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$K^{40}/Ar^{40}$ AGE DATING ON GLAUCONITES AND PALEONTOLOGIC INTERPRETATION NEAR THE CRETACEOUS-TERTIARY TRANSITION IN TEXAS

by

LAURA M. GAMMILL

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APPROVED, THESIS COMMITTEE:

[Signatures and names]

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ABSTRACT

Several exposures of the Cretaceous-Tertiary contact in Texas were searched for material suitable for radiometric age dating. Glauconites from Littig Pit, Travis County, Texas were sufficient in quality and quantity. $K^{40}/Ar^{40}$ dating on glauconites from Littig Pit indicates that 4 to 6 Ma of lowermost Tertiary section are missing. At least one nannofossil zone and at least two foraminiferal zones missing from the lowermost Tertiary limit the unconformity to 2.5 to 5 Ma. The concordant radiometric and paleontologic dates refute the view of Odin that all low potassium glauconites are suspect. The uppermost Cretaceous represents an undetermined amount of time.

It is possible that the Midway Group was deposited rapidly during the last major Paleocene transgression of Vail et al. (1977). The data supports the conclusion of Berggren and Aubert (1975) that the Midway fauna are correlatable worldwide. The iridium layer of Alvarez et al. (1982) is missing at the Littig Pit, confirming missing section and illustrating how this iridium layer may be used as a worldwide time marker.
ACKNOWLEDGEMENTS

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
</tbody>
</table>

I. INTRODUCTION 1

II. PREVIOUS WORK 5
   CRETACEOUS-TERTIARY TRANSITION WORLDWIDE 5
   CRETACEOUS-TERTIARY TRANSITION IN TEXAS 9
   GLAUCONITES 10
     Suitability for Dating 10
     Previous Application 11
     Possible Error Sources 13
   IRIDIUM ANOMALY 15

III. REGIONAL GEOLOGY 19

IV. STRATIGRAPHY 21

V. SAMPLE COLLECTION 24
   LITTIG PIT 24
     Sampling 24
     Availability of Datable Minerals 25
     Condition of Fossils 27
   BRAZOS RIVER 28
     Sampling 28
     Availability of Datable Minerals 29
   GUADALUPE RIVER 30

VI. RADIOMETRIC DATING 31
   SAMPLE PREPARATION 31
   POTASSIUM ANALYSIS 32
   ARGON ANALYSIS 33
   AGE CALCULATIONS 35
   DISCUSSION OF RESULTS 36

VII. SEDIMENTOLOGY 40
   INTRODUCTION 40
   SAMPLE PREPARATION 42
   SETTLING TUBE AND MICROSCOPE 44
   CONCLUSIONS 56
<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Map View of Texas Showing Outcrop Localities.</td>
<td>3</td>
</tr>
<tr>
<td>2) Map View of Littig Pit Showing Locations of Sampling Stations.</td>
<td>26</td>
</tr>
<tr>
<td>3) Grain Size Curve for Glauconite Study.</td>
<td>45</td>
</tr>
<tr>
<td>4) Grain Size Curve for Littig Member.</td>
<td>51</td>
</tr>
<tr>
<td>5) Grain Size Curve for Sand Sorting Study.</td>
<td>52</td>
</tr>
<tr>
<td>6) Grain Size Curve for Kemp Clay Formation.</td>
<td>55</td>
</tr>
<tr>
<td>7) Distribution of Foraminifera and Calcareous Nannofossils at Littig Pit.</td>
<td>60</td>
</tr>
<tr>
<td>8) Estimated Water Depth of Sample Deposition.</td>
<td>63</td>
</tr>
<tr>
<td>9) Relative Sea Level Curve for Paleocene and Early Eocene.</td>
<td>69</td>
</tr>
<tr>
<td>10) Tertiary Age Ranges.</td>
<td>73</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Iridium Determinations at Littig Pit.</td>
<td>18</td>
</tr>
<tr>
<td>II. Results of Potassium-40/Argon-40 Analyses of Glauconites from Littig Pit.</td>
<td>34</td>
</tr>
<tr>
<td>III. Potassium-40/Argon-40 Age Determinations on Glauconites from Littig Pit.</td>
<td>38</td>
</tr>
<tr>
<td>IV. Grain Counts on Glauconite.</td>
<td>47</td>
</tr>
<tr>
<td>V. Microscopic Sample Descriptions.</td>
<td>53</td>
</tr>
</tbody>
</table>
L Introduction

The Cretaceous-Tertiary (K-T) transition is a major period boundary typically marked by a reduction in diversity or extinction of marine vertebrates, calcareous nannoplankton, and foraminifera. The Late Cretaceous was a time of geologic activity as well as biologic upheaval. On a global scale, the final major regression of the seas from the continents occurred at this time. Volcanic activity in the Gulf Coast was prolific during the Late Cretaceous and resumed by the Late Oligocene (Hunter and Davies, 1981). The Laramide orogeny in the western United States had a large influence on sedimentation during the Tertiary. Thus, the K-T boundary marks a time of varied natural phenomena. This important contact is represented in Texas by a limited number of exposures, the stratigraphic completeness and location of which are in dispute despite much detailed paleontologic study.

Mesozoic aged strata in the Gulf Coast have long been proved to be consistent hydrocarbon reservoirs. In particular, the Late Cretaceous Taylor and early Cenozoic Midway and Wilcox formations have been extensively studied. Nevertheless, a clear three-dimensional understanding of sediment distribution has yet to be resolved. The rapid sedimentation rate in the Gulf Coast Geosyncline, coupled with numerous eustatic fluctuations, present difficulties in sedimentologic interpretation. The Cretaceous-Tertiary contact occurs within a mixed interval of taxa located in a rather undistinguished sequence of transgressive sands and clays. Geochemical resolution of the boundary may be useful, as the boundary is lithologically and paleontologically indistinct.

Radiometric age dating which is directly correlated to biostratigraphy is lacking to support any of the several proposed paleontologic correlations for
the boundary. Baldwin and Adams (1971) derived potassium-40/argon-40 Upper Cretaceous ages for igneous rocks cutting Taylor age strata along the Balcones Fault trend of Texas. Rubidium–strontium work on Paleozoic glauconites by Morton and Long (1980) also included a Cretaceous glauconite from the Llano region. Ghosh (1972) utilized bentonites and glauconites for potassium-40/argon-40 age dating of Alabama-Mississippi-Texas Cretaceous and Tertiary formations. This work was later verified by Beck (1981). Ghosh and Beck demonstrated the applicability of potassium/argon dating to Tertiary sedimentary sections. Beck achieved viable dates from low potassium glauconites for Eocene samples in Texas. Ghosh made numerous suggestions for the improvement of the geologic time scale, including work on the K-T boundary at Littig Pit. Obradovich (1964) also dated glauconites from Littig, obtaining several viable age dates. The locations of exposures studied in this thesis are shown on Figure 1.

