RECONSTRUCTING CENTRAL TEXAS HOLOCENE SOIL EROSION AND CLIMATE USING CARBON, OXYGEN AND STRONTIUM ISOTOPES:

A RESEARCH PROPOSAL

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PROJECT SUMMARY

Today, in Central Texas, thin soils mantle the Cretaceous limestone bedrock of the Edwards Plateau. However, fossils of burrowing mammals contained in Central Texas cave deposits indicate the soils were once much thicker. Local extinction of these burrowing organisms at approximately 8,000 years BP is coincident with changing color, texture, and accumulation rates of sediments in several Central Texas caves, suggesting significant soil erosion affected the Edwards Plateau during the Holocene. The goal of my research is to determine the magnitude, timing, rate, and cause of Holocene soil erosion through an isotopic investigation of fossiliferous, well-dated deposits within Hall's Cave, Kerr County, Texas.

I propose to quantify ancient soil erosion through a new technique that relies on the contrasting $^{87}Sr/^{86}Sr$ ratios of different soil strontium (Sr) sources. Thin soils should reflect the Sr isotopic composition of the underlying bedrock while thick soils should reflect the isotopic composition of surficial soil components such as eolian silicates. To test this hypothesis, I propose to measure the Sr isotopic composition of soils from various depths in modern soil profiles. After establishing the relationship between the modern soil Sr composition and soil depth, I will analyze the $^{87}Sr/^{86}Sr$ ratio of fossils from Hall's Cave that represent biomineralized materials produced in equilibrium with ancient soil water. Therefore, I will be able to utilize the $^{87}Sr/^{86}Sr$ ratio of fossil plants and animals as a proxy for ancient soil depth. This correlation will be useful to reconstructing the timing, rates, and magnitude of Holocene soil erosion on the Edwards Plateau.

I also plan to investigate the associated causes of Holocene soil erosion in Central Texas. The stable C and O isotopic composition of fossils and organic material from the Hall's Cave deposit will be analyzed to test the hypothesis that either an increase in aridity or an increase in the seasonality of precipitation contributed to extensive soil erosion on the Edwards Plateau. An increase in aridity would be indicated by an increase in the relative proportion of C4 to C3 grasses in an ecosystem, which in turn is reflected in the C isotopic composition of organic matter. An increase in aridity would also be indicated by enriched ^{18}O compositions of fossil carbonate. However, an increase in seasonality could produce lower $\delta^{18}O$ values than expected for summer precipitation that would be reflected in the $\delta^{18}O$ of fossil carbonate forming during the summer months. Therefore, to interpret the isotopic data, it is essential to compare these results to local and regional vertebrate fauna, pollen, fluvial, and geochemical records.

INTRODUCTION

Problem Statement

Significant soil erosion has affected the Edwards Plateau since the last glacial maximum. Several lines of evidence including vertebrate fossils and sediment characteristics in Central Texas cave-fill deposits suggest soils were much thicker in the Early Holocene. However, the timing, rate, and cause of Holocene soil erosion are not well understood. The purpose of this project is 1) to reconstruct the magnitude, timing, and rate of Holocene soil erosion on the Edwards Plateau, 2) to determine the utility of Sr isotopes in fossil materials as a proxy for ancient soil thickness, and 3) to evaluate with stable C and O isotopes the possible environmental factors leading to Central Texas Holocene soil erosion.

Geological Setting

Today, thin soils, supporting live oak and ashe juniper parklands and grasslands (Toomey, 1993) mantle the Cretaceous limestone bedrock of the Edwards Plateau in Central Texas. Near the primary study area, Hall's Cave in Kerr County, Texas, shallow, stony soils (between 7 and 18 inches deep) of the Tarrant-Eckrant-Purves and Tarpley-Eckrant-Roughcreek soil associations cover the Cretaceous Segovia Limestone of the Edwards Group (Fig. 1) (Dittemore and Coburn, 1986). However, deeply weathered soils formerly covered Central Texas as evidenced by red, clay-rich deposits found in several Central Texas caves including Hall's Cave, Longhorn Caverns, Friesenhahn Cave, and Cave Without a Name (Toomey, 1989). Toomey (1993) suggests these reddish clay-rich cave deposits are derived from the erosion of thick, deeply weathered, red soils that formerly covered the Edwards Plateau.

Although thin soils dominate Central Texas landscapes, isolated areas of thick red, clay-rich soils (2-3 feet deep) occur in uplands of the Edwards Plateau and include the Spires and Depault soil units of the Spires-Tarpley-Tarrant and Eckrant-Kerrville-Rock Outcrop soil associations, respectively (Fig. 1) (Dittemore and Coburn, 1986). These soils, often identified by post oak stands (Bill Armstrong, personal communication), are perhaps relicts of thick soils forming under a more humid climatic regime of the past. Other evidence for formerly thick soils on the Edwards Plateau comes from fossils of burrowing mammals, such as the prairie dog *Cynomys*, contained in the red sediments of Hall's Cave. The burrowing depth of this organism indicates the soils in the vicinity of Hall's Cave were, in the past, between 3 and 6 feet deep (Toomey, 1993). The absence of thick soils today, coupled with the local extinction of the burrowing prairie dog *Cynomys* after 8,000 years BP suggest significant soil erosion has affected the Edwards Plateau during the Holocene. Further evidence for soil erosion is found in the changing color, texture, and accumulation rate of sediments within Hall's Cave (Fig. 2) (Toomey, 1993).

Location

In order to reconstruct a history of Holocene soil erosion and climate change on the Edwards Plateau, this study will involve an isotopic investigation of fossil materials contained in deposits within Hall's Cave, Kerr County Texas (Fig. 1). Hall's Cave is an ideal location to study rapid and small-scale changes in climate and soil erosion. Over the last 15,000 years, sheet wash and mass wasting over the 29,000 m^2 drainage area north of Hall's Cave, have transported sediments into the cave providing an almost continuous record of Quaternary sedimentation and environmental change (Toomey, 1993). Additionally, vertebrate remains have been deposited into the cave mostly as raptor and carnivore meal remains, but also by sheet wash and animals living and dying in the cave (Toomey, 1993). These fossils provide environmental and climatic constraints on paleo moisture, temperature, and soil depth. Furthermore, Hall's Cave is an appropriate location for this paleoenvironmental study as classified and catalogued fossil materials collected in 5 cm intervals from the deposit are available at the University of Texas Vertebrate Paleontology Laboratory for isotopic analysis. Finally, the Hall's Cave chronology, consisting of 152 high-precision AMS radiocarbon dates over the last 15,000 years, facilitates detailed resolution of Central Texas environmental change (Stafford and Toomey, in progress) (Fig. 3). This chronology makes Hall's Cave the longest, most continuous, well-dated Quaternary terrestrial sequence in Central Texas. Comparing my results to local environmental interpretations from vertebrate fossil assemblages and sedimentology at Hall's Cave (Toomey, 1993), and also to regional climate proxies such as pollen data (Bryant and Holloway, 1985), invertebrate fossil assemblages (Neck, 1987), fluvial geomorphology (Blum and Valastro, 1989 and 1994), cave speleothem geochemistry (Musgrove, 2000), and soil carbonate (Humphrey and Ferring, 1994) and soil organic matter (Nordt et al., 1994) isotopic compositions, will provide a more complete basis to understand Central Texas climate change and landscape evolution.

Approach

I propose to apply an innovative technique that relies on the contrasting $^{87}Sr/^{86}Sr$ ratios of different soil Sr sources to reconstruct the timing, magnitude, and rate of Holocene soil erosion on the Edwards Plateau. Several studies have shown that the components of soils (i.e. airborne dusts, weathering bedrock, etc.) can be identified on the basis of the distinct $^{87}Sr/^{86}Sr$ ratios of the different sources (Borg and Banner, 1996; Mizota and Matsuhisa, 1995; Miller et al., 1993; Grousset et al., 1992; Aberg et al., 1989; Graustein and Armstrong, 1983). Three sources contribute Sr to soils on the Edwards Plateau (Fig. 4). Cretaceous marine limestone bedrock contributes Sr with a relatively low $^{87}Sr/^{86}Sr$ ratio, reflecting the isotopic composition of Cretaceous seawater. The other sources of Sr to soils are Sr from eolian deposition as well as Sr from the weathered limestone silicate residuum. Both of these silicate sources are enriched in continentally-derived radiogenic Sr and therefore have a high $^{87}Sr/^{86}Sr$ ratio.

Strontium from all three sources is available in the soil water for uptake through biologic and geologic processes (Graustein, 1989; Capo et al., 1998). Graustein and Armstrong (1983), Gosz and Moore (1989), Nakano et al. (1992 and 1993), Miller et al. (1993), and Kennedy et al. (1993) have shown that the Sr isotopic composition of plants reflects the Sr isotopic composition of the exchangeable soil Sr. Therefore, the $^{87}Sr/^{86}Sr$ of plants, and animals eating these plants, records the $^{87}Sr/^{86}Sr$ of the soil substrate. As soil thins by erosion, the proportion of bedrock-derived Sr in the soil, relative to eolian Sr, will increase and therefore the $^{87}Sr/^{86}Sr$ will decrease. Because Sr isotopes are not fractionated by biological processes (Graustein, 1989), measuring the $^{87}Sr/^{86}Sr$ of plant and animal tissues produced from soil water provides an indirect measurement of the ancient soil water Sr composition and thus soil depth. Preliminary analyses of hackberry seed carbonate and rodent tooth enamel from Hall's Cave indicate the $^{87}Sr/^{86}Sr$ decreases through time, potentially reflecting soil erosion (Fig. 5).

Alternative Techniques

Currently, there are few tools available to reconstruct ancient soil thickness and erosion rates. At Hall’s Cave, changes in sediment properties and fossil accumulation rates provide only an estimate of increased soil erosion after 8,000 years BP (Toomey, 1993). In other places, cosmogenic isotopes such as ^{10}Be and ^{26}Al have been used to determine net erosion and erosion rates from rock (Lal, 1991; Nishiizumi et al., 1991; Albrecht et al., 1993; Gillespie and Bierman, 1995), regolith, sediments (Granger et al., 1996), and remnant soils (Barg and Lal, 1992). However, in contrast to cosmogenic isotopes, which yield long-term average soil erosion rates, using Sr isotopes as a proxy for soil depth allows one to constrain more accurately the dynamics of an eroding landscape.

ANALYTICAL METHODS

Materials

To determine how the Sr isotopic composition of soil water changes with depth in the modern system, I will analyze the $^{87}Sr/^{86}Sr$ of modern soil, vegetation, and biomineralized plant and animal tissues. In order to address the issue of Holocene soil erosion, I will analyze the Sr, O, and C isotopic composition of fossils from Hall's Cave, cataloged at the University of Texas Vertebrate Paleontology Laboratory, including: hackberry seeds (*Celtis*), Microtine rodent teeth (*Microtus sp.)* and land snails (*Rabdotus dealbatus*). Hackberry trees produce seeds with biomineralized aragonite and opal seed coats (endocarps) allowing for their preservation in the fossil record (Jahren, 1996). These hackberry endocarps are abundant throughout the Hall's Cave deposit. X-ray diffraction analysis of several hackberry seed specimens indicates that hackberry seeds as old as 20 ka maintain their original aragonite mineralogy. Additionally, Microtine rodent molars from *Microtus ochroghaster* (prairie vole), *Microtus pinetorum* (woodland vole), and *Microtus pennsylvanicus* (meadow vole) as well as shells of the land snail *Rabdotus dealbatus* are also found at many levels within the Hall's Cave. The availability, abundance, and structural and mineralogical integrity of these paleontologically non-diagnostic fossils in the Hall's Cave deposit make them logical candidates for isotopic analysis.

Strontium Isotope Analyses of the Modern System

In order to reconstruct a history of Central Texas Holocene soil erosion, I must first prove the $^{87}Sr/^{86}Sr$ of the soil varies with depth in the modern soils. To do this, I will analyze the $^{87}Sr/^{86}Sr$ of soil leachates collected from five horizons in a well-developed soil profiles near Hall's Cave in the Kerr Wildlife Management Area (Fig. 1). These thick, clay-rich soils of the Spires-Tarpley-Tarrant soil association are presumed to be relict, pre-erosional soils from the early Holocene. The $^{87}Sr/^{86}Sr$ of soil leachates in horizons close to the surface should be influenced more by eolian-derived silicates than the underlying limestone bedrock, resulting in high $^{87}Sr/^{86}Sr$ ratios. Likewise, deeper soil horizons will contain more bedrock-derived Sr and thus soil leachates from these horizons will have a lower $^{87}Sr/^{86}Sr$ ratio. For comparison, I will also analyze a soil profile from the thin soils in the vicinity of Hall's Cave.

Another way to evaluate whether the soil water $^{87}Sr/^{86}Sr$ ratio changes with depth is to compare the $^{87}Sr/^{86}Sr$ of different plants growing on the same soil, but accessing water from different depths. For example, shallowly-rooted forbs and grasses access soil water near the surface and thus should have a high ^{87}Sr/^{86}Sr ratio. In contrast, deeply-rooted trees will have lower ^{87}Sr/^{86}Sr ratios reflecting soil water from deeper horizons less influenced by atmospheric deposition. Therefore, I will analyze the ^{87}Sr/^{86}Sr of leaf material from fifteen different plants growing on the same soil, but having shallow, intermediate, and deep rooting depths (grasses, small shrubs, and hackberry trees, respectively).

One final way that I will test the variation in soil ^{87}Sr/^{86}Sr with depth is to compare the Sr isotopic composition of different herbivores feeding on plants with different rooting depths. As the ^{87}Sr/^{86}Sr of plants will vary with rooting depth, so should the ^{87}Sr/^{86}Sr ratio of organisms feeding on these different vegetation types. For example, ^{87}Sr/^{86}Sr of tooth enamel from grazers should reflect the ^{87}Sr/^{86}Sr of shallowly-rooted grasses and forbs. Similarly, the ^{87}Sr/^{86}Sr of tooth enamel from arboreal feeders should reflect the ^{87}Sr/^{86}Sr ratio of deeply-rooted trees. Therefore, I will analyze the ^{87}Sr/^{86}Sr of tooth enamel from animals living in the same area, but having different dietary habits including 3 squirrels (arboreal feeders) and 3 mice (grazers).

Strontium Isotope Analyses of Fossil Materials

Testing the variability of ^{87}Sr/^{86}Sr with depth from different materials in the modern environment will establish the potential utility of using the Sr isotopic composition of fossils and sediments as a proxy for ancient soil depth. Additionally, it will provide a framework from which to interpret ancient soil depths and the relative change in soil depth through time. In order to reconstruct the erosional history in the vicinity of Hall's Cave, I will analyze the ^{87}Sr/^{86}Sr ratio of aragonitic fossil hackberry seed coats preserved in Hall's Cave as well as enamel from Microtine rodent molars. Preliminary data suggests the ^{87}Sr/^{86}Sr of fossil tooth enamel and hackberry seeds varies throughout the Hall's Cave record and more importantly that the ^{87}Sr/^{86}Sr ratios decrease through time as expected by progressive soil erosion on the Edwards Plateau (Fig 5).

First, I will analyze 20 hackberry seed endocarps from different depths, in the Hall's Cave deposit. Additionally, I will analyze 5 hackberry seeds from the same horizon (assumed to be the same age) for 3 different depths to detect possible diagenetic alteration of inherent variability in the ^{87}Sr/^{86}Sr of hackberry seed aragonite. To further test the hypothesis that the ^{87}Sr/^{86}Sr ratio decreases with soil depth, I will measure the ^{87}Sr/^{86}Sr ratio of enamel from 20 fossil vole *(Microtus sp.)* molars contained in several levels in the Hall's Cave deposit. Of these 20 teeth, I will analyze 11 teeth from different levels and 3 teeth from the same depth for three different depths to determine the variability of samples through time and among samples of the same age. Finally, I will analyze the $^{87}Sr/^{86}Sr$ of tooth enamel from 8 fossil squirrels (from the same stratigraphic level as the *Microtus* samples) in order to compare the Sr isotopic composition of organisms feeding on plants with different rooting depths.

Strontium Measurements Techniques

Soil, vegetation, tooth enamel, and hackberry seed endocarps for Sr isotopic analysis will be prepared according to clean lab standards. After pretreatment with ultrasonication and weak acetic acid leaching to remove surface and secondary carbonate contaminants, samples will be dissolved in strong acids and the Sr will be isolated by ion exchange column chemistry techniques. The samples will be analyzed on the University of Texas thermal ionization mass spectrometer. Aliquots of each sample will be saved for ICP-MS to acquire Sr and other trace element concentrations. A summary of Sr isotopic analysis is given in Table 1.

Carbon and Oxygen Isotope Analyses of Fossils

The Sr isotopic composition will provide information about the timing and rates of soil erosion on the Edwards Plateau; however, it does not address the cause of Central Texas soil erosion. For this study I will test two climate variables that would result in increased Holocene soil erosion: 1) an increase in aridity, and 2) an increase in the seasonality of precipitation. A drier climate would lead to drier soils with less vegetative cover prone to erosion by wind, mass wasting, and run-off. However, soil erosion can also be triggered by wetter climatic conditions. For example, more seasonal precipitation results in rapid saturation of soils leading to increased run-off and denudation of the soil.

In Hall's Cave, the proportion of least shrew to desert shrew decreases between 14 and 10.5ka, 5 and 2.5 ka, and after 1 ka, suggesting a local, if not regional, decrease in effective moisture (Toomey, 1993). To test this hypothesis, I will measure the $\delta^{13}C$ of organic materials in Hall's Cave. The $\delta^{13}C$ ratio of soil organic matter (Cerling, 1984) has proven to be a valuable indicator of the relative proportion of C3 to C4 plants in ancient ecosystems. Because the ratio of C3 to C4 grasses is a function of aridity, where drought-tolerant C4 grasses increase relative to C3 vegetation during warm, dry climates, the $\delta^{13}C$ of fossil organic matter can be used as a proxy for the atmospheric moisture (Nordt et al., 1994; Humphrey and Ferring, 1994). Therefore, I plan to analyze the $\delta^{13}C$ of isolated organic matter from 15 sediment samples and 15 collagen extracts from dated bone materials contained in the Hall's cave deposit. These data will either support or reject the hypothesis that an increase in aridity contributed to increased soil erosion during the intervals suggested by vertebrate fossil evidence (Toomey, 1993). Pollen analysis from Hall's Cave will also complement these results.

Toomey et al. (1993) discuss climate model simulations for increased seasonality during the Early Holocene. To test the hypothesis that changes in seasonality (intensity of summer precipitation) contributed to episodes of Holocene soil erosion, I will measure the $\delta^{18}O$ of fossils from Hall's Cave and use that as a proxy for the relative amount of precipitation. Several factors may contribute to variation in $\delta^{18}O$ of meteoric water in one location over time including changes in temperature, relative humidity, the amount of rainfall, the season of rainfall, and the source of moist airmasses (Faure, 1986; Goodfriend, 1992; Lecolle, 1985; and Yapp, 1979). However, to a first approximation, at the latitude of Central Texas, the $\delta^{18}O$ of mean annual precipitation is a function of relative humidity and the amount of precipitation.

Several studies have shown that the $\delta^{18}O$ of land snail shell carbonate can be used as a proxy for the $\delta^{18}O$ of meteoric water (Goodfriend 1992 and 1996; Lecolle, 1985; Yapp, 1979). In particular, Goodfriend (1996) demonstrates that carbonate from individual growth layers in the land snail *Rabdotus* records seasonal changes in the $\delta^{18}O$ of precipitation. However, carbonate is not added to the shell during seasons of low moisture availibility (Goodfriend, 1992). Therefore, I will analyze the $\delta^{18}O$ of carbonate from 20 different land snail shells (*Rabdotus dealbatus*) from different levels and 5 shells from the same stratigraphic horizon for three different levels and use that ratio as a proxy for the average composition of winter-spring precipitation.

Jahren (1996) and Jahren et al. (1998) demonstrate the $\delta^{18}O$ of modern hackberry seed aragonite can be used as a proxy for the composition of mid to late growing season (summer-fall) precipitation. Therefore, I will analyze the $\delta^{18}O$ of aliquots of the same 35 fossil hackberry seed endocarps from Hall's Cave used for Sr analysis. Due to increased temperature and evaporation, the $\delta^{18}O$ of summer precipitation should be enriched relative to winter precipitation in ^{18}O. Thus, the $\delta^{18}O$ of the hackberries should be more positive than the $\delta^{18}O$ of the land snails. Limited data suggests this may be reflected in fossils from Hall's Cave (Fig. 6). However, lower $\delta^{18}O$ values for hackberry seed carbonate may indicate increased amounts (or intensity) of summer precipitation as Lawrence (1998) shows high frequency tropical storm activity depletes summer precipitation in ^{18}O. Therefore, comparing the $\delta^{18}O$ of snail and hackberry seed carbonate representing rainfall from different times of the year may be useful in resolving changes in seasonality throughout the Holocene. Because the $\delta^{18}O$ of precipitation can be affected by multiple variables, comparing the oxygen isotopic data to other climate proxies is essential to interpreting changes in aridity, temperature, or the amount and seasonality of precipitation. For example, comparing this data to inter-annual climate records such as speleothem growth layers would further elucidate the seasonal nature of Holocene precipitation. I will also compare the $\delta^{18}O$ and $\delta^{13}C$ ratios. Together, the $\delta^{13}C$ and $\delta^{18}O$ will confirm whether the $\delta^{18}O$ of fossil materials is reflecting the amount of precipitation or changes in aridity.

Stable Carbon and Oxygen Isotope Techniques

Carbon and oxygen isotopic analyses will be performed in the stable isotopes laboratory at The University of Texas. After ultrasonicating and powdering carbonate samples, the $\delta^{18}O$ and $\delta^{13}C$ will be measured using a multi-prep sampling system in combination with a dual inlet mass spectrometer. Carbonate samples will be reacted in phosphoric acid at 90°C. The liberated CO_2 gas will be cryogenically purified to remove water and non-CO_2 vapors prior to measurement on the IR mass spectrometer. Organic matter will be isolated from cave sediments and sent, along with prepared collagen extracts, to the University of Texas Marine Science Institute for $\delta^{13}C$ analysis. A summary of O and C isotopic analyses is included (Table 1.)

Expected Results

I expect the $^{87}Sr/^{86}Sr$ ratios in modern soil, plant, and tooth material to show a progressive decrease in $^{87}Sr/^{86}Sr$ with increasing soil depth. I also expect fossil tooth, and hackberry seed carbonate materials to show a decrease in $^{87}Sr/^{86}Sr$ with time, corresponding to progressive soil erosion. A gradual decrease in the $^{87}Sr/^{86}Sr$ ratios should be resolved after 8 ka, consistent with local extinction of the burrowing prairie dog *Cynomys* at this time (Toomey, 1993). I expect the hackberry seed aragonite and vole and squirrel tooth enamel to show similar decreasing $^{87}Sr/^{86}Sr$ trends. However, I do not expect these fossil groups to have the same Sr isotopic composition. By consuming shallow rooting grasses and forbs, the Microtine rodents (voles) incorporate the $^{87}Sr/^{86}Sr$ of shallow soil waters into their mineralized tissues. Conversely, squirrels from the same stratigraphic level should have a $^{87}Sr/^{86}Sr$ ratio more similar to the limestone bedrock as they are feeding on deeply rooted trees. Therefore, although the $^{87}Sr/^{86}Sr$ isotopic compositions of the vole tooth enamel should be higher than the hackberry seed and squirrels for any given time due to the differences in the depth of soil water access, their $^{87}Sr/^{86}Sr$ ratios should still follow the same decreasing trend.

Summarizing evidence from pollen, vertebrate remains, cave fill sediments, and fluvial incision, Toomey et al. (1993) interpret Central Texas climate became appreciable more arid after 8,000 years BP (Fig. 7) leading to extensive Holocene soil erosion. Therefore I expect the onset of soil erosion to temporally correlate with the regional evidence for increased aridity. An increase in aridity would result in soil waters enriched in ^{18}O and therefore the land snail and hackberry carbonate should show similar, but not equal, increasing $\delta^{18}O$ values just prior to 8 ka. Simultaneously, an increase in aridity would be indicated by more positive $\delta^{13}C$ values of organic matter from the Hall's Cave deposit indicating an increase in the relative proportion of C4 to C3 plants. Furthermore, the stable isotopic data should be consistent with regional palynological, paleontological, geomorphic, and geochemical proxies for climate change. For example, the isotopic data should show similar trends as isotopic studies on Central Texas pedogenic carbonates (Humphrey and Ferring, 1994) and soil organic matter (Nordt et al., 1994). An increase in aridity should also correspond to regional increase in grasses as seen Central Texas pollen records (Bryant and Holloway, 1985). This decrease in vegetation would promote soil erosion and fluvial incision as suggested by evidence from the Central Texas Pedernales and Colorado River deposits (Blum and Valastro, 1989 and 1994).

ISSUES AND CONCERNS

Fossil Diagenesis

The meaning of isotopic data from Holocene fossil materials in Hall's Cave is contingent upon the mineralogical integrity of the Holocene samples. The young geologic age of the deposit (less than 15,000 years BP) increases the potential for fossils to preserve a biogenic, rather than diagenetic, isotopic composition. Also the preservation of the original aragonite mineralogy of hackberry seeds can be used as an index for the extent of diagenetic alteration of as diagenetic alteration would convert unstable aragonite to calcite. Preliminary x-ray diffraction analysis of aragonite and calcite mixtures show that with similar sample preparation, approximating the percent calcite and aragonite is possible (Fig. 8). Therefore, x-ray diffraction will be used to determine the mineralogical composition of the hackberry seeds. Samples will be selected for isotopic analysis only if they maintain the original aragonite mineralogy. Preliminary XRD data indicates even fossil hackberry seeds as old as 20 ka maintain their original aragonite mineralogy (~5% calcite and 95% aragonite) suggesting diagenesis has not yet affected these samples.

Recently, many studies have been concerned with the preservation of *in vivo* Sr isotopic signatures in fossil bones and teeth (Budd et al., 2000; Grupe et al., 1997 and 1999; Koch et al., 1992 and 1997; Schmidtz et al., 1997; Horn and Müller-Sohnius, 1991; Sealy et al., 1991; Nelson et al., 1986; Sillen and Sealy, 1986). However, Budd et al. (2000) and Koch et al. (1997), and have found tooth enamel to be less effected by diagenesis than more porous dentin and bone tissues. Therefore, I will isolate and analyze only the enamel portion of fossil teeth to reduce the possibility of isotopic alteration. Acid-pre-treatment (Grupe et al., 1997), x-ray diffraction (Hoppe and Koch, 1999; Nelson et al., 1986), step-wise leaching (Sealy et al., 1991; Koch et al., 1992), and trace element analysis (Banner, 1995) are possible techniques to minimize and assess the effects of diagenesis. Thus, fossil tooth enamel samples will be pretreated with weak acetic acid, and mechanically scraped to remove secondary carbonates and possible clay contamination. Additionally, elemental concentrations of fossil hackberry seed and tooth enamel, will be obtained by ICPMS. Trace element concentrations, and atomic proportions of these elements, can provide information about fluid-mineral interactions, influx of elements to the soil, as well as selective absorption of elements in more porous mineral phases.

Cave Depositional Processes

To derive paleoclimate information from Hall's Cave, one must make assumptions about the depositional processes in Hall's Cave. First, Toomey (1993) assumed that the sediments and fossils deposited in Hall's Cave were eroded from a near-by source and deposited without intermediate storage into the cave by sheet wash. If fossils were from a more remote source, they may reflect different environmental conditions. For example, due to the spatial variability in soil thickness, fossils transported a greater distance or brought in by raptors also flying great distances could reflect a greater diversity of soil thickness, making soil erosion histories more difficult to interpret from the isotopic and paleontological data from Hall's Cave. Also, the time between the organisms death and its deposition in the cave may vary as the materials may have been temporarily out of the hydrologic and mass wasting cycles. If this is true, fossils from the same levels in the cave may be different ages. To minimize these concerns, multiple samples from closely spaced stratigraphic levels will be analyzed. However, the consistency and resolution of radiocarbon dates and dominant fossil depositional modes (Fig. 3) suggest these concerns may be insignificant.

IMPLICATIONS

The significance of this study is three-fold. First, I will be testing a new technique to determine paleo soil thickness and erosion rates. I propose to reconstruct Holocene soil erosion history on the Edwards Plateau using Sr isotopic composition of fossils as a proxy for ancient soil thickness. This technique could potentially be applied to many geologic settings where the bedrock $^{87}Sr/^{86}Sr$ ratios differ from the silicate soil components. It is a valuable technique because it does not assume a constant rate of erosion, and can be used to model the dynamics of an eroding landscape, even in the absence of the original soil. Next, my study will add to our understanding of the magnitude and timing of soil erosion as well as the environmental factors leading to the erosion. This has application to studies of modern soil erosion, anthropogenic acceleration of soil erosion rates, and soil conservation. Currently, only estimates of net soil erosion are available for Central Texas. This study will clarify the dynamics of the past soil erosion, including the rates and magnitude of soil erosion episodes. Finally, with careful consideration of the materials and techniques, as well as the existing paleoclimate information, this new isotopic data from Hall's Cave will provide valuable insights into local environmental change. I will use stable C and O isotopes along with existing paleoclimate records from Central Texas to interpret the possible environmental factors leading to this soil erosion. Combining several lines of evidence, including pollen, vertebrate paleontology, and isotopic data will provide a more complete basis from which to make paleoenvironmental interpretations, resulting in better resolution of the climatic fluctuations associated with Holocene post-glacial warming.

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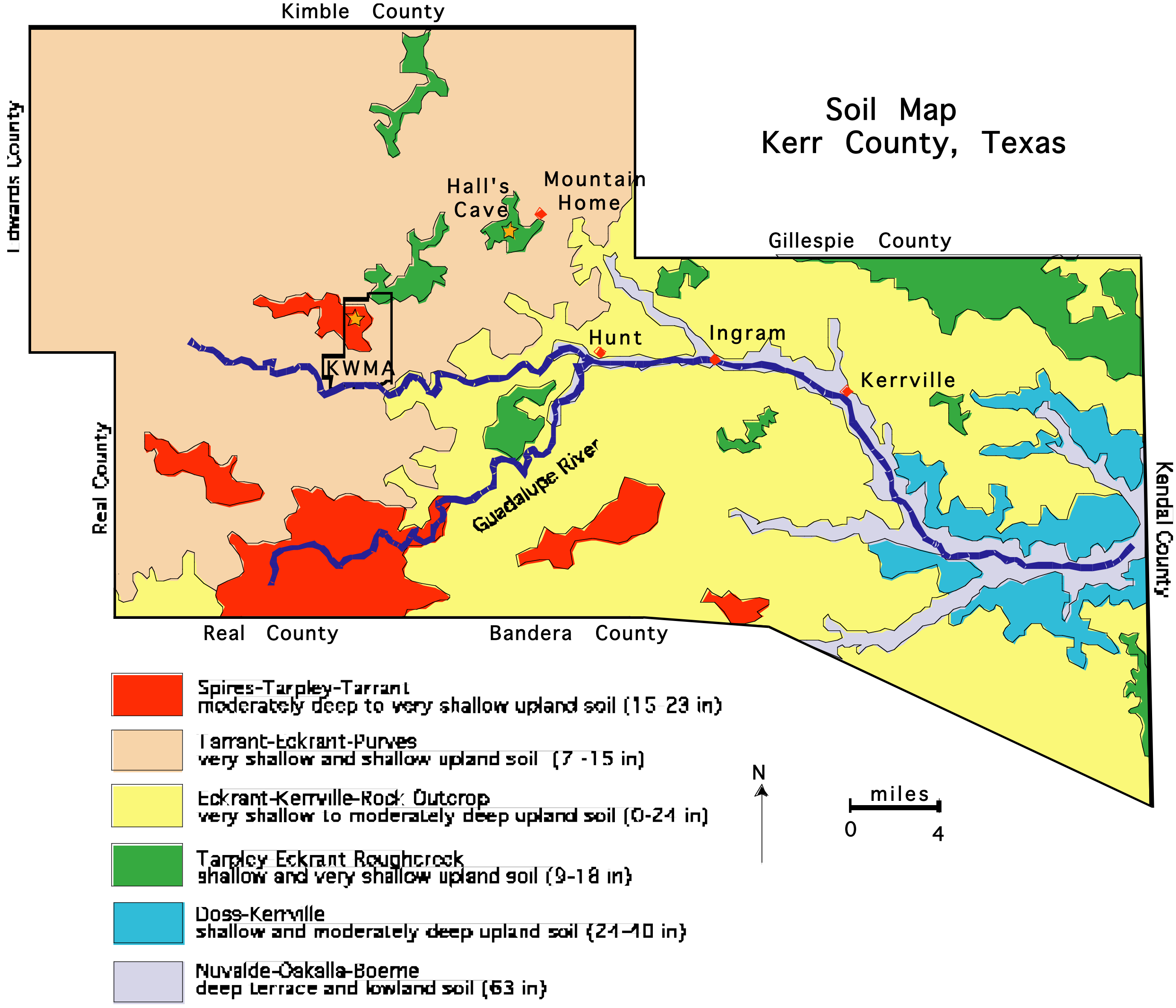

Figure 1. Soil map of Kerr County modified after Dittemore and Coburn (1986). Most soils are thin (approximately 20 inches or less), however thicker soils occur near rivers and as isolated patches of reddish-brown soils of the Depault and Spires soil units of the Spires-Tarpley-Tarrant, and Eckrant-Kerrville-Rock Outcrop soil associations, respectively. Throughout Kerr County, the underlying bedrock is Cretaceous marine limestones of the Edwards Group (Segovia and Fort Terret formations). However, the older Cretaceous Glen Rose Limestone is exposed in river drainages in eastern Kerr County. The primary study areas (Hall's Cave and Kerr Wildlife Management Area) are also depicted.

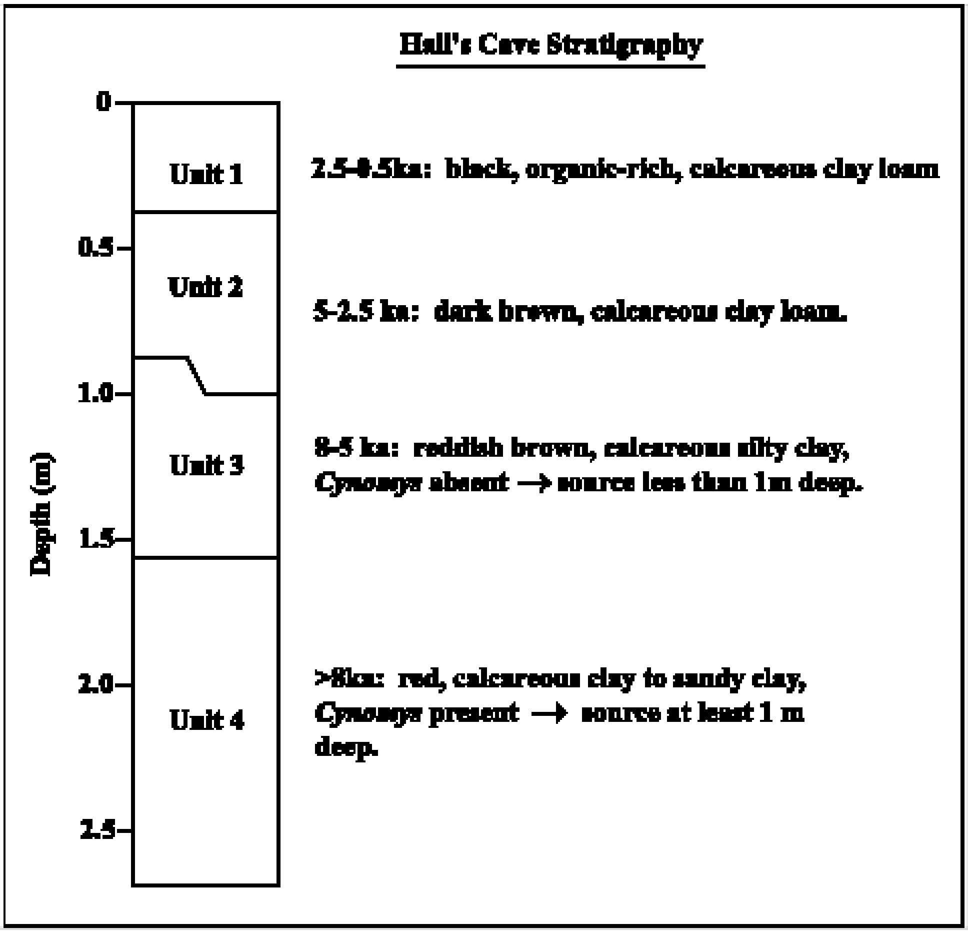

Figure 2. Stratigraphy of the Hall's Cave deposit from Toomey (1993). The red sediments at the base of the deposit represent erosion of a deeply-weathered thick soil. A possible analog for this thick soil is the Spires soil unit. Note the change from red, coarse-grained sediments containing fossils of the burrowing prairie dog *Cynomys* to finer-grained reddish-brown sediments lacking *Cynomys* fossils at 8 ka. After 8 ka, the cave fill becomes darker and more enriched in organic matter and suggesting the erosion of less-well-developed soils.

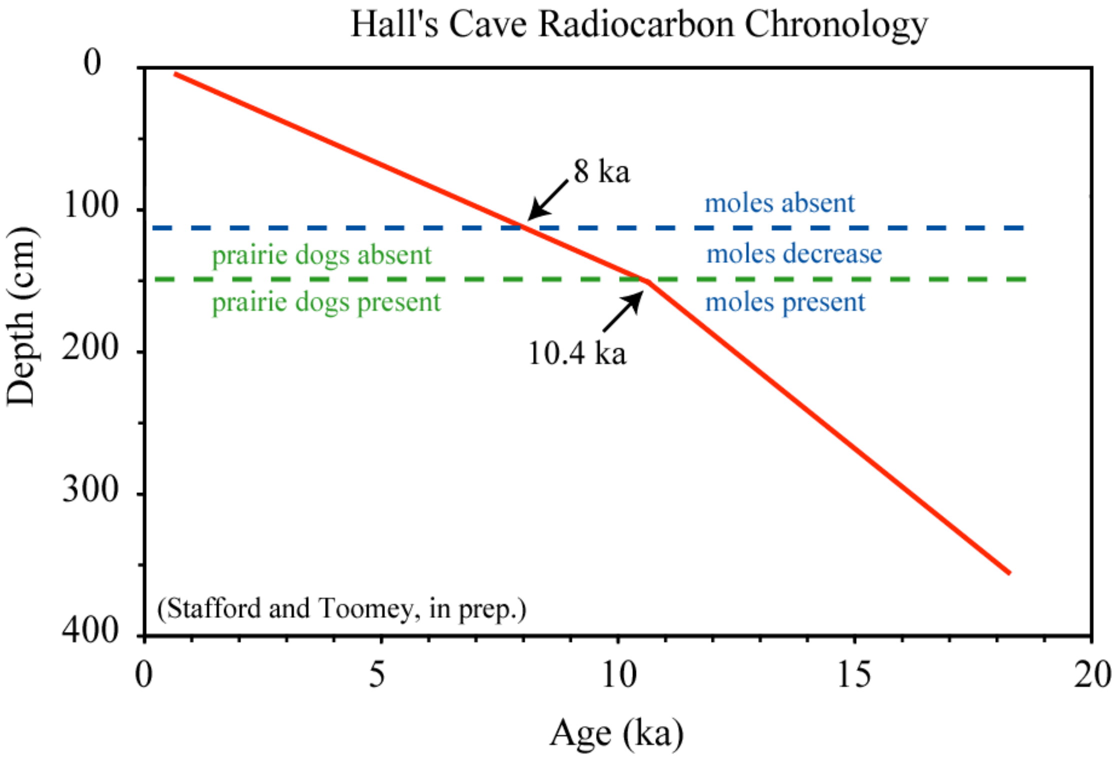

Figure 3. Summary of unpublished AMS radiocarbon dates for Hall’s Cave from Stafford and Toomey (in prep.). Dated materials include cave sediment, bone, hearth charcoal, and gastropod carbonate.

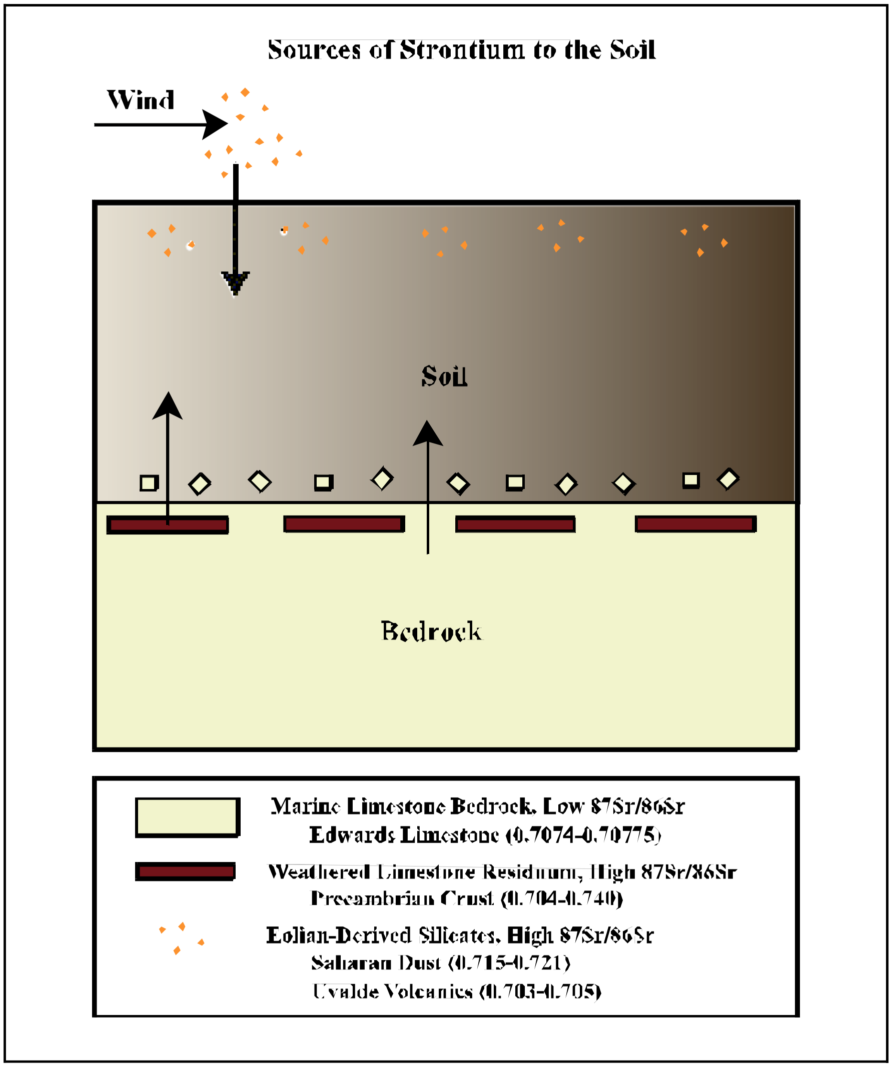

Figure 4. Sources of Sr to soils of Central Texas and their distinct $^{87}Sr/^{86}Sr$ isotopic compositions. Weathering of the underlying bedrock will contribute Sr with a marine isotopic composition to the lower soil horizons. However, insoluble residues from the dissolution of the marine limestone will contribute Sr with an "old continent" signature. Far-traveled Saharan dusts and nearby Uvalde volcanics and Precambrian granites in the Llano area are all possible eolian silicate sources to Central Texas soils. Like the continental crust, these eolian silicates will also be enriched in radiogenic Sr. The Sr isotopic composition for the Edwards limestone bedrock is from a compilation of measurements in Oetting et al. (1996). Values for Precambrian crustal rocks (i.e. Llano granites) are from Faure (1986). Values for the Uvalde volcanics and Saharan dusts are from Wittke and Mack (1993) and Grousset et al. (1992), respectively.

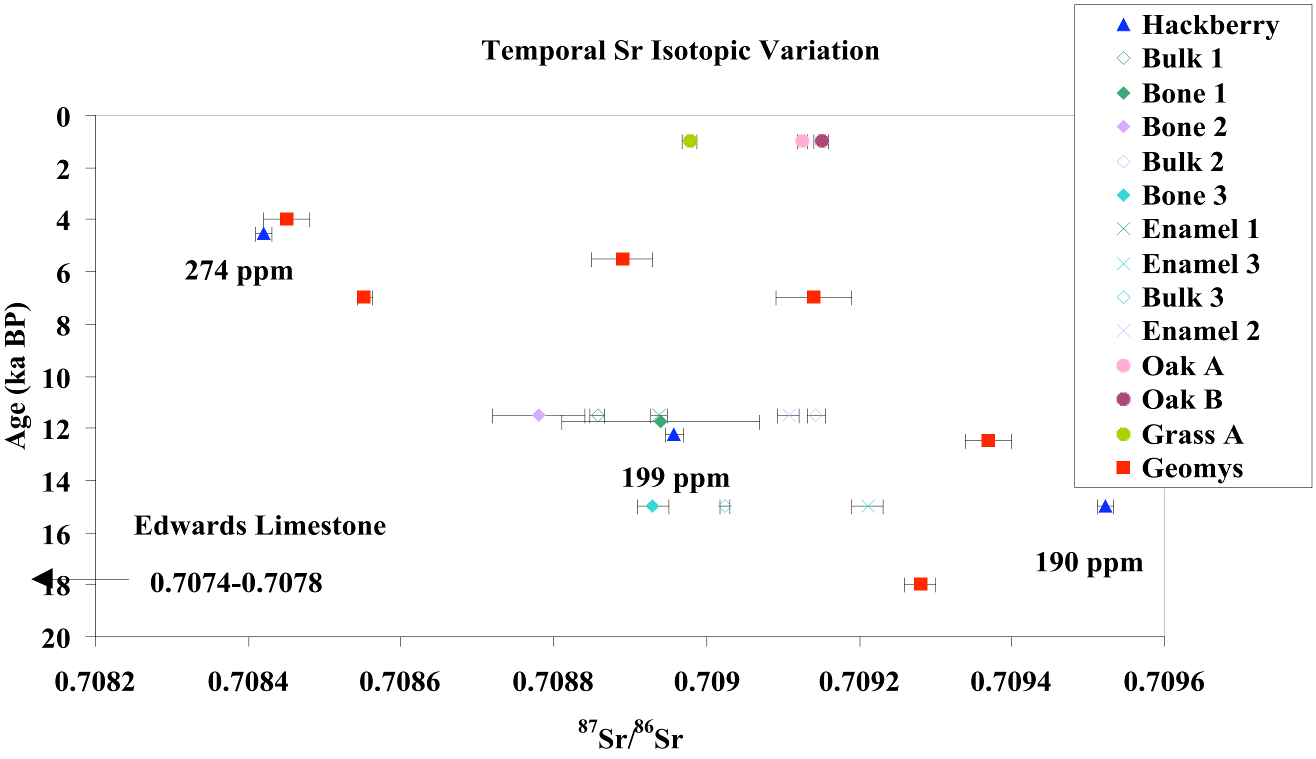

Figure 5. Preliminary $^{87}Sr/^{86}Sr$ data for fossil materials in the Hall's Cave deposit. Enamel from pocket gopher (*Geomys*) incisors were prepared and analyzed by Lyn Murray (1999). Hackberry seed aragonite and bone and molar tooth material from voles (*Microtus*), and vegetation samples are from this study. Bulk tooth sample (enamel + dentin), bone, and enamel samples are from three separate specimens of *Microtus sp.* collected from Hall's Cave (#1, 2, and 3). Symbols of the same color are from the same specimen. Error bars indicate analytical error in measuring the $^{87}Sr/^{86}Sr$ ratio. The Sr isotopic composition from the Cretaceous Edwards Limestone is from Oetting et al. (1996) and is a good estimate for the Segovia Limestone host rock of Hall's Cave. After 12 ka, *Geomys* tooth enamel and hackberry seed aragonite show decreasing $^{87}Sr/^{86}Sr$ ratios with depth potentially reflecting changes in soil depth with time. Bone and bulk tooth (enamel and dentin) for the Microtine rodents vary in isotropic composition, even for samples from the same horizon, suggesting the more porous bone and dentin tissues are poor records of en vivo Sr isotopic composition. Oak A is a live oak growing on thick soil near grass A, while Oak B is a live oak growing on thin soil.

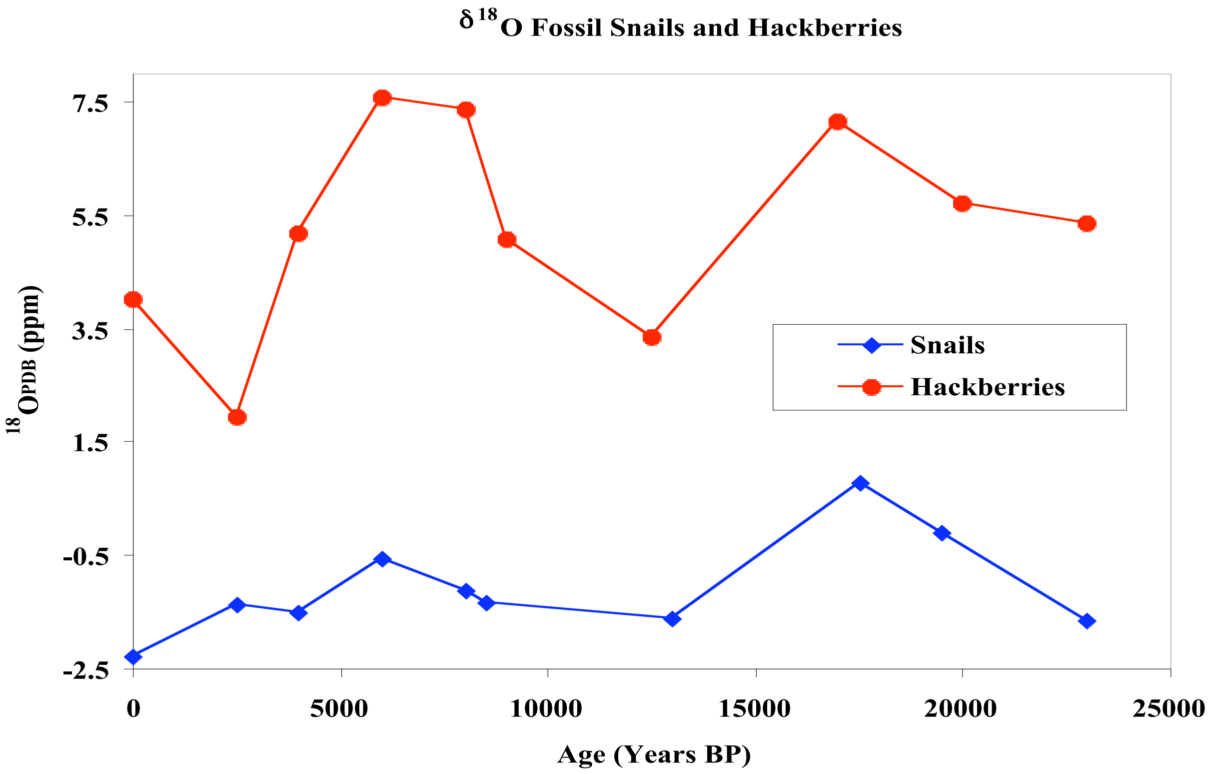

Figure 6. Preliminary oxygen isotopic compositions for fossil carbonate materials from Hall's Cave. Before 4 ka, the snails and hackberry seed oxygen isotope values show similar trends, however, the magnitude of the isotopic shifts is much greater in the hackberry seeds than in the land snails (*Rabdotus dealbatus*).

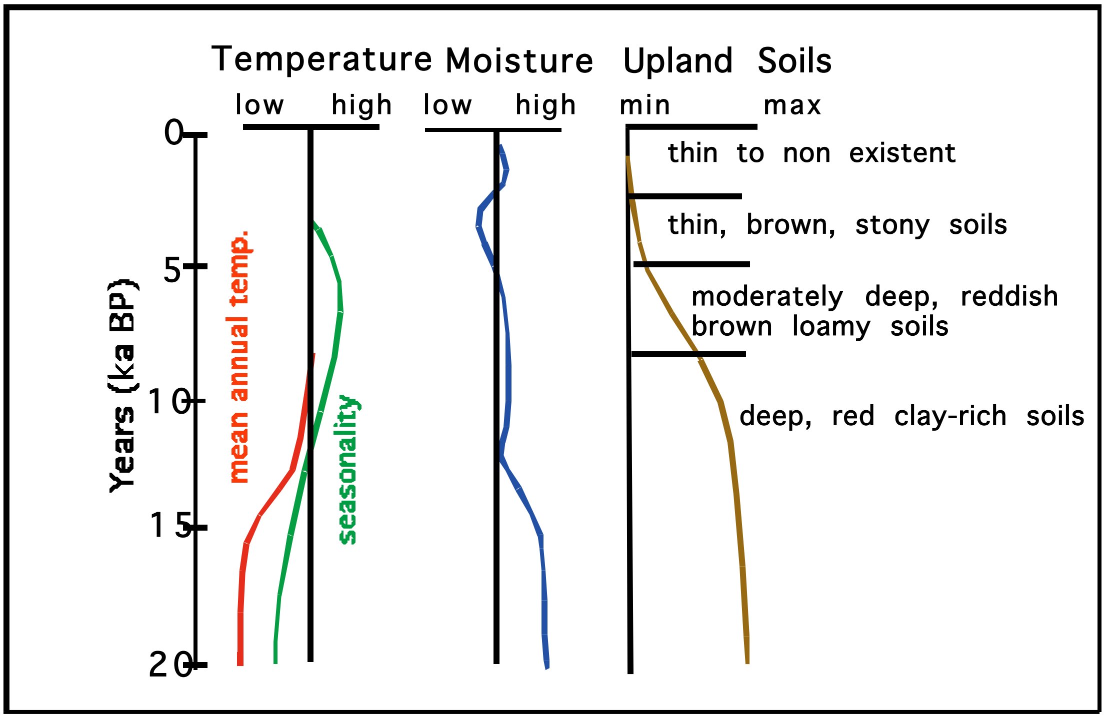

Figure 7. Summary of Late Quaternary climate and environmental changes from Toomey et al. (1993). Proxies used to reconstruct this history of environmental change include vertebrate paleontology, palynology, cave sedimentology, fluvial geomorphology, and climate models. Notice the rapid decrease in the thickness of upland soils about 8 ka coincident with an increase in seasonality and mean annual temperatures but following a peak in aridity at about 12 ka.

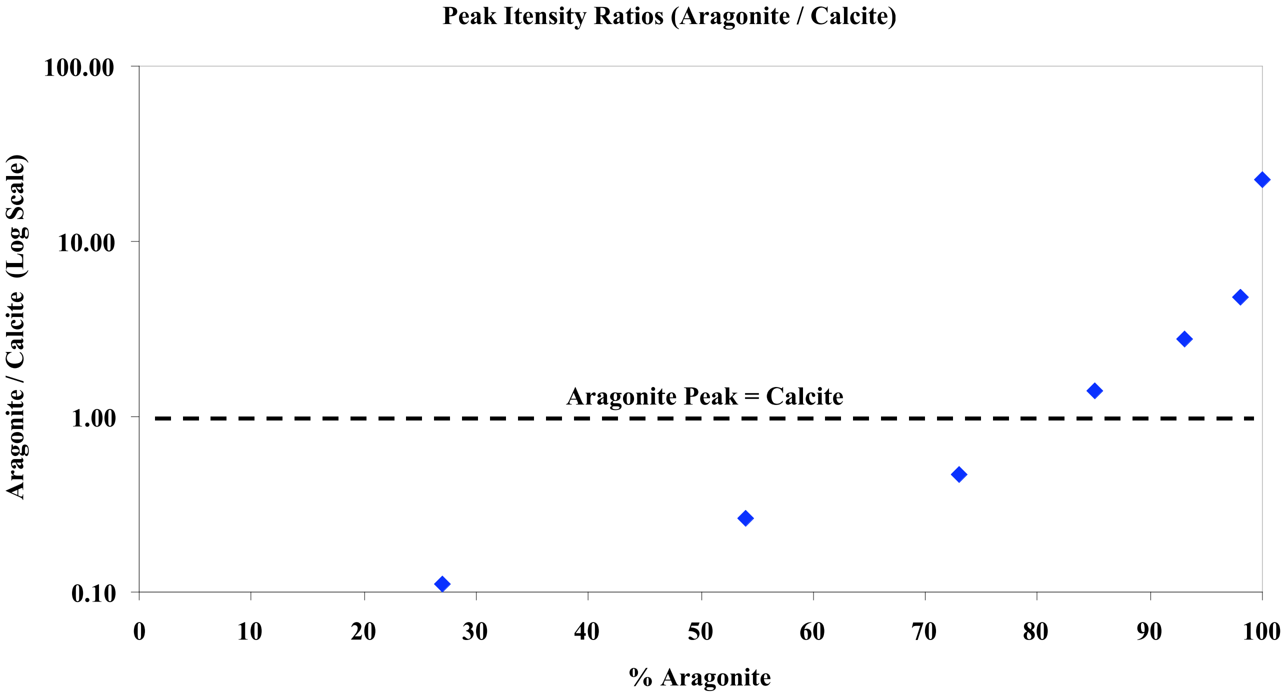

Figure 8. X-ray diffraction results from mixtures of powdered mollusk shell calcite and coral aragonite. Data points reflect the average of three x-ray diffraction analysis for each mixture. Results show the ratio of the aragonite to calcite peak intensity is related to the amount of aragonite. Note that for the aragonite peak to be larger than the calcite peak, the mixture must contain more than 75% aragonite. A similar trend is also observed in peak areas. This suggests that XRD analysis of samples will be useful to determine semi-quantitatively the extent of digenetic alteration of the hackberry seed aragonite.

Analysis	**Instument**	**Material**	**Number**
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Fossil Hackberry Seeds	35
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Fossil Voles (grazers)	20
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Fossil Squirrels (arboreal feeders)	8
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Modern Herbivores	6
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Modern Soil Leachates	10
$^{87}Sr/^{86}Sr$	TIMS, UT Austin	Modern Leaves	15
SUBTOTAL			**94**
$\delta^{13}C$ and $\delta^{18}O$	Stable MS, UT Austin	Fossil Hackberry Seeds	35
$\delta^{13}C$ and $\delta^{18}O$	Stable MS, UT Austin	Fossil Snails	35
$\delta^{13}C$	MSI, UT Port Aransas	Cave Sediment Organic Matter	15
$\delta^{13}C$	MSI, UT Port Aransas	Bone Organic Matter	15
SUBTOTAL			**100**
Elemental Concentrations	ICPMS, UT Austin	Fossil Hackberry Seeds	35
Elemental Concentrations	ICPMS, UT Austin	Fossil Voles (grazers)	20
Elemental Concentrations	ICPMS, UT Austin	Fossil Squirrels (arboreal feeders)	8
Elemental Concentrations	ICPMS, UT Austin	Modern Herbivores	6
Elemental Concentrations	ICPMS, UT Austin	Modern Soil Leachates	10
Elemental Concentrations	ICPMS, UT Austin	Modern Leaves	15
SUBTOTAL			**94**
X-ray Diffraction	XRD, UT Austin	Fossil Hackberry Seeds	35
X-ray Diffraction	XRD, UT Austin	Cave Sediment	20
X-ray Diffraction	XRD, UT Austin	Modern Soils	10
SUBTOTAL			**65**
TOTAL ANALYSIS			**353**

Table 1. Proposed isotopic, elemental, and mineralogical analysis. Fossil samples are from the Hall's Cave deposit and are cataloged at the University of Texas Vertebrate Paleontology Laboratory. Modern soil, animal, and vegetation samples will be taken from Kerr Wildlife Management Area and the vicinity of Hall's Cave in Kerr County, Texas.