmospheric Sciences*, 33: 1844-1873.

Gehlbach, F. R. and R. C. Gardner
1983 Relationships of Sugar Maples (Acer *saccharum* and A. *grandidentatum*) in Texas and Oklahoma with Special Reference to Relict Populations. *The Texas Journal of Science* 35: 231-237.

Gibson, J.
1969 *Archaeological Survey at Caddo Lake, Louisiana and Texas.* Southern Methodist University, Contributions in Anthropology, No. 6. Dallas

Gilmore, K. and O. McCormick
1982 Red River Archaeological Project Phase I & II. Contributions in Archaeology No. 2, Archaeology Program, Institute of Applied Sciences, North Texas State University. Denton.

Givens, C. R. and F. M. Givens
1987 Age and Significance of Fossil White Spruce (Picea glauca), Tunica Hills, Louisiana-Mississippi. *Quaternary Research* 27: 283-296.

Gleason, H. A.
1922 Vegetational History of the Middle West. *Annals of the Association of American Geographers* 12: 39-26.

Godfrey, C. L., G. S. McKee, and H. Oakes
1973 General Soil Map of Texas. Texas Agricultural Experiment Station, Texas A&M University and Soil Conservation Service, U.S. Department of Agriculture. College Station, Texas.

Goodfriend, G. A.
1988 Mid-Holocene Rainfall in the Negev Desert from 13C of Land Snail Shell Organic Matter. *Nature* 333: 757-760.

1990 Rainfall in the Negev Desert during the Middle Holocene, based on 13C of Organic Matter in Land Snail Shells, *Quaternary Research* 34:2: 186-197.

Gould, R. W.
1962 Texas Plants-A Checklist and Ecological Summary. Texas Agricultural Experiment Station, Bulletin MP-585, College Station.

Graham, A. and C. Heimsch
1960 Pollen Studies of some Texas Peat Deposits. *Ecology* 41: 751-763.

Graham, R. W. and E. L. Lundelius
1984 Coevolutionary Disequilibrium and Pleistocene Extinctions. In *Quatarnary Extinctions: A Prehistoric Revolution*, P. S. Martin and R. G. Klein (eds.), pp. 223-249, University of Arizona Press, Tucson.

Gray, H. H.
1984 Archaeological Sedimentology of Overbank Silt Deposits on the Floodplain of the Ohio River near Louisville, Kentucky. *Journal of Archaeological Science* 11:421-432.

Gray, J. and S. J. Song
1984 Climatic Implications of the Natural Variations of D/H Ratios in Tree Ring Cellulose. *Earth and Planetary Science Letters* 70: 129-138.

Guillet, B., P. Faivre, A. Mariotti and J. Khobzi
1988 The 14C Dates and 13C/12C Ratios of Soil Organic Matter as a Means of Studying the Past Vegetation in Intertropical Regions: Examples from Columbia (South America). *Palaeogeography, Palaeoclimatology, Palaeoecology* 65: 51-58

Guiot, J.
1987 Late Quaternary Climatic Change in France Estimated from Multivariate Pollen Time Series. *Quaternary Research* 28: 100-118.

Guiot, J., A. Pons, J. L. de Beaulieu and M. Reille
1989 A 140,000-Year Continental Climate Reconstruction from two European Pollen Records. *Nature* 338: 309-313.

Gunn, J. and D. O. Brown
1982 Eagle Hill: A Late Quaternary Upland Site in Western Louisiana. Special Report No. 12. Center For Archaeological Research, University of Texas at San Antonio.

Guthrie, R. Dale
1990 *Frozen Fauna of the Mammoth Steppe, The Story of Blue Babe.* University of Chicago Press, Chicago.

Guy, J. A.
1990 Previous Archaeological Investigations. In *The Archaeology and Bioarchaeology of the Gulf Coastal Plain, Volume 1,* by D. A. Story, J. A. Guy, B. A. Burnett, M. D. Freeman, J. C. Rose, D. G. Steele, B. W. Olive and K. J. Reinhard. pp. 27-130. Arkansas Archaeological Survey Research Series No. 38. Fayetteville.

Haas, H., V. Holliday and R. Stuckenrath
1986 Dating of Holocene Stratigraphy with Soluble and Insoluble Organic Fractions at the Lubbock Lake Archaeological Site, Texas: An Ideal Case Study. *Radiocarbon* 28: 2A: 473-485.

Hall, Stephen A.
1977 Geology and Palynology of Archaeological Sites and Associated Sediments. In *The Prehistory of the Little Caney River, 1976 Field Season,* edited by D.O. Henry. pp. 13-41. University of Tulsa Contributions in Archaeology No. 1. Tulsa.

1982 Late Holocene Paleoecology of the Southern Plains. *Quaternary Research* 17: 391-407.

1983 Review "Ferndale Bog and Natural Lake: Five Thousand Years of Environmental Change in Southeastern Oklahoma" by Lois E. Albert. *Plains Anthropologist* 28: 150-151.

1990 Channel Trenching and Climatic Change in the Southern U.S. Great Plains. *Journal of Geology* 18:342-345.

Hathaway, H.
1987 Archaeomagnetic Laboratory Report, Appendix E. In *Hunter-gatherer adaptations along the prairire margin. Richland Creek Technical Series, Vol. III*:271-272. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University. Dallas.

1988 Magnetometer Survey Results for Sites 41DL148, 41DL149, and 41DL184. Chapter 11. In *Late Holocene prehistory of the Mountain Creek drainage. Joe Pool Lake Archaeological Project, Volume I:* pp. 245-258. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University. Dallas.

Hays, J. D., J. Imbrie and N. J. Shackleton
1976 Variations in the Earth's Orbit: Pacemaker of the Ice Ages. *Science* 194: 1121-1132.

Heaton, T. H. E.
1987 The 15N/14N Ratios of Plants in South Africa and Nambia: Relationship to Climate and Coastal/Saline Environments. *Oecologia* 74: 236-246.

Heaton, T. H. E., A. S. Talma, and J. C. Vogel
1986 Dissolved Gas Paleotemperatures and 18O Variations Derived from Groundwater near Uitenhage, South Africa. *Quaternary Research* 25: 79-88.

Heaton, T. H. E., J. C. Vogel, G. von la Chevallerie and G. Collett
1986 Climatic Influence on the Composition of Bone Nitrogen. *Nature* 322: 822-823.

Heinrich, Paul V.
1986 Geomorphology of Seven Sites at the Jewett Mine Project, Appendix A. In *National Register Assessments of Archaeological and Historical Resources at the Jewett Mine, Leon County, Texas*, by R. C. Fields, S. V. Lisk, J. M. Jackson, M. D. Freeman and G. L. Bailey. Reports of Investigations, No. 48. Austin: Prewitt and Associates, Inc.

Henderson, J.
1979 The Mothershead Spring Site. Publications in Archaeology, Report 12. Texas State Department of Highways and Public Transportation. Austin.

Heusser, C. J., L. E. Heusser and S. S. Streeter
1980 Quaternary Temperatures and Precipitation for the North-West Coast of North America. *Nature* 286: 702-704.

Heusser, C. J. and S. S. Streeter
1980 A Temperature and Precipitation Record of the Past 16,000 Years in Southern Chile. *Science* 210: 1345-1347.

Hibbard, C. W.
1960 An Interpretation of Pliocene and Pleistocene Climates in North America. *Annual Report of the Michigan Academy of Sciences, Arts and Letters* 62: 5-30.

Hillaire-Marcel, Claude, Anne-Marie Aucour, Raymonde Bonnelfille, Guy Riollet, Annie Vincens and David Williamson
1989 13C/Palynological Evidence of Differential Residence Times of Organic Carbon prior to its Sedimentation in East African Rift Lakes and Peat Bogs. *Quaternary Science Review* 8: 207-212.

Hocker, H. W., Jr.
1956 Certain Aspects of Climate as Related to the Distribution of Loblolly Pine. *Ecology* 37: 824-834.

Hofman, J. L.
1989 Land of Sun, Wind, and Grass. In, *From Clovis to Comanchero: Archaeological Overview of the Southern Great Plains*, by J.L. Hofman, R.L.Brooks, J.S. Hays, D.W.Owsley, R.L.Jantz, M.K.Marks, and M.H. Manhein. Arkansas Archaeological Survey Research Series, No. 35. Fayetteville.

Holliday, V. T.
1987 A Reexamination of Late-Pleistocene Boreal Forest Reconstructions for the Southern High Plains. *Quaternary Research* 28: 238-244.

1989 Middle Holocene Drought on the Southern High Plains. *Quaternary Research* 31: 74-82.

Holloway, R. G.
1981 Preservation and Experimental Diagenesis of the Pollen Exine. Unpublished Ph.D. Dissertation, Texas A&M University, College Station, Texas.

1987a Pollen Analysis of a Sediment Core from Buck Creek Marsh, Wood County, Texas. In *Introduction to the Richland Creek Archaeolgical Project: Environmental Background and Cultural Setting,* J. E. Bruseth and R. Moir (eds.). Richland Creek Technical Series, volume 1. Dallas: Archaeological Research Program, Southern Methodist University.

1987b Late Holocene Paleoenvironmental Studies in Northcentral Texas. In *Introduction to the Richland Creek Archaeolgical Project: Environmental Background and Cultural Setting,* J. E. Bruseth and R. Moir (eds.). Richland Creek Technical Series, volume 1. Dallas: Archaeological Research Program, Southern Methodist University.

1989 Experimental Mechanical Pollen Degradation and its Application to Quaternary Age Deposits. *The Texas Journal of Science* 41: 131-145.

1990 Analysis of macrobotanical remains from 41LN29A and 41LN106. In *Excavations at the Charles Cox, Lambs Creek Knoll and Buffalo Branch sites, Jewett Mine Project, Leon and Freestone Counties, Texas*, Ross C. Fields (ed.), Reports of Investigations, No. 70, p. 539-549.

Holloway, R. G. and V. M. Bryant, Jr.
1984 Picea Glauca Pollen from Late Glacial Deposits in Central Texas. *Palynology* 8: 21-32.

Holloway, R. G., L. M. Raab and R. Stuckenrath
1987 Pollen Analysis of Late-Holocene Sediments from a Central Texas Bog. *The Texas Journal of Science* 39: 71-79.

Hooghiemstra, H.
1984 Vegetational and Climatic History of the High Plain of Bogotá, Colombia: A Continuous Record of the Last 3.5 Million Years. Hisrschberg, Germany: J. Cramer.

Hsu, Dick Ping
1969 Appraisal of the Archaeologicl Resources of Titus County Reservoir, Titus, Camp and Franklin Counties, Texas. Texas State Building Commission and Texas Water Development Board, Archaeological Survey Report, No. 4, Austin.

Huebner, Jeff and Thomas Boutton
in prep Stable Isotopes and Bison Diet in Texas.

Hughes, M. K., P. M. Kelly, J. R. Pilcher, and V. C. LaMarche
1982 *Climate from Tree-Rings.* Cambridge: Cambridge University Press.

Huntley, D. J., D. I. Godfrey-Smith, and M. L. W. Thewalt
1985 Optical Dating of Sediments. *Nature* 313:105-107.

Huesser, Calvin J., L. E. Huesser and S. S. Streeter
1980 Quaternary Temperatures and Precipitation for the North-West Coast of North America. *Nature* 286:702-704.

Huesser, Calvin J. and Stephen Streeter
1980 A Temperature and Precipitation Record of the Past 16,000 Years in Southern Chile. *Science* 210:1345-1347.

Hyatt, R. D. and K. Doehner
1975 Archaeological Research at Cooper Lake Northeast Texas, 1973. Institute for the Study of Earth and Man. Southern Methodist University. Dallas.

Hyatt, R. D. and H. F. Mosca III
1972 Survey of the Cultural Resources of the Proposed Big Pine Lake, Texas. Research Report 15. Archaeology Research Program, Southern Methodist University. Dallas.

Imbrie, J. and K. P. Imbrie
1979 *Ice Ages, Solving the Mystery.* Harvard University Press, Cambridge.

International Atomic Energy Agency
1973 Environmental Isotope Data No. 4: World Survey of Isotope Concentration in Precipitation (1968-1969). Technical Reports Series No. 147. International Atomic Energy Agency, Vienna.

1975 Environmental Isotope Data No. 5: World Survey of Isotope Concentration in Precipitation (1970-1971). Technical Reports Series No. 165. International Atomic Energy Agency, Vienna.

1979 Environmental Isotope Data No. 6: World Survey of Isotope Concentration in Precipitation (1972-1975). Technical Reports Series No. 192. International Atomic Energy Agency, Vienna.

1986 Environmental Isotope Data No. 8: World Survey of Isotope Concentration in Precipitation (1980-1983). Technical Reports Series No. 264. International Atomic Energy Agency, Vienna.

Jackson, A. T.
1938 The Fall Creek Sites. In *Annual report of WPA and the University of Texas Archaeological Research, Lake Buchanan 1936-1937*. Study No. 26. Bureau of Research in the Social Sciences, The University of Texas, Austin.

Jackson, M. P. A. and S. J. Seni
1984 Suitability of Salt Domes in the East Texas Basin for Nuclear Waste Isolation: Final Summary of Geologic and Hydrogeologic Research (1978 to 1983). Geological Circular 84-1. Bureau of Economic Geology. The University of Texas at Austin.

Jasper, John P. and Robert B. Gagosian
1990 The Sources and Deposition of Organic Matter in the Late Quaternary Pigmy Basin, Gulf of Mexico. *Geochimica et Cosmochimica Acta* 54: 1117-1132.

Johnson, E. H.
1931 The Natural Regions of Texas. *The University of Texas Bulletin*, No. 3113: 1-148.

Johnson, L., Jr.
1962 The Yarbrough and Miller Sites of Northeastern Texas, with a Preliminary Definition of the La Harpe Aspect. *Bulletin of the Texas Archaeological Society* 32: 141-284.

1989 Great Plains Interlopers in the Eastern Woodlands during Late Paleo-Indian times. Office of the State Archaeologist Report 36. Texas Historical Commission, Austin.

Jones, G. A., A. J. T. Jull, T. W. Linick and D. J. Donahue
1989 Radiocarbon Dating of Deep-Sea Sediments: A Comparison of Accelerator Mass Spectrometer and Beta-Decay Methods. *Radiocarbon* 31: 105-116.

Jones, G. A. and W. F. Ruddiman
1982 Assessing the Global Meltwater Spike. *Quaternary Research* 17: 148-172.

Jordan, Terry G.
1973 Pioneer Evaluation of Vegetation in Frontier Texas. *Southwestern Historical Quarterly* LXXVI: 233-254.

Jurney, David H.
1987 Biotic Resources at the Prairie Margin at the time of European Settlement. In *Introduction to the Richland Creek Archaeological Project, Environmental Background and Cultural Setting, Richland Creek Technical Series, Volume 1*, Archaeology Research Program, Southern Methodist University, p. 49-54.

1988 Early Historic Vegetation Zones. In *Historic Farming on the Hogwallow Prairies, Ethnoarchaeological Investigations of the Mountain Creek Area, North Central Texas*, compiled by David H. Jurney, Susan A. Lebo and Melissa M. Green, Joe Pool Lake Archaeological Project, Volume II, Archaeology Research Program, Southern Methodist University, p. 333-351.

Kellman, Martin C.
1980 *Plant Geography*, (2nd Edition). London: Methuen & Co., Ltd.

Kelly, Robert L.
1983 Hunter-Gatherer Mobility Strategies. *Journal of Anthropological Research* 39: 227-306.

Klepinger, L. L. and R. W. Mintel
1986 Metabolic Considerations in Reconstructing Past Diet from Stable Carbon Isotope Ratios of Bone Collagen. In *Proceedings of the 24th International Archaeometry Symposium*, J. S. Olin and M. J. Blackman, eds., pp 43-48, Washington: Smithsonian Institution Press.

Knox, J. C.
1983 Responses of River Systems to Holocene Climates. In: H.E. Wright, Jr. (editor), *Late Quaternary Environments of the United States,* Vol. 2, the Holocene. University of Minnesota Press, Mineapolis.

Kolb, C.R.
1976 Topographic Lows Above Domes, pp. 407-414. In *An Investigation of the Utility of Gulf Coast Salt Domes for the Storage or Disposal of Radioactive Waste*, edited by J.D. Martinez, R.L. Thoms, D.H. Kupfer, C.R. Smith, Jr., C.R. Kolb, E.J.Newchurch, R.E. Wilcox, T.A. Manning, Jr., M. Romberg, A.J. Lewis, and J.E. Rovik. Louisiana State University, Institute for Environmental Studies, ORNL-SUB-4112-25.

Kolb, C.R. and G. G. Fredlund
1981 *Palynological Studies, Vacherie and Rayburn's Domes, North Louisiana Salt Dome Basin*. Institute for Environmental Studies, Louisiana State University, Baton Rouge.

Krishnamurthy, R. V., M. J. DeNiro and R. K. Pant
1982 Isotope Evidence for Pleistocene Climatic Changes in Kashmir, India. *Nature* 298: 640-641.

Kroch, G. C. and J. Nisbet
1983 Some Structural Aspects of a Western Cross Timbers Forest in North Central Texas. *The Texas Journal of Science* 35: 41-45.

Krueger, H. W. and C. H. Sullivan
1984 Models for Carbon Isotope Fractionation between Diet and Bone. In *Stable Isotopes and Nutrition*, J. R. Turnland and P. E. Johnson, pp. 205-220, Symposium Series No. 258, Washington: American Chemical Society.

Küchler, A. W.
1964 Potential Natural Vegetation of the Coterminous United States. American Geographical Society Special Publication No. 36, 116p.

Kutzbach, J. E.
1981 Monsoon Climate of the Early Holocene: Climate Experiment with the Earth's Orbital Parameters for 9000 Years Ago. *Science*, 214: 59-61.

Kutzbach, J. E. and P. J. Guetter
1984 The Sensitivity of Monsoon Climates to Orbital Parameter Changes for 9000 Years BP: Experiments with the NCAR General Circulation Model. In *Milankovitch and Climate*, A. L. Berger, J. Imbrie, J. Hays, G. Kukla and B. Saltzman (eds.), Part 2, p. 801-820, D. Reidel Publishing Company.

1986 The Influence of Changing Orbital Parameters and Surface Boundary Conditions on Climate Simulations for the Past 18000 Years. *Journal of the Atmospheric Sciences*, 43: 1726-1759.

Kutzbach, J. E. and F. A. Street-Perrott
1985 Milankovitch Forcing of Fluctuations in the Level of Tropical Lakes from 18 to 0 kyr BP. *Nature* 317:130-134.

Land, L. S., E. L. Lundelius and S. Valastro
1980 Isotopic Ecology of Deer Bones. *Palaeogeography, Palaeoclimatology, Palaeoecology* 32: 143-151.

Larkin, T. J. and G. W. Bomar
1983 Climatic Atlas of Texas. Texas Department of Water Resources, Austin, pp. 151.

Larson, D. A., V. M. Bryant and T. S. Patty
1972 Pollen Analysis of a Central Texas Bog. *The American Midland Naturalist* 88: 358-367.

Lecolle, P.
1985 The Oxygen Isotope Composition of Landsnail Shells as a Climatic Indicator: Applications to Hydrology and Paleoclimatology. *Isotope Geoscience* 4: 157-182.

Lenzer, J.
1980 Geology and Geomorphology. In *The Hanna Site, An Alto Village in Red River Parish,* by P. M. Thomas, Jr., L. J. Campbell, and S. R. Ahler. pp. 45-70. Louisiana Archaeology, No. 5. Lafayette.

Leopold, L. B., M. G. Wolman, and J. P. Miller
1964 *Fluvial Process in Geomorphology*. San Francisco: Freeman.

Letolle, R.
1980 Nitrogen-15 in the Natural Environment. In *Handbook of Environmental Isotope Geochemistry, 1. The Terrestrial Environment*. A. P. Fritz and J. Ch. Fontes (eds.), pp. 21-47. Amsterdam: Elsevier.

Lewis, R. O.
1981 Use of Opal Phytoliths in Paleo-Environmental Reconstruction. *Journal of Ethnobiology* 1: 175-181.

Libby, Leona Marshall
1983 *Past Climaties: Tree Thermometers, Commodities and People*. Austin: University of Texas Press.

Long, A.
1982 Stable Isotopes in Tree Rings. In *Climate from Tree Rings*, M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. Lamarche, Jr. (eds.), pp. 13-18 Cambridge: Cambridge University Press.

Longinelli, A.
1984 Oxygen Isotopes in Mammal Bone Phosphate: A New Tool for Paleohydrological and Paleoclimatological Research? *Geochimica et Cosmochimica Acta* 48: 385-390.

Lorrain, Dessamae and Norma Hoffrichter
1968 Archaeological Survey and Excavation at Pat Mayse Reservoir , Texas. Report submitted to the National Park Service by the River Basin Salvage Project, Southern Methodist University, Dallas.

Lowe, J. J., S. Lowe, A. J. Fowler, R. E. M. Heldges and T. J. F. Austin
1988 Comparison of Accelerator and Radiometric Radiocarbon Measurements Obtained from Late Devensian Lateglacial Lake Sediments from Llyn Gwernan, North Wales, UK. Boreas 17: 355-369.

Luckman, Brian and John Gray
1990 Oxygen Isotope Ratios from Tree Rings Containing Compression Wood. *Quaternary Research* 33: 117-121.

Lundelius, E. L., R. W. Graham, E. Anderson, J. E. Guilday, J. A. Holman, D. Steadman, and S. D. Webb
1983 Terrestrial Vertebrate Faunas. In *Late Quaternary Environments of the United States, Volume I, the Late Pleistocene*, S. C. Porter (ed.), pp. 311-353, University of Minnesota Press, Minneapolis.

Luz, Boaz, Allison B. Comie and Henry P. Schwarcz.
1990 Oxygen Isotope Variations in Phosphate of Deer Bones. *Geochimica et Cosmochimica Acta* 54:1723–1728.

Luz, Boaz, Yehoshua Kolodny and Michal Horowitz
1984 Fractionation of Oxygen Isotopes between Mammalian Bone-Phosphate and Environmental Drinking Water. *Geochimica et Cosmochimica Acta* 48: 1689-1693.

Magaritz, M. and A. J. Amiel
1980 Calcium Carbonate in Calcareous Soil from the Jordan Valley, Israel: Its Orgin Revealed by the Stable Carbon Isotope Method. *Soil Science Society of America Journal* 44: 1059-1062.

Magaritz, M. and J. Heller
1980 A Desert Migration Indicator-Oxygen Isotope Composition of Land Snail Shells. *Palaeogeography, Palaeoclimatology, Palaeoecology* 32: 153-162.

1981 Land-Air Boundary Environ as Recorded by the 18O/16O and 13C/12C Isotope Ratios in Shells of Land Snails. *Earth and Planetary Science Letters* 52: 101-106.

Mallouf, R. J.
1976 Archaeological Investigations at Proposed Big Pine Lake, 1974-1975: Lamar and Red River Counties, Texas. Archaeological Survey Report 18. Texas Historical Commission. Austin.

Manabe, S. and D. G. Hahn
1977 Simulation of the Tropical Climate of an Ice Age. *Journal of Geophysical Resources* 82: 3889-3991.

Mandel, R. D.
1987 Geomorphological Investigations. Chapter 4. In *Buried in the Bottoms: The Archaeology of Lake Creek Reservoir, Montgomery County, Texas*, by L. C. Bement, R. D. Mandel, J. F. de la Teja, D. K. Utley, and S. A. Turpin. Research Report 97, Texas Archaeological Survey, The University of Texas at Austin.

in prep Preliminary Results of Geomorphological and Soil Stratigraphic Investigations at Cooper Lake, Texas. In *Archaeological Survey and Preliminary Evaluations of Unsurveyed Portions of Cooper Lake 1989*, D. H. Jurney, J. Bohlin, M. Masucci, B. A. C. Cole and S. Linder-Linsley (eds.), Archaeology Research Program, Dallas: Southern Methodist University.

Mandel, Rolfe D., Leland Bement and S. Christopher Caran
1987 Geoarchaeological Investigations at Lake Creek Valley, Southeastern Texas. *Current Research in the Pleistocene* 4: 132-134.

Marietta, K. L. and E. S. Nixon
1983 Vegetational Analysis of a Post Oak-Black Hickory Community in Eastern Texas. *The Texas Journal of Science* 35: 197-203.

1984 Vegetation of an Open, Prairie-Like Community in Eastern Texas. *The Texas Journal of Science* 36: 25-32.

Marino, Bruno D. and Michael J. DeNiro
1987 Isotopic Analysis of Archaeobotanicals to Reconstruct Past Climates: Effects of Activities Associated with Food Preparation on Carbon, Hydrogen and Oxygen Isotope Ratios of Plant Cellulose. *Journal of Archaeological Science* 14: 537-548.

Marks, P. L. and P. A. Harcombe
1981 Forest Vegetation of the Big Thicket, Southeast Texas. *Ecological Monographs* 51: 287-305.

McBride, J.R.
1983. Analysis of Tree Rings and Fire Scars to Establish Fire History. *Tree-Ring Bulletin* 43:51-67.

McCormick, O. F., III
1973 The Archaeological Resources in the Lake Monticello Area of Titus County, Texas. Contributions in Anthropology, No. 8. Department of Anthropology, Southern Methodist University, Dallas.

McDonald, J. N.
1981 *North American Bison: Their Classification and Evolution*. University of California Press, Berkeley.

McGregor, D. E.
1987 Lithic Raw Material Utilization. In *Hunter-Gatherer Adaptations Along the Prairie Margin: Site Excavations and Synthesis of Prehistoric Archaeology. Richland Creek Technical Series, Vol. III,* edited by D.E.McGregor and J.E.Bruseth, pp. 185-195. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University, Dallas.

McGregor, D. E. and J. E. Bruseth (editors)
1987 Hunter-Gatherer Adaptations along the Prairie Margin: Site Excavations and Synthesis of Prehistoric Archaeology. Richland Creek Technical Series, Vol. III. Archaeology Research Program, Southern Methodist University, Dallas.

McGregor, D. E. and J. Bohlin
1987 Excavations at 41FT193, the Perry Site. In *Hunter-Gatherer Adaptations along the Prairie Margin: Site Excavations and Synthesis of Prehistoric Archaeology*. Richland Creek Technical Series, Vol. III, edited by D.E.McGregor and J.E.Bruseth, pp. 29-52. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University, Dallas.

McKenzie, J. A. and G. P. Eberli
1987 Indications for Abrupt Holocene Climatic Change: Late Holocene Oxygen Isotope Stratigraphy of the Great Salt Lake, Utah. In *Abrupt Climatic Change,* W. H. Berger and L. D. Labeyrie (eds.), pp 127-136, D. Reidel Publishing Company.

Meltzer, David J. and Michael B. Collins
1987 Prehistoric Water Wells on the Southern High Plains: Clues to Altithermal Climate. *Journal of Field Archaeology* 14: 9-28.

Michels, J. W.
1973 *Dating Methods in Archaeology*. Seminar Press, New York.

Milankovitch, M.
1930 Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen. In W. Köppen and R Geiger (eds.) *Handbuch der Klimatologie*, I (A) Gebrüder Borntraeger: Berlin.

Nakai, N. and M. Koyama
1987 Reconstruction of Paleoenvironments from the View-Points of the Inorganic Constituents, C/N Ratio and Carbon Isotope Ratio in the 1400m Core from Lake Biwa. In: S. Horie (ed.), History of Lake Biwa, Institute of Paleolimnology and Paleoenvironment on Lake Biwa, Contribution No. 553, Kyoto University, Japan.

Natelhoffer, K. J. and B. Fry
1988 Controls on Natural Nitrogen-15 and Carbon-13 Abundances in Forest Soil Organic Matter. *Soil Science Society of America Journal* 52: 1663-1640.

Nixon, E. S., L. F. Chambless and J. L. Malloy
1973 Woody Vegetation of a Palmetto [Sabal minor (Jacq.) Pers.] area in East Texas. *The Texas Journal of Science* 24: 535-541.

Nixon, E. S., R. L. Ehrhart, S. A. Jasper, J. S. Neck and J. R. Ward
1983 Woody Streamside Vegetation of Prairie Creek in East Texas. *The Texas Journal of Science* 35: 205-213.

Nixon, E. S., J. W. Higgins, P. L. Blanchette and F. A. Roth
1980. Woody Vegetation of a Wet Creek Branch in East Texas. *The Texas Journal of Science* 32: 337-341.

Nixon, E. S., J. Matos and R. S. Hansen
1987 The Response of Woody Vegetation to a Topographic Gradient in Eastern Texas. *The Texas Journal of Science* 39: 367-375.

Nixon, E. S. and J. A. Raines
1976 Woody Creekside Vegetation of Nacogdoches County, Texas. *The Texas Journal of Science* 27: 443-452.

O'Connell, J. F.
1987 Alyawara Site Structure and its Archaeological Implications. *American Antiquity* 52: 74-108.

Olson, G. W.
1981 *Soils and Environment, A Guide to Soils Surveys and their Applications.* New Your, Chapman and Hall.

Owen, G. and D. J. Schmidly
1986 Environmental Variables of Biological Importance in Texas. *The Texas Journal of Science* 38: 99-119.

Parker, P. L.
1964 The Biogeochemistry of the Stable Isotopes of Carbon in a Marine Bay. *Geochimica et Cosmochimica Acta* 28: 1155-1164.

Parks, H. B.
1935 Plant Life at Ottine. In First Scientific Field Meet, Palmetto State Park, Ottine, Texas, unpublished manuscript.

Patrick, R.
1938 Part V-Diatom Evidence from the Mammoth Pit. In The Occurrence of Flints and Extinct Animals in Pluvial Deposits near Clovis, New Mexico, Edgar B. Howard (ed.), *Proceedings Philadelphia Academy Natural Sciences* 90: 15-24.

1946 Diatoms from Patschke Bog, Texas. *Notulae Naturae* 170: 1-7.

Patrick, R. and C. W. Reimer
1966 *The Diatoms of the United States*, Vol. 1. Monographs of the Academy of Natural Sciences of Philadelphia, 13, 688 pp.

1975 *The Diatoms of the United States*, Vol. 2, Part 1. Monographs of the Academy of Natural Sciences of Philadelphia, 13, 213 pp.

Patton, P.C., Dibble, D.S.,
1982. Archeologic and Geomorphic Evidence for the Paleohydrologic Record of the Pecos River in West Texas. *American Journal of Science* 82, 97–121.

Pearsall, Deborah M.
1989 *Paleoethnobotany: A Handbook of Procedures*. San Diego: Academic Press.

Perttula, T. K.
1986 Prehistoric Ceramic Materials, Appendix 4. In *"This Everlasting Sand Bed": Cultural Resources Investigations at the Texas Big Sandy Project, Wood and Upshur Counties, Texas*, edited by T.K. Perttula, B.D. Skiles, M.B. Collins, M.C. Trachte, and F. Valdez, Jr. Report of Investigations 52, Prewitt and Associates, Inc. Austin.

Perttula, T. K., B. D. Skiles, M. B. Collins, M. C. Trachte, and F. Valdez, Jr.
1986 "This Everlasting Sand Bed": Cultural Resources Investigations at the Texas Big Sandy Project, Wood and Upshur Counties, Texas. Report of Investigations 52, Prewitt and Associates, Inc. Austin.

Peter, D. E. and D. E. McGregor
1988 Late Holocene Prehistory of the Mountain Creek Drainage. Joe Pool Lake Archaeological Research Project, Vol. 1. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University, Dallas.

Peter, D. E. D. E. McGregor, J. R. Newman, B. C. Yates, G. W. Rutenberg, G. J. Fritz, and J. E. Bruseth
1988 Site 41DL184. In *Late Holocene Prehistory of the Mountain Creek Drainage*. Joe Pool Lake Archaeological Research Project, Vol. 1, pp. 99-125. Archaeology Research Program, Institute for the Study of Earth and Man, Southern Methodist University, Dallas.

Piperno, Dolores R.
1988 *Phytolith Analysis: An Archaeological and Geological Perspective*. San Diego: Academic Press.

Potzger, J. E. and B. C. Tharp
1943 Pollen Record of Canadian Spruce and Fir from Texas Bog. *Science* 98: 584.

1947 Pollen Profile from a Texas Bog. *Ecology* 28: 274-280.

1954 Pollen Study of Two Bogs in Texas. *Ecology* 35: 462-466.

Price, T. D. (ed.)
1989 *The Chemistry of Phehistoric Human Bone.* Cambridge: Cambridge University Press.

Rabenhorst, M. C., L. P. Wilding and L. T. West
1984 Identification of Pedogenic Carbonates using Stable Carbon Isotope and Microfabric Analyses. *Soil Science Society of America Journal* 48: 125-132.

Railey, J. A., and A. Gwynn Henderson.
1986 "Middle and Late Woodland Occupation at Green Sulphur Springs." *West Virginia Archaeologist* 38: 22-39.

Rainey, Mary
1974 The Quaternary Stratigraphy of the North Sulpher River. Unpublished M.A. Thesis, Dallas: Southern Methodist University.

Ressel, D.
1979 Soil Survey of Lamar and Delta Counties, Texas. U.S. Department of Agriculture, Soil Conservation Service.

Reineck, H.-E. and I. B. Singh
1985 Depositional Sedimentary Environments. Springer-Verlag. Berlin

Rhodes, E. F
1988 Methodological Considerations in the Optical Dating of Quartz. *Quaternary Sciences Review* 7:395-400.

Rice, Elroy L.
1962 The Microclimate of Sugar Maple Stands in Oklahoma. *Ecology* 43: 19-25.

Rice, Elroy L. and William T. Penfound
1959 The Upland Forests of Oklahoma. *Ecology* 40: 593-608.

Robinson, Ralph L.
1979 Biosilica and Climatic Change at 41GD21 and 41GD21A. In *Archaeological investigations of Two Prehistoric Sites on the Coleto Creek Drainage, Goliad County, Texas*, by Dan E. Fox. Center for Archaeological Research, The University of Texas at San Antonio, Archaeological Survey Report 69.

1982 Biosilica Analysis of Three Prehistoric Archaeological Sites in the Choke Canyon Reservoir, Live Oak County, Texas: Preliminary Summary of Climatic Implications. In *Archaeological Investigations at Choke Canyon Reservoir, South Texas: The Phase I Findings*, edited by Grant D. Hall, Stephen L. Black and Carol Graves. Center for Archaeological Research, The University of Texas at San Antonio, Choke Canyon Series: Volume 5: 597-599.

Rosenzweig, Michael L.
1968 Net Primary Productivity of Terrestrial Communities: Prediction from Climatological Data. *The American Naturalist* 102: 67-74.

Round, F. E.
1973 *The Biology of Algae* (2nd Edition). London: Edward Arnold.

Saucier, R. T.
1990 Late Quaternary Geologic History of the Western Lowlands. In *Field Guide to the Mississippi Alluvial Valley, Norhteast Arkansas and Southeast Missouri,* edited by M.J.Guccione and E.M.Rutledge. Friends of the Pleistocene, South Central Cell. Fayetteville, Arkansas.

Salomons, W. and W. G. Mook
1976 Isotope Chemistry of Carbonate Precipitation and Dissolution in Soils. *Soil Science* 122: 15-24.

Schafale, M. P. and P. A. Harcombe
1983 Presettlement Vegetation of Hardin County, Texas. *The American Midland Naturalist* 109: 355-366.

Schneider, Stephen H.
1987 Climate Modeling. *Scientific American* 256: 5: 72-80.

Schneider, Stephen H. and Randi Londer
1984 *The Coevolution of Climate and Life*. Sierra Club Books, San Francisco.

Schnitzer, M.
1982 Organic Matter Characterization. In *Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties,* edited by A. L. Page, R. H. Miller and D. R. Keeney, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison.

Schoeninger, Margaret J. and Michael J. DeNiro
1982 Carbon Isotope Ratios of Apatite from Fossil Bone Cannot be used to Reconstruct Diets of Animals. *Nature* 297: 577-578.

Schoeninger , Margaret J., Michael J. DeNiro, Henrik Tauber
1983 Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science* 220: 1381-1383.

Scholtz, Anton
1986 Palynological and Palaeobotanical Studies in the Southern Cape. Unpublished M. A. Thesis, University of Stellenbosch, Stellenbosch, South Africa.

Schwartz, D., A. Mariotti, R. Lanfranchi and B. Guillet
1986 13C/12C Ratios of Soil Organic Matter as Indicators of Vegetation Changes in the Congo. *Geoderma* 39: 97-103.

Scott-Cummings, Linda
1991 Pollen, Phytolith, Macrofloral and Charcoal Analyses in the Jewett Mine Project Aarea, Texas.

Sealy, J. C., N. J. van der Merwe, A. Lee-Thorp, and J. L. Lanlam
1987 Nitrogen Isotopic Ecology in Southern Africa: Implications for Environmental and Dietary Tracing. *Geochimica et Cosmochimica Acta* 51: 2707-2717.

Semken, H. A., Jr.
1983 Holocene Mammalian Biogeography and Climate Change in the Eastern and Central United States. In *Late Quaternary Environments of the United States, Volume 2, The Holocene*, edited by H. E. Wright, pp 182-207, University of Minnesota Press, Minneapolis.

1988 Environmental Interpretations of the "Disharmonious" Late Wisconsin Biome of Southeastern North America. In *Late Pleistocene and Early Holocene Paleoecology and Archaeology of the Eastern Great Lakes Region*, edited by R. S. Laub, N. G. Miller and D. W. Steadman, pp 185-194, Buletin of the Buffalo Society of Natural Sciences 33.

Shafer, H. J.
1967 An Archaeological Survey of Robert Lee Reservoir, Coke County, Texas. Survey Report No. 4. Texas Archaeological Salvage Project, The University of Texas at Austin.

Shaw, R. B., K. C. Volman and F. E. Smeins
1980 Modern Pollen Rain and Vegetation on the Edwards Plateau, Texas. *Palynology* 4: 205-213.

Shearer, G., D. H. Kohl and S. H. Chien
1978 The Nitrogen-15 Abundance in a Wide Variety of Soils. *Soil Science Society of America Journal* 42: 899-902.

Shemesh, A. Y. Kolodny and B. Luz
1983 Oxygen Isotope Variations in Phosphate of Biogenic Apatites, II. Phosphorite Rocks. *Earth and Planetary Science Letters* 64: 405-416.

Siegenthaler, U. and H. Oeschger
1980 Correlation of 18O in Precipitation with Temperature and Altitude. *Nature* 285: 314-317.

Sillen, Andrew, Judith C. Sealy and Nikolaas J. van der Merwe
1989 Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity* 54: 504-512.

Slaughter, Bob H.
1975 Ecological Interpretation of Brown Sand Wedge Local Fauna. In *Late Pleistocene Environments of the Southern High Plains*, edited by Fred Wendorf and James J. Hester, Fort Burgwin Research Center, No. 9, Ranchos de Taos.

Slaughter, Bob H. and B. Reed Hoover
1963 The Sulphur River Formation and the Pleistocene Mammals of the Ben Franklin Local Fauna. *Journal of the Graduate Research Center*, SMU 31: 3: 117-131.

Smith, B. W., E. J. Rhodes, S. Stokes, N. A. Spooner, and M. J. Aitken
1990 Optical Dating of Sediments: Initial Quartz Results from Oxford. *Archaeometry* 32 (1) 19-31.

Soil Survey Staff
1975 Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. U.S. Department. of Agriculture, Handbook 436. U.S. Govt. Print. Office, Washington, DC.

Sorenson, C. J., R. D. Mandel and J. C. Wallis
1976 Changes in Bioclimate Inferred from Palaeosols and Palaeohydrologic Evidence in East-Central Texas. *Journal of Biogeography* 3: 141-149.

Speth, John, D.
1983 *Bison Kills and Bone Counts, Decision Making by Ancient Hunters*. University of Chicago Press: Chicago.

Stafford, Thomas W., Jr.
1984 Quaternary Stratigraphy, Geochronology, and Carbon Isotope Geology of Alluvial Deposits in the Texas Panhandle. Unpublished Ph.D. dissertation, The University of Arizona: Tuscon.

Stafford, Thomas W., Jr. and Holmes A. Semken, Jr.
1990 Accelerator 14C Dating of Two Micromammal Species Representative of the Late Pleistocene Disharmonious Fauna from Peccary Cave, Newton County, Arkansas. *Current Research in the Pleistocene* 7: 129-132.

Stahle, David W.
1990 The Tree-Ring Record of False Spring in the Southcentral USA. Unpublished PhD Dissertation, Arizona State University, Tempe.

Stahle, David W. and M. K. Cleaveland
1988 Texas Drought History Reconstructed and Analyzed from 1698 to 1980. *Journal of Climate* 1: 59-74.

Stahle, David W., Edward R. Cook and James W. C. White
1985 Tree-Ring Dating of Baldcypress and the Potential for Millennia-Long Chronologies in the Southeast. *American Antiquity* 796-802.

Stahle, David W. and J. G. Hehr
1984 Dendroclimatic Relationships of Post Oak across a Precipitation Gradient in the Southcentral United States. *Annals of the Association of American Geographers* 74: 561-573.

Stahle, David W., J. G. Hehr, G. G.Hawkes, M. K. Cleaveland, and J. R. Baldwin
1985 Tree-Ring Cronologies for the Southcentral United States. Tree-Ring Laboratory and Office of the State Climatologist, Department of Geography, University of Arkansas, Fayetteville.

Stevenson, Marc G.
1991 Beyond the Formation of Hearth Associated Artifact Assemblages. In *The Interpretation of Archaeological Spatial Patterning*, edited by Ellen M. Kroll and T. Douglas Price. Plenum Press, New York.

Story, D. A.
1990 Environmental Setting. In *The Archaeology and Bioarchaeology of the Gulf Coastal Plain*: Volume 1, edited by D.A. Story, J.A. Guy, B.A. Burnett, M.D. Freeman, J.C. Rose, D.G. Steele, B.W. Olive, and K.J. Reinhard. Arkansas Archaeological Survey Research Series No. 38. Fayetteville.

Story, D. A., J. A.Guy, B. A. Burnett, M. D. Freeman, J. C. Rose,D. G. Steele, B. W. Olive, and K. J. Reinhard
1990 *The Archaeology and Bioarchaeology of the Gulf Coastal Plain*. Arkansas Archaeological Survey Research Series No. 38.

Stuiver, Minze
1975 Climate Versus Changes in 13C Content of the Organic Component of Lake Sediments During the Late Quaternary. *Quaternary Research* 5: 251-262.

Stuiver, Minze and P. J. Reimer
1986 A Computer Program for Radiocarbon Age Calibration. *Radiocarbon* 28:1022-1030.

Sullivan, J. R. and E. S. Nixon
1971 A Vegetational Analysis of an area in Nacogdoches County, Texas. *The Texas Journal of Science* 67-79.

Sullivan, T. L.
n.d. Archaeological investigations at Lake Bob Sandlin, Texas. Research Report 99. Archaeological Research Program, Southern Methodist University, Dallas.

Taylor, R. E.
1987 *Radiocarbon Dating, An Archaeological Perspective.* Orlando: Academic Press.

Teeri, J. A. and L. G. Stow
1976 Climatic Patterns and the Distribution of C4 Grasses in North America. *Oecologia* 23: 1-12.

Tharp, B. C.
1939 The Vegetation of Texas. The Texas Academy of Science, Houston.

Thomas, J. R.
1977 Soil Survey of Red River County, Texas. U.S. Department of Agriculture, Soil Conservation Service.

Thornbury, W. D.
1976 *Regional Geomorphology of United States.* John Wiley & Sons. New York.

Thornthwaite, C. Warren
1931 The Climates of North America According to a New Classification. *Geographical Review* 21: 633-655.

Thornthwaite, C. Warren and J. R. Mather
1957 Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Drexel Institute Technology, Laboratory of Climatology, Publications on Climatology 10: 181-311.

Thurmond, J. P.
1981 Archaeology of the Cypress Creek Basin, Northeastern Texas and Northwestern Louisiana. M.A. thesis, Department of Anthropology, the University of Texas at Austin.

Tieszen, L. L., M. M. Senyimba, S. K. Imbamba and J. H. Troughton
1979 The Distribution of C3 and C4 Grasses and Carbon Isotope Discrimination Along an Altitudinal and Moisture Gradient in Kenya. *Oecologia* 37: 337-350.

Trewartha, G.T.
1968 *An Introduction to Climate*. New York: McGraw-Hill Book Company.

Turpin, S. A.
1988 Seminole Sink: Excavation of a Vertical Shaft Tomb Val Verde County, Texas. *Plains Anthropologist*, Memoir 22, 33 (122), Part 2: 119-132.

Tusenius, M. L.
1989 Charcoal Analytical Studies in the North-Eastern Cape, South Africa. *South African Archaeological Society, Goodwin Series* 6: 77-83.

Twiss, Page. C., Erwin Suess and R. M. Smith
1969 Morphological Classification of Grass Phytoliths. *Proceedings: Soil Science Society of America* 33: 109-115.

van der Merwe, N. J.
1982 Carbon Isotopes, Photosynthesis, and Archaeology. *American Scientist* 70: 6: 586-606.

1986 Carbon Isotope Ecology of Herbivores and Carnivores. *Palaeoecology of Africa* 17: 123-132.

van der Merwe, Nikolaas J. and Eresto Medina
1989 Photosynthesis and 13C/12C Ratios in Amazonian Rain Forests. *Geochimica et Cosmochimica Acta* 53: 1091-1094.

Vines, Robert A.
1977 *Trees of East Texas.* University of Texas Press, Austin.

Virginia, R. A. and C. C. Delwiche
1982 Natural 15N Abundance of Presumed N2-Fixing and non-N2-Fixing Plants from Selected Ecosystems. *Oecologia* 54: 317-325.

Vogel, J. C.
1978a Recycling of Carbon in a Forest Environment. *Oecologia Plantarum* 13: 89-94.

1978b Isotopic Assessment of the Dietary Habits of Ungulates. *South African Journal of Science* 74: 298-301.

Vogel, J. C., A. Fuls and R. P. Ellis
1978 The Geographical Distribution of Kranz Grasses in South Africa. *South African Journal of Science* 74: 209-215.

Vogel, J. C. and N. J. van der Merwe
1977 Isotopic Evidence for Early Maize Cultivation in New York State. *American Antiquity* 42: 238-242.

Volkoff, B. and C. C. Cerri
1987 Carbon Isotopic Fractionation in Subtropical Brazilian Grassland Soils. Comparison with Tropical Forest Soils. *Plant and Soil* 102: 27-31.

von Post, L.
1918 Skogasträd Pollen i Sydvenska Torvmosselagerföldjer. *Förhandlingar Skandinavika Naturforskeres* 16: 432-465.

von Schirnding, Y., N. J. van der Merwe and J. C. Vogel
1982 Influence of Diet and Age on Carbon Isotope Ratios in Ostrich Eggshell. *Archaeometry* 24: 3-20.

Webb, T. and R. A. Bryson
1972 Late and Postglacial Climatic Change in the Northern Midwest, USA: Quantitative Estimaes Deriverd from Fossil Pollen Spectra by Multivariate Statistical Analysis. *Quaternary Research* 2: 70-115.

Webb, T., III., and D. R. Clark
1977 Calibrating Micropaleontological Data in Climatic Terms: A Critical Review. *Annals of the New York Academy of Sciences* 288: 93-118.

Weniger, D.
1984 *The Explorers' Texas: The Lands and Waters*. Austin: Eakin Press.

Wigley, T. M. L.
1982 Oxygen-18, Carbon-13, and Carbon-14 in Tree Rings. In *Climate from Tree Rings*, edited by M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. Lamarche, Jr., pp 18-21, Cambridge: Cambridge University Press.

Wilding, L. P. and L. R. Drees
1968 Biogenic Opal in Soils as an Index of Vegetative History in the Prairie Peninsula. In *The Quaternary of Illinois*, edited by R. E. Bergstrom, University of Illinois College of Agriculture, Special Publication 14, pp. 96-103.

Williams, J. H., R. G. Barry and W. M. Washington
1974 Simulation of the Atmospheric Circulation using the NCAR Global Circulation Model with Ice Age Boundary Conditions. *Journal of Applied Meterorology* 13: 305-317.

Wilson, R. E.
1989 The Vegetation of a Pine-Oak Forest in Franklin County, Texas, and its Comparison with a Similar Forest in Lamar County, Texas. *The Texas Journal of Science* 41: 167-176.

Wilson, R. E. and D. Hacker
1986 The Sanders Cove Pines: Vegetational Analysis of a Pinus echinata-Quercus alba Community in Northern Lamar County, Texas. *The Texas Journal of Science* 38: 183-190.

Winsborough, Barbara
1991 Diatom Paleoecology of Lacustrine Sediments from East Texas with Evidence of Local Ground-Water Chemistry Anomalies. In *Excavations at the Bottoms, Rena Branch, and Moccasin Springs Sites, Jewett Mine Project, Freestone and Leon Counties, Texas*, edited by Ross C. Fields, L. Wayne Klement, C. Britt Bousman, Steve A. Tomka, Eloise F. Gadus and Margaret A. Howard, pp 369-382. Report of Investigations, Number 82. Prewitt and Associates, Inc., Austin Texas.

Witty, J. E. and E. G. Knox
1964 Grass Opal in Some Shestnut and Forest Soils in North Central Oregon. *Proceedings: Soil Science Society of America* 36: 639-641.

Wolfman, D.
1982 Archeomagnetic Dating in Arkansas and the Border Areas of Adjacent States. In *Arkansas Archaeology in Review*, edited by N.L. Trubowitz and M.D. Jeter, pp. 277-300. Research Series 15. Arkansas Archaeological Survey. Fayetteville.

Woodall, J. N.
1969 Archaeological Excavations in the Toledo Bend Reservoir, 1966. Southern Methodist University, Contributions in Anthropology, No. 3. Dallas.

Woollard, G. P.
1958 Areas of Tecctonic Activity in the United States as Indicated by Earthquake Epicenters. *American Geophysical Union Transactions* 39:1135-1150.

Woolridge, H. G., A. Adams, M. Davis, P. Denny, P. Nichols, B. Stewart, R. Stephenson, and G. Woodall
1981 A Cultural Resources Inventory and Assessment of the Proposed Stacy Reservoir, Concho, Coleman, and Runnels Counties, Texas, Vol. I: Prehistoric Cultural Resources. Document 81052. Espey, Huston and Associates, Inc. Austin.

Yapp, C. J.
1979 Oxygen and Carbon Isotope Measurements of Land Snail Shell Carbonate. *Geochimica et Cosmochimica Acta* 43: 629-635.

Yap, Crayton J. and Samuel Epstein
1977 Climatic Implications of D/H Ratios of Meteoric Water over North America (9500-22,000 B.P.) as Inferred from Ancient Wood Cellulose C-H hyrogen. *Earth and Planetary Science Letters* 34: 333-350.

Yurtsever, Y. and J. R. Gat
1981 Atmospheric Waters. In *Stable Isotope Hydrology,* edited by J. R. Gat and R. Gonfiantini. Vienna: International Atomic Energy Agency, pp. 103-142.

Zimmerman, M. H.
1982 Flunctional Xylem Anatomy of Angiosperm Trees. In *New Perspectives in Wood Anatomy*, edited by P. Baas, Martinus Nijhoff: The Hague, p.59-70.