The purpose of this thesis is to obtain a meaningful relative age date for the K-T boundary, utilizing the potassium/argon method on glauconites. Correlation of the boundary, as defined by radiometric analysis, with the rapid faunal decline noted in this section would support the idea of a catastrophic Late Cretaceous extinction event. Numerous extinction mechanisms leading to this biological crisis have been proposed (Russell, 1982), including the controversial asteroid impact theory (Alvarez et al., 1980, Alvarez et al., 1982, Rampino and Reynolds, 1983).

Several workers have noted the apparently concomitant deposition of an iridium and platinum metal enriched clay layer with the K-T transition. Alvarez et al. (1982) cite these phenomena as evidence for a major asteroid impact at the close of the Cretaceous. They propose that the impact led
Figure 1. Map View of Texas Showing Outcrop Localities.
indirectly to the observed extinctions through the creation of a worldwide sunlight-blocking dust cloud thrown up from the point of asteroid impact. They suggest that this dust cloud obscured sunlight for a sufficient period of time to disrupt the food chain and cause the observed species extinctions. The acceptance of theories involving extraterrestrial impacting bodies as causal agents for major extinctions is considered by some to be a return to the ideas of catastrophism in evolution proposed by Cuvier and D'Orbigny in the early nineteenth century. In light of these hypotheses, there is new interest among geoscientists to re-examine the K-T transition.

At least three geochemical iridium anomalies have been measured and reported very near the K-T boundary at one site—the Brazos River in Texas (Asaro et al., 1982, Ganapathy, 1981). Recent re-evaluation of the data suggests that these anomalies are more accurately the overall enrichment of a single stratigraphic unit rather than separate peaks (Hansen, personal communication). Whatever the interpretation given to the iridium layer, it may nevertheless be a useful time marker. If the iridium-enriched clay layer can be demonstrated to be unique, continuous, and synchronous with the K-T boundary, it will serve as a distinct stratigraphic marker horizon. Radiometric age dates derived from associated mineral layers will be independent marker horizons for the correlation of Gulf Coast stratigraphy.
Previous Work

Cretaceous-Tertiary Transition Worldwide

The Earth has experienced five periods of major extinctions in geologic history. The Cretaceous-Tertiary contact marks one such event which is correlatable worldwide. The boundary is unconformable in many exposures, resulting in some controversy for the precise placement of the contact. Intercontinental correlations of Cretaceous and Tertiary strata based solely on sedimentology are complicated by locally variant lithologies and structural histories.

Perhaps the most useful tool for intercontinental correlation of these strata is the judicious application of magnetostratigraphy. Early studies of the paleomagnetic polarity of these sequences indicated that the period of extinction tends to coincide with a time of reverse magnetic polarity (Alvarez et al., 1982). Nevertheless, numerous exceptions have been reported. Payne et al. (1983) note that the palynological K-T boundary occurs within a normal polarity zone and suggest that extinctions were not synchronous worldwide. However, Shoemaker (personal communication) refutes these findings. His re-analysis of these samples indicates that the normal polarity is an overprint on a true reversed primary polarity. Morner (1982) reviewed the literature, which included various attempts to correlate the biostratigraphy of terrestrial and marine sections with the corresponding measured magnetic polarities. He concluded that the K-T boundary corresponds with neither a geomagnetic reversal nor the famed extinction of the dinosaurs. Morner did find a correspondence between the biostratigraphic boundary and the iridium anomaly. It appears that, despite the promise of the usefulness of magnetostratigraphy for intercontinental correlation, there remains a real difficulty in applying the
data to paleontologic findings. Various workers place the biostratigraphic boundary, even at the same outcrop, in differing positions. This practice leads to ambiguity in interpretation of the paleomagnetic data. Officer and Drake (1983) also reviewed the literature, concluding that the Cretaceous-Tertiary boundary should not be considered to be one worldwide catastrophic event. They suggest that the boundary is better characterized as a transition—a variety of events occurring over a range of time and places.

Paleontologic work on the K-T transition has been widespread and detailed. Work has concentrated on identifying and attempting to explain events at the K-T contact. Efforts to explain the seeming worldwide extinction of fauna have led to numerous extinction hypotheses. These proposals include both gradual and rapid changes in climatic, atmospheric, or oceanographic conditions. Archibald and Clemens (1982) discussed their view that Cretaceous-Tertiary boundary events were the result of gradual processes. Still other investigators cite sound evidence supporting a rapid, catastrophic event (Bramlette and Martini, 1964; Bramlette, 1965; Hsu, 1980; Smit and Hertogen, 1980). The variety of extinction theories can be placed in six interrelated categories: (1) natural cycle, (2) Arctic spillover, (3) sea level fluctuations, (4) volcanoes, (5) magnetic reversal, and (6) extraterrestrial bodies.

Raup (1982) suggests that the effected species simply declined as a result of their natural evolutionary scheme. Gartner and McGuirk (1979) invoke an influx of fresh water from the Arctic Ocean into the world's oceans following the continental rifting of Greenland and Norway. According to their scenario, the influx of cold fresh water resulted in a massive phytoplankton kill and oxygen deficiency at oceanic depths, which disrupted the food chain.
A decrease in rainfall is thought to have occurred as well, which led to the decline of land animals. Sea level fluctuations could also have caused a collapse in the food chain as the number of environmental niches were limited, migratory pathways were disrupted, and the amount of erosion decreased, bringing fewer nutrients into the oceans.

McLean (1982) proposes that increased volcanic activity at the end of the Cretaceous resulted in massive amounts of volcanic dust. He theorizes that this atmospheric dust blocked the sun, lowering world temperatures. Excess carbon dioxide released into ocean waters lowered the water pH, drastically altering ocean water chemistry and causing faunal decline. Calamity is also suggested to have resulted from a magnetic reversal. According to this theory, a change in the Earth's polarity resulted in a disruption of the atmosphere, allowing an influx of harmful ultraviolet radiation which precipitated a variety of events harmful to life.

The extraterrestrial impact hypothesis has recently received wide attention. Hsu (1980) proposed that a large comet struck in the ocean at the end of the Cretaceous, releasing cyanide gas into the world's oceans. This gas produced a rise in the carbonate compensation depth, limiting the range of fauna with carbonate tests and disrupting the food chain. Other investigators call for the impact of a supernova (Russell, 1982). Alvarez et al. (1980, 1981) and Ganapathy (1981) cite geochemical evidence supporting the theory that the impact of an asteroid resulted in widespread extinctions at the close of the Cretaceous. This impact supposedly injected huge amounts of sunlight-blocking dust into the atmosphere, suppressing photosynthesis, heating the Earth, and also resulting in a disastrous acid rain. Several recent
conferences held to discuss these various extinction hypotheses have reached no consensus.

A great deal of work has been done to correlate specific Cretaceous-Tertiary microfossil assemblages intercontinentally. Bolli (1957, 1966) devised standard fossil zonation schemes for Paleocene planktonic foraminifera which were slightly revised by Stainforth et al. (1975). Hay and Mohler (1967, 1969) devised standard zonations for Cenozoic calcareous nannoplankton which have worldwide applicability. Martini (1970, 1971) proposed a similar scheme for a global standard nannoplankton zonation.

Paleocene and Lower Eocene planktonic foraminifera were correlated from the Atlantic and Gulf Coastal Plains by Loeblich and Tappan (1956). Berggren and Aubert (1975) produced a very thorough study of the worldwide distribution of Paleocene benthonic foraminifera. Their report included discussions of "Midway-type fauna", including the formations exposed at Littig Pit. Berggren and Aubert detailed evidence that this assemblage was globally distributed during the Paleocene. Hay et al. (1967) attempted to correlate calcareous nannoplankton of the Gulf Coast and Europe.

Attempts to define an absolute age date for the K-T boundary date from the early work of Holmes who published the first numerical time scales. Various authors have placed the contact somewhere in the interval from a maximum of 75 Ma to a minimum of 63 Ma ago (VanHinte, 1978). The various ages suggested for inclusion into the standard geologic time scale are highly suspect on the material age dated, the method used for age dating, and interpretation of the investigator. Dating schemes include radiometric, geomagnetic, and biostratigraphic time scale correlations. Numerous difficulties hamper intercontinental correlation of age date results. Lanphere
and Jones (1978) reviewed the data available for North America and concluded that the best age of the K-T boundary in North America is 65 to 66 Ma. Owens and Sohl (1973) postulate an age range of 59.1 to 63.2 Ma for the K-T contact of the New Jersey Coastal Plain. Odin et al. (1978) adopted an age of 65 ± 1 Ma for this contact.

**Cretaceous-Tertiary Transition in Texas**

The K-T contact has been a favorite subject for geological fieldtrips in Texas. The sedimentology and paleontology of these strata has been described by Smith (1959, 1962), Folk et al. (1961), and in a series of recent articles (Maddocks, 1982). Hunter and Davies (1981) and Ewing and Caron (1982) studied the distribution of volcanic sediments in Texas and the Gulf Coast during the Late Cretaceous and Tertiary. Rainwater (1960, 1964, 1967) presents a lucid account of the regional sedimentary history across the K-T boundary. Recent sedimentologic studies of the K-T boundary in Texas include the works of Pessagno (1969), Hansen (1982a), Kocurek (1983), Butler (1982), and Stanton (1982).

Paleontologic study of the K-T boundary was largely influenced by the early foraminiferan descriptions in the Midway Formation by Plummer (1926). More recently, Gartner (1965, 1968) studied the biostratigraphy of calcareous nanofossils in Upper Cretaceous deposits of Texas. Jiang (1980, 1983) has completed a detailed study of nanofossils at the Littig Pit and Brazos River localities. Cate (1983) and Maddocks (1983) continue their work with ostracods at these localities while Hansen (1982a, 1982b, 1983) is currently studying the macrofossils. Ganapathy et al. (1981) and Asaro et al. (1982, 1983) have published their results of geochemical profiling at the Brazos River. The
geochemical profile across the K-T contact at Littig Pit has been measured by Asaro et al. This study is unpublished to date.

Radiometric age dating utilizing glauconites in Texas includes the work of Beck (1981), who obtained reproducible and accurate age dates from low potassium Tertiary glauconites. Obradovich (1964) and Ghosh (1982) derived K^40/Ar^40 age dates for samples from the K-T contact at Littig Pit. Obradovich obtained ages of 58 and 59 Ma for the glauconites nearest the contact while Ghosh derived an age of 59 Ma. However, these dates were not directly correlated to the biostratigraphy of the section.

**Glauconites**

Suitability for Dating

The geologic time scale is largely based on stratigraphic correlation of sedimentary sequences. In order to establish absolute age dates for points on the time scale, it is necessary to date the time of sedimentation. However, most sediments are detrital and cannot be dated directly. Therefore, it is essential to date materials which formed in place at, or very near, the time of deposition. Several authigenic minerals exist which might be useful for radiometric age dating. However, most are either easily recrystallized, too scarce, or too low in a suitable parent nuclide to be routinely used for dating.

Glauconites, on the other hand, are common throughout the sedimentary column. They are relatively high in potassium, making K^40/Ar^40 dating feasible. Glauconites are frequently associated with marine fauna with which radiometric data can be correlated. The mineral is fragile and unlikely to be transported far from its place of origin. Therefore, glauconite is seldom detrital and radiometric dates derived from this mineral can be considered a reflection of the time of deposition. However, it is important to study the
depositional history of a sample in order to make a meaningful interpretation of the radiometric data.

**Previous Application**

Glauconites have been utilized for radiometric age dating for samples ranging from Cambrian to Pliocene in age. Herzog et al. (1958) were among the first investigators to attempt to radiometrically date glauconite. Their Rb/Sr analyses of a wide range of samples indicated that glauconite was a potentially useful mineral for age dating. Burst (1958) concluded that glauconite could be used for both radiometric correlation and environmental interpretation.

Hurley et al. (1960) also evaluated the use of K/Ar and Rb/Sr age dating methods for glauconite and stated that glauconites yielded consistently low ages. However, this work has been sharply criticized due to the small number of samples evaluated and the poor laboratory techniques employed (Ghosh, 1972). Another paper published the following year, Everden et al. (1961), concluded that K/Ar dating of glauconite and illite produce viable results. Their dates were checked by K/Ar dating of associated volcanic material. K/Ar dates from volcanic material are widely considered to be accurate. Everden et al. (1960) stressed the importance of careful sample selection, an understanding of the pertinent geologic history, and proper laboratory techniques to derive an accurate radiometric age date.

Hower (1961) studied the structure and composition of glauconite and felt that these characteristics altered with increasing geologic age. He attributes the trend of seeming decrease in apparent age for increasingly older samples to an uptake of potassium with age. However, Ghosh (1972) argues that this trend is due to the nature of the original formation of the mineral,
not subsequent alterations. Ghosh found that there was indeed a correlation between mineralogic perfection and higher potassium contents. However, he felt that the structure of the mineral was more closely related to the lithology in which it occurred rather than the length of time which had passed since the mineral's formation. Hower (1961) pointed out that glauconites which are associated with argillaceous rocks tend to have a structure low in potassium. Since most of the glauconites dated in the Tertiary occur in argillaceous rocks, it follows that Tertiary samples are not anomalously high in potassium and yield acceptable dates (Ghosh, 1972).

Owens and Sohl (1973) obtained consistent results with the K/Ar method on Upper Cretaceous-lower Tertiary glauconites of the New Jersey-Maryland Coastal Plain. They tested their results with corresponding paleontologic age dates. In this study, glauconite ages were consistent along strike and tended to become younger moving upward in the stratigraphic section. Owens and Sohl (1973) proposed an age for the K-T boundary of 59.1 to 63.2 Ma. They avoided dating glauconite that might have undergone deep burial. The increase in temperature and pressure due to deep burial has been suggested to result in a loss of argon and a decrease in the apparent age of the sample. Owens and Sohl used samples which had been buried at less than 300 feet. Odin et al. (1977) suggested that argon loss does not occur before the sample reaches a depth of 6000 feet or a temperature of 320°C. It seems likely that glauconite samples collected from surface exposures in the tectonically quiescent Gulf Coast should not be affected by argon loss due to deep burial.

Odin et al. (1978a) utilized glauconite from northwestern Europe to study the Paleogene time scale. They carefully studied the accuracy of glauconite dates by correlating these dates with radiometric dates from
stratigraphically equivalent volcanic samples. Odin et al. (1978a) concluded that no systematic difference existed between ages derived from the glauconites and the volcanic materials. Furthermore, they stated that the glauconites did not systematically yield dates either younger or older than other radiometric clocks. Odin et al. (1977) obtained dates consistent with other samples using glauconites containing as little as 4.08 percent potassium. This work refutes Odin's stand that glauconites containing less than seven percent $K_2O$ ($=5.8$ percent K) are unsuitable for dating.

**Possible Error Sources**

Several hypotheses have been suggested to explain the apparent tendency of glauconites to yield anomalously low ages, especially with increasing depth in the stratigraphic column. Hurley et al. (1960) proposed a late diagenetic gain in potassium following deposition. Ghosh (1972) criticized this hypothesis as being based on very few samples and a bias in the repeated analysis of samples from only a few localities. Furthermore, Ghosh notes an apparent relationship between potassium content of the glauconite and the lithology in which the glauconite is found. Glauconites from massive and dense rocks are more susceptible to argon loss than glauconites from less compact rocks due to a decrease in interstitial water pressure. Since most Tertiary glauconites occur in argillaceous rocks (Hower, 1961), these glauconites are less likely to lose argon than older glauconites, which occur mostly in dense carbonates. Thus, isotopic dates from Tertiary glauconites often show close agreement with isotopic dates from stratigraphically equivalent volcanic material. On the other hand, radiometric dates from glauconites stratigraphically older than the Upper Cretaceous show an increasing tendency to be anomalously young with increasing depth in the section.
Everden et al. (1961) suggested that low ages resulted from argon loss upon heating due to deep burial or other thermal event. The sediments of the Late Cretaceous and Tertiary Gulf Coast were not subjected to a great overburden or high heat flow in areas at a distance from Late-Cretaceous igneous activity. Ghosh (1972) concluded that a major reason for the low ages achieved from glauconites reported in the literature was simply due to the large number of samples taken from deep cores. The deep core samples were subject to the effects of high pressure and temperature, making them susceptible to argon loss.

The heterogeneity (mixed mineral composition) of glauconite pellets has been cited as a cause of anomalously young dates (Owens and Sohl, 1973). Beck (1982) demonstrated that, for pellets composed of chlorite and glauconite, accurate age dates can indeed be obtained. In this case, the chlorite does not alter the date since it contains no potassium but acts only as an inconsequential diluent. Butler (1983) examined the mineralogy across the K-T boundary at Littig Pit using x-ray diffraction. Butler reported that no chlorite was found in the interval from one meter below to three meters above the contact. Thus, the samples collected for radiometric dating in this thesis contain no chlorite which would increase the relative error for the date.

Weathering of glauconites has been widely assumed to result in a preferential leaching of argon. Obradovich (1964) and Ghosh (1972) tested this hypothesis by dating pellets which had been ultrasonically cleaned of increasing amounts of their outer material. They concluded independently that no appreciable age differences existed in dating complete or reduced samples. Therefore, weathering does not in itself result in a lowering of isotopic ages for glauconites. However, they note that it is of utmost
importance to thoroughly clean the samples of contaminating detrital material. The detrital material certainly effects the resultant age (Ghosh, 1972).

Lastly, the radiometric dates obtained may appear to be anomalous to the investigator if the exact position or biostratigraphic age of the sample is not known. Incorrect assumptions regarding the expected age for the sample or an erroneous understanding of the geologic history will certainly bias the interpretation of age results. The possibility of reworking of the glauconites should be carefully investigated.

**Iridium Anomaly**

Numerous investigators have recently re-examined the K-T transition as it is exposed worldwide. This renewed interest is a result of the suggestion by Alvarez et al. (1982) that a major asteroid impact led to the extinction or marked decline of biota at the close of the Cretaceous. Evidence for this catastrophic event is the apparently concomitant deposition of an iridium and platinum metal enriched clay layer with the K-T transition. Noble metals which typically show only slight terrestrial abundances are enriched in this clay by factors of five to one hundred over normal abundances. The measured amounts of these elements are suggestive of cosmic abundances. Therefore, these anomalies are interpreted to be indicative of asteroid debris (Ganapathy, 1980; Smit and Hertogen, 1980; Alvarez et al., 1982) or cometary debris (Hsu, 1980; Kyte et al., 1980). These geochemical anomalies have been noted in close association with the K-T transition at some fifty sites worldwide (Asaro et al., 1983). Iridium anomalies have also been found in association with the Eocene-Oligocene boundary (Alvarez et al., 1982). In this case, the anomaly is also directly associated with a microtektite strewnfield, strengthening the meteorite-impact hypothesis (Glass, 1983). These anomalies do not occur
randomly throughout the stratigraphic column and have been found in both terrestrial and marine sediments. Whatever the interpretation presented for the iridium layer, it is clear that the layer may be useful as a chronological marker for regional and intercontinental correlations. Many of the sections in which the iridium anomaly has been located have already been studied in detail. The biostratigraphy for some sections is well known and the marker can be placed with confidence in its proper chronology. In other sections, the iridium marker promises to resolve long standing controversies of correlation.

In the southern United States, an iridium abundance anomaly was first noted by Orth et al. (1981) in the Raton Basin of northeastern New Mexico. This iridium peak occurs within terrestrial sediments at the point of a marked extinction of several species of Late Cretaceous-age pollen. Two separate investigators have located iridium anomalies at the Brazos River (Eloise) locality in Texas. Ganapathy et al. (1981) reported a fifty-fold increase in iridium within marine sediments precisely at the suggested K-T contact. Their measurements were derived from samples collected in ten centimeter increments from an interval forty centimeters above to sixty centimeters below the biostratigraphic boundary. They report a high of 2.1 ppb of iridium at the contact. (Normal crustal abundance for iridium is 0.05-0.1 ppb.) Asaro et al. (1982, 1983) also noted geochemical anomalies associated with the contact at the Brazos River. They sampled the same section in one centimeter increments and found a maximum of 4.3 ppb of iridium within ten centimeters of the biostratigraphic boundary. Furthermore, Asaro et al. (1982, 1983) noted that ninety-seven percent of the iridium measured occurred in the immediate vicinity of the K-T boundary.
The Littig Pit has been sampled only recently. The section here is commonly considered to be unconformable at the K-T contact. The stratigraphy of the Littig Section is very similar to that found at the Brazos River. Therefore, missing section at Littig Pit should be reflected in a missing iridium enrichment. Recent work at the University of California at Berkeley shows that the iridium layer is indeed missing (Table I). These findings support the assumption that section is missing from the lowermost Tertiary at Littig Pit. Moreover, this work illustrates how the K-T iridium anomaly may be used as a chronologic marker.
TABLE I

IRIDIUM DETERMINATIONS AT LITTIG PIT

(Asaro, personal communication)

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<thead>
<tr>
<th>Stratigraphic Unit</th>
<th>Centimeters from erosional K-T contact</th>
<th>Iridium in $10^{-9}$ gm/gm (parts per billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pisgah Member</td>
<td>120-130</td>
<td>&lt;0.24</td>
</tr>
<tr>
<td>Littig Member</td>
<td>60-70</td>
<td>&lt;0.22</td>
</tr>
<tr>
<td>Littig Member</td>
<td>20-30</td>
<td>&lt;0.26</td>
</tr>
<tr>
<td>Littig Member</td>
<td>10-20</td>
<td>&lt;0.16</td>
</tr>
<tr>
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<td>&lt;0.20</td>
</tr>
<tr>
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<td>&lt;0.18</td>
</tr>
<tr>
<td>Kemp Formation</td>
<td>10-20</td>
<td>&lt;0.20</td>
</tr>
<tr>
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<td>&lt;0.33</td>
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<tr>
<td>Kemp Formation</td>
<td>90-100</td>
<td>&lt;0.22</td>
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</table>

NOTES: Samples collected by T. Hansen, U. of Texas at Austin, and analyzed by neutron activation by F. Asaro, U. of California at Berkeley. All values calculated to the 95% confidence level (2 sigma).

Stratigraphic units above the K-T Contact are part of the Midway Group and those below the Contact are part of the Navarro Group.
III. Regional Geology

The sample locations lie within the Gulf Coast Geosyncline, which has been a basin of deposition since Triassic time. Marked transgression along with basin subsidence created extensive shallow seas during the Lower Cretaceous, resulting in a thick carbonate and argillaceous mudstone stratigraphy (Rainwater, 1967). Seas continued expanding through Upper Cretaceous time, apparently placing the outcrop locales in a middle to outer shelf environment (Kocurek, 1983). Sediments of the Upper Cretaceous are typically marl, chalk, and argillaceous mudstone.

The Laramide orogeny at the close of the Upper Cretaceous caused an influx of terrigenous sediments into the northwest Gulf of Mexico during the Cenozoic. Sediments were derived from the Ouachita Mountains to the north and the southern Rocky Mountains to the northwest. Large volumes of Midway silts and clays were derived from recently uplifted Cretaceous marina strata (Rainwater, 1967). Overall deposition in the region thus shifts from Mesozoic marine strata to Cenozoic nonmarine strata.

Sea level dropped relatively quickly at the end of the Cretaceous and continued to fall throughout the Tertiary. Anoxic shales containing abundant glauconites in this section indicate comparatively shallow restricted basins (Cloud, 1955; Smith, 1962). Late Paleocene and Eocene sedimentation was marked by transgressions and regressions of the sea. Cenozoic deposits in Texas are typically deltaic. The shifting nature of deltas over time, coupled with fluctuations in sea level, created complex vertical and lateral facies shifts which hamper regional correlations (Stanton, 1983). Rainwater (1967) stated, moreover, that sea level fluctuations at this time were local phenomena.
and not related on a regional scale. Thus, sedimentologic interpretations based on widely separated outcrops can be only tenuously compared in a regional sense.

Regarding the Mesozoic/Cenozoic boundary, Rainwater (1967) found that sedimentation during this interval in Texas was continuous. He cites no evidence of erosional or paleontological unconformity. However, more detailed work by Stanton (1983) indicates a period of nondeposition across the K-T boundary. Paleontological studies report both conformity (Cate, 1983; Jiang, 1983) and unconformity (Gartner, 1965; Hansen, 1982a, 1982b, 1983) at the boundary. Interpretations are highly dependent on the specific outcrop and faunal assemblage chosen for study.
IV. Stratigraphy

The uppermost Cretaceous stratigraphic unit of South and East-Central Texas is the Kemp Formation of the Navarro Group. This is overlain by the Tertiary Littig and Pisgah Members of the Kinkaid Formation of the Midway Group. Appendix A illustrates this stratigraphic column. The nature of the K-T transition is strongly debated but is commonly labeled a disconformity in the literature. While sedimentary section may or may not be missing at the boundary in South and East-Central Texas, the contact certainly becomes unconformable in East Texas proper (Barnes, 1974d; Flawn, 1979).

The K-T transition has three frequently studied surface exposures in Texas. The Littig Pit, Walker Creek, and Eloise (Brazos River) localities lie on a line paralleling the overall northeast-southwest trend of Gulf Coast sedimentation. The Littig Pit is the most westerly and the Eloise is the most easterly of these sites. Structural complexities are minimal; nearly undeformed beds dip gently four degrees to the southeast.

The uppermost Kemp Formation is exposed at all three localities. The unit is composed of dark grey and yellow-brown, poorly indurated montmorillonitic clay. This faintly laminated clay is interrupted by, and often drapes over fine grained siltstone beds. The well indurated sandy siltstone is commonly massive but may contain clay clasts, burrows on both upper and lower surfaces, and symmetrical oscillation ripples. There is considerable evidence of loading, including flame structures and ball-and-pillow structures. Kocurek and Hansen (1982) felt that the sedimentary structures indicated rapid deposition on a muddy substrate. The siltstone units are interpreted to be deltaic frontal splays deposited on the prodelta during storm events. Kocurek and Hansen (1982) suggest that the Late Cretaceous was a time of deltaic
shifting or retreat during a regional transgression. Sands decrease and glauconite content increases nearing the K-T contact, indicating increasingly sediment-starved reducing conditions as facies shifted seaward (Rainwater, 1964, 1967). Glauconite was deposited within an impinging oxygen minimum zone. By late Navarro time, the three outcrop sites were located 70-100 miles offshore between large, if only roughly located, deltaic depocenters (Kocurek, 1983). The scenario of these investigators is quite viable. However, it is worth noting that the sedimentary structures observed within the siltstones of the Kemp Clay Fm. at Littig are not necessarily confined to the deltaic environment. These hummocky sands may represent lower shoreface deposits. This question is addressed in this thesis (see Sedimentology).

The Littig Member of the Kincaid Formation forms the base of the Tertiary at Littig Pit. The fossiliferous, glauconitic burrowed sand of this unit forms a somewhat prominent ledge in the surrounding glauconitic and bioturbated dark grey claystones. Kocurek and Hansen (1982) interpret the Littig Member to represent a condensed zone formed during a rapid regional transgression. However, evidence presented in this thesis suggests that this unit may be a residual lag deposit (see Sedimentology). The Littig Member is present at Littig Pit and Walker Creek but is apparently not present at Eloise. The complicated structures found at the Eloise site are interpreted by Hansen and Kocurek (1982) as a possible turbidite sequence resulting from a storm surge in this inner to outer shelf environment. The turbidite found here is thought to replace the Littig Member. The lateral extent of this particular turbidite has been traced and it is known to be a local event. However, its existence points to the possibility of other turbidites in the section.
Following deposition of the Littig Member, continued transgression placed all three locales perhaps farther offshore, seaward of now smaller deltas (Kocurek, 1983). Kocurek suggests that the most rapid sedimentation shifts at this time from the Littig Pit to Eloise, thickening the sedimentary section at the Eloise exposure.

The oldest unit exposed in these cuts is the lowermost Paleocene Pisgah Member of the Kinkaid Formation. The Pisgah Member is composed of glauconitic, yellow bioturbated claystone broken by numerous thin, fossiliferous sparsely glauconitic sands. Kocurek (1983) suggests that these sands were deposited during a rapid transgression across the mid to outer continental shelf. The sands were interrupted by clay deposition during more quiescent times. Terrestrial deposition dominates in the overlying Eocene Wilcox Formation. The lack of marine strata indicates that the outcrop belt was located much farther onshore during Eocene time, landward of any deltaic influence (Kocurek, 1983; Rainwater, 1967).
V. Sample Collection

Littig Pit

Sampling

Samples used in this study were taken from the C.I. Payne Brick Company clay quarry located in eastern Travis County, Texas. The quarry is also referred to in the literature as the Elgin-Butler Company clay pit. The quarry lies approximately six miles southwest of the town of Elgin and 1-3/4 miles south of Littig, Texas.

The dimensions of the pit have varied in time as this is an actively mined quarry. Different outcrop surfaces are variously covered or exposed. However, the presently oblong quarry can be described as roughly nine hundred feet in length, three hundred fifty feet in width, and fifty to sixty feet deep at its greatest depth.

Earlier work at this locality includes an unpublished 1950's study by H. G. Stenzel and R. W. Barker, who studied the exposed Littig Member. Jiang (1980) described the numerous calcareous nannofossils and Cate (1982) has studied the ostracods. Macrofauna of the boundary were described by Hansen (1982). Kocurek and Hansen (1982) have combined this paleontological information with the observed sedimentology to propose a sedimentological interpretation for the section. John Butler, of the University of Houston, has studied the minerology, finding no chlorite in the vicinity of the boundary which might be confused with glauconite (Butler, 1983).

Samples were collected in the quarry using the detailed stratigraphic column of Kocurek and Hansen (1982) as a guide. Due to the dissemination of fine-grained glauconite throughout the sediments, it was necessary to collect and clean at least five hundred grams of sediment for each sample. Samples
were collected from each glauconitic stringer in the quarry, with emphasis given to the interval one meter above to one meter below the suggested Kemp/Littig (K-T) contact. The exact location of each sample in the stratigraphic column and within the quarry is given in Appendix A and Figure 2, respectively. The strata are very nearly horizontal, resulting in a "layer-cake" stratigraphy in this exposure. However, the quarry walls were slumped, fresh samples were not easily taken, and key markers were masked. Most of the samples were collected where the K-T transition is exposed on the southern quarry wall (Figure 2). Sample L07 was collected from a clayey bed containing large concretions located 0.3 meters above the proposed K-T contact. Samples L20 and L21, which were also radiometrically age dated, were found within .3 meters of one another within a glauconitic clayey sand 2 meters above the contact. Thus, these three samples were collected from a roughly two meter interval. Given the generally accepted sedimentation rate for the region of 10 centimeters/1,000 years, this interval represents only about 20,000 years. The resolution of radiometric age dating does not approach this degree of detail, making these three samples essentially stratigraphically equivalent.

Availability of Datable Minerals

Despite the frequent mention by numerous investigators of the proliferation of glauconite in this section, close inspection of the outercrop yielded only a limited amount of glauconite. Glauconite was rare or absent from all but the upper 0.5 meter of the Cretaceous and is sparse above the first two meters of the Tertiary. The mineral formed a minor dispersed constituent of the sandy stringers within the Cretaceous. Within the Tertiary section, glauconite was concentrated in very thin, discontinuous layers
Figure 2. Map View of Littig Pit Showing Locations of Sampling Stations.
alternating with layers of phosphate crystals. Samples L20 and L21 were collected from these layered deposits. The quarry was visited several times over the course of this study. Since the quarry is active, later samples were collected from newly cut faces and are likely to be fresher than earlier-collected samples. This is the case of samples L20 and L21, which are stratigraphically equivalent to L07 but were collected four to five feet deeper into the quarry wall. Thus, samples L20 and L21 were less weathered and of better quality than sample L07. A series of samples was collected to answer specific sedimentologic questions concerning the history of these glauconites and environmental interpretation of observed sedimentary structures. This study is discussed in the Sedimentology chapter of this thesis.

A thorough search was made of the entire section to collect samples of bentonite. It was hoped that radiometric analysis of included sanidine and biotite would be useful for verifying the radiometric ages derived from the glauconites. Earlier investigators had reported a bentonitic layer six to ten feet above the K-T contact. Despite trenching efforts at the outcrop and an attempt to elutriate suspected bentonitic clays in the laboratory, no bentonite was found in the sediments at Littig Pit.

Condition of Fossils

Numerous fragile brachiopod and pelecypod fossil casts were observed but not collected throughout the section. Unbroken gastropod molds, shell fragments, and ichthyoliths were common within the Littig Member. This study did not concentrate on the macrofossils in the quarry, but these were studied by Hansen (1982). Hansen noted the sparsity and poor preservation of macrofossils at the Littig, especially above the K-T contact.
Later microscopic examination of the Littig samples collected for this thesis revealed that the calcareous microfossils were also poorly preserved. This poor preservation hampered species identification, especially within the Cretaceous. Planktonic foraminifera were generally better preserved. Many foraminiferal specimens were unbroken and easily separated from their clayey matrix. The condition of microfossils is more fully discussed elsewhere in this thesis (see Paleontology).

**Brazos River (Eloise)**

**Sampling**

The second outcrop of interest to this thesis is exposed where the Brazos River cuts the K-T contact in Milam County, Texas. The sample locality lies about 290 meters downstream of Farm to Market Road 413, on the western riverbank. A well core has been taken of the section another 250 meters downstream and a second outcrop of the boundary is found approximately three-quarters of a mile farther downstream from the core site (Hansen, personal communication). Preliminary study by Hansen indicates that the southern outcrop is the most conformable but contains no glauconite. Therefore, the northern outcrop was sampled.

Previous work on this section includes a study of the calcareous nannofossils by Jiang (1980). Ostracods have been studied by Cate (1982) along with unpublished work on ostracods by Rosalie Maddocks. Hansen (1982) described the macrofauna. Kocurek and Hansen (1982) studied the sedimentology of the section. Asaro et al. (1982) analyzed geochemical anomalies in this outcrop while the mineralogy was studied by Butler (1983).

The outcrop consists mostly of Tertiary shale and siltstone. The glauconitic sandy Littig Member sampled at Littig Pit is apparently
stratigraphically equivalent to a coarse fossiliferous unit sampled at the Brazos River. Kocurek and Hansen (1982) interpret this Brazos River sand and its related strata as a classic Bouma A-D turbidite sequence. The K-T contact is proposed to lie at the base of this turbiditic sand. The basal contact is an highly irregular scoured surface containing rip-up clasts of black claystone. The turbiditic sand drapes over or pinches out over these clasts.

Availability of Datable Minerals

Numerous investigators reported glauconite at the Brazos River locality. The western exposure along the Brazos River was investigated on three separate occasions. The outcrop containing the strata of both Cretaceous and Tertiary age, as well as section above and below the contact, was carefully collected. Only the turbiditic sand collected within less than one foot of the proposed K-T contact appeared to contain glauconite in hand sample. No evidence of bentonite was found.

Hand samples of the turbiditic sand were extremely fossiliferous, containing numerous pelecypod fragments. The dark green sand was coarse grained and highly pyritic. Microscopic examination revealed 25–35% pyrite in addition to shell fragments, calcite, phosphates, and clay but little or no glauconite to allow a determination of age. Earlier investigators concentrated on the paleontology upsection rather than the K-T contact. Apparently, these workers failed to examine this coarse sand microscopically and mistook the abundant pyrite for glauconite in hand sample.

Interestingly, the pyrite was well formed and very fresh. Crystals were bright with no tarnish, and withstood ultrasonic cleaning indicating little to no weathering and a lack of oxidation. The presence of pyrite indicates a low eH, reducing environment. Nevertheless, glauconite did not form in this
setting. The lack of glauconite may be due to the rapid deposition of these sediments or the fragility of the mineral in transport.

**Guadalupe River**

Barnes (1974b,c) and Fisher (1974a,b) indicate that the K-T contact crosses U.S. Interstate Highway 10 (I-10) and the Guadalupe River east of San Antonio, Texas. Sellards (1919) detailed exposures of the Navarro and Midway Formations in nearby Leon, Salado, Dry Santa Rosa, and Rosillo Creeks. Investigation of strata along these creeks failed to reveal any sediments containing glauconite in hand sample. Topographic relief along the interstate highway was not sufficient to produce a viable exposure of the contact.

Numerous samples were collected from Tertiary and Cretaceous age strata in the vicinity of the Nolte Steel Mill. The Nolte Steel Mill is located on the eastern bank of the Guadalupe River approximately one mile north of I-10. Hand sample descriptions of all samples collected are listed in Appendix B. No glauconite was found in microscopic examination of these samples and no bentonitic layer was found in any of the section studied. While the precise location of the K-T contact was not found, it was felt that samples were collected within a few stratigraphic feet of the contact. Further work in this area will probably show that the contact is exposed within the Acme Brick Company quarry on the western bank of the Guadalupe River. This quarry appears to be a large operation, requiring special permission for entry. Given the dip of the sampled strata and the mapping work of earlier workers (Barnes, 1974b, c; Fisher, 1974a, b), it is reasonable to assume that the contact is exposed either within the quarry or on the company property along Young's Creek, a small creek which flows into the Guadalupe River.
VL Radiometric Dating

Sample Preparation

Untreated fresh samples were weighed and one-half of each sample was reserved. Consolidated samples were gently crushed using an iron mortar and pestle. The rust introduced in this fashion did not affect the experiment since the rust is inert and contains no potassium or argon. Loosely consolidated samples were elutriated in 500 milliliter graduated cylinders to remove the finer particles. Sandy samples were elutriated for eighteen hours while clayey samples were washed for forty-eight hours. Microscopic examination after washing showed that the most promising samples contained abundant dark green to black botryoidal glauconite. These pellets were five to ten microns in diameter. Samples also contained abundant clay, quartz, and phosphates in addition to a variety of shallow water marine shells, tests, and their fragments.

Clays adhering to glauconite grains, wedged in crevices of the glauconite, or loose clays were removed by ultrasonic cleaning in water for twelve to fifteen minutes. Fine particulates were decanted at two-minutes intervals during washing time. Samples were then washed ultrasonically in acetone for thirty seconds to remove adsorbed water along with adhering nonpolar particles and, finally, gently dried under heat lamps for ten minutes.

Dried samples were sieved through 38 mesh and 74 mesh polyethylene screens and collecting pans. The fraction coarser than 38 mesh was returned to the sample bags. The +74 mesh fraction was separated on the Frantz Isodynamic Magnetic Separator.

Using the magnetic separator, glauconite was extracted from sample L07 between .45 amperes and .55 amperes with the magnet at 20-30 degrees
forward slope and 15 degrees side slope. Phosphates remaining in the sample were removed at .37 amperes. Samples L20 and L21 required .90 to .93 amperes for glauconite extraction. Phosphates and fossils were removed from L20 and L21 at settings of 1.1 to 1.2 amperes. The greater amperage required to separate L20 and L21 may indicate that these two samples are fresher than L07, having been taken deeper in the outcrop. Later work indicated that L07 was very likely weathered. The nonmagnetic fractions were reserved to study any included microfossils. Microscopic examination of the separate after magnetic separation revealed 80-85 percent glauconite pellets. The remainder included glauconite and shell fragments. An average of one gram of mineral separate for each sample was sent to an independent laboratory for radiometric analysis.

**Potassium Analysis**

Direct flame photometry analysis was carried out in the laboratory of Teledyne Isotopes, Inc. of Westwood, New Jersey. Potassium analysis was performed twice for each sample and the results checked against a lithium internal standard. The internal standard was added to both the unknown and standard solutions so that the intensity of the potassium radiation could be compared to that of the internal standard. The results obtained in the potassium analysis are presented in Table II. The percent of potassium contained in a given sample was calculated according to the following formulas:
1) \[
\frac{\text{Conc.} \times D}{1 \times 10^{-6}} = \text{Amnt. K}
\]

2) \[
\frac{\text{Amnt. K}}{\text{Total Wt.}} = \%K
\]

Where
- Conc. = Concentration measured by flame photometry (gm/ml)
- D = Dilution of sample (micrograms/ml)
- Amnt. K = Absolute amount of K (gm)
- Total Wt. = Total weight of sample (gm)
- \%K = Percent K contained in sample

**Argon Analysis**

The method of isotope dilution was employed to measure the amount of radiogenic argon contained in each glauconite sample at the laboratory of Teledyne Isotopes, Inc. The results of argon analysis using their Nier-type mass spectrometer are shown on Table II.

Two samples at a time were placed in separate molybdenum crucibles within a single glass fusion tower and isolated from the remainder of the system. The two crucibles were sufficiently separated from each other such that heating of one sample using an induction furnace coil did not inadvertently heat the second sample. The uppermost sample was fused and analysed first and the vacuum reattained, followed by fusion and analysis of the lower sample. Care was taken in heating so that excited particles of the upper sample did not fall to and contaminate the lower sample.

A metal pipette was utilized to introduce the Ar-38 tracer spike into the gas to be analysed. The Ar-38 spike is calibrated regularly against the interlaboratory standard Bern 4M muscovite as well as other standards. The muscovite calibration is a mineralogical calibration, not an absolute physical
Table II

Results of Potassium-40/Argon-40 Analyses of Glauconites from Littig Pit

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>K in % (Glauconite Separate)</th>
<th>% Ar-40 Radiogenic</th>
<th>Ar-40 RAD (scc/gmx10^-5)</th>
<th>Age In Megayears</th>
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<tbody>
<tr>
<td>L20</td>
<td>2.32</td>
<td>40.4</td>
<td>.510</td>
<td>57.1 ± 2.9</td>
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<tr>
<td></td>
<td>2.34</td>
<td>30.8</td>
<td>.514</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>54.0</td>
<td>.552</td>
<td></td>
</tr>
<tr>
<td>L21</td>
<td>2.38</td>
<td>52.4</td>
<td>.552</td>
<td>59.1 ± 3.0</td>
</tr>
<tr>
<td></td>
<td>2.38</td>
<td>46.6</td>
<td>.554</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>42.1</td>
<td>.560</td>
<td></td>
</tr>
<tr>
<td>L07</td>
<td>5.13</td>
<td>71.7</td>
<td>1.00</td>
<td>52.3 ± 2.6</td>
</tr>
<tr>
<td></td>
<td>5.14</td>
<td>69.4</td>
<td>1.08</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>74.3</td>
<td>1.10</td>
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</tr>
</tbody>
</table>

Table II. Results are listed in descending stratigraphic order. Ages are calculated using IUGS constants (Steiger and Jaeger, 1977). The overall accuracy of the analytical technique is five percent.
one. The Ar-38 tracer spike is determined to be accurate to better than three percent.

**Age Calculations**

The argon peak heights were used by Teledyne to mathematically determine the quantity of radiogenic argon in the original samples. The ratios of argon-38 spike relative to argon-36 and argon-40 were calculated and corrections were made for the known isotopic composition of any atmospheric argon contamination.

Ages were calculated according to the currently accepted age equation:

$$ t = 1.885 \times 10^9 \log_e \left( 9.068 \frac{40\text{Ar rad}}{40\text{K}} + 1 \right) $$

Where

- $t$ = time since formation before present (yrs.)
- $40\text{Ar}$ = concentration of radiogenic argon (moles)
- $40\text{K}$ = concentration of potassium isotope (moles)

The decay constants and isotopic abundance of potassium-40 recommended by the IUGS Subcommission on Geochronology were used (Steiger and Jaeger, 1977). The applicable constants were:

$$ \lambda_\alpha = 4.96 \times 10^{-10} \text{/year} (40\text{K to } 40\text{Ca}) $$

$$ \lambda_\beta = 0.581 \times 10^{-10} \text{/year} (40\text{K to } 40\text{Ar}) $$

$40\text{K/K total} = 1.167 \times 10^{-4} \text{ atom per atom of natural potassium}$

Isotopic/abundance (atomic %) $\begin{align*}
39\text{K} &= 93.2581 \\
40\text{K} &= 0.01167
\end{align*}$

$40\text{Ar} / 36\text{Ar atmospheric} = 295.5$
Ages were derived using the values of the peak heights, the spike composition, and the atmospheric isotopic composition. From this information and the above values, the ratio of argon-40 to spike argon-38 was calculated by Teledyne. This allowed a determination of the amount of radiogenic argon-40 in the sample and, thus, the age calculation.

Factors effecting the age calculations included the precision with which the isotopic ratios of argon could be measured, the precision of the potassium analyses, and the precision of the $^{38}\text{Ar}$ spike calibration. The percentage of radiogenic $^{40}\text{Ar}$ can have a large effect on the error. Samples with a small amount of radiogenic $^{40}\text{Ar}$ result in a dominance of the $^{40}\text{K}$ term in the age equation and the relative error increases.

Discussion of Results

The results of potassium-40/argon-40 analyses presented on Table II indicate low but reproducible values for the amounts of radiogenic argon-40 and potassium contained in the glauconites from Littig Pit. The apparent ages, including error margins, for all three glauconite samples range from a minimum of 49.7 Ma to a maximum of 62.1 Ma. However, sample L07 yields a date which is eight to eleven percent lower than the ages obtained for samples L20 and L21, respectively. This anomalous date may be the result of detrital contamination due to weathering at the outcrop. As discussed earlier, sample L07 was not collected from a fresh cut at the outcrop, as were samples L20 and L21. Furthermore, the argillaceous material was more difficult to physically separate from the glauconite in sample L07. Even following final cleaning, clay was tightly embedded within the sutures of these glauconite pellets. It is suspected that the age was affected by the difficulty
of magnetically separating and ultrasonically cleaning contaminants from this sample. On the other hand, there is a possibility that the calculated age is accurate but does not date the event desired. It is possible that sample L07 was not originally deposited at this stratigraphic level but was originally formed elsewhere. Subsequent reworking may have redeposited this glauconite at its present higher stratigraphic level. In this case, the radiometric age of sample L07 would be anomalously young. This possibility is examined in the following chapter.

Apparent ages for samples L20 and L21 range from 54.2 Ma to 62.1 Ma. Assuming that the Cretaceous-Tertiary boundary is accurately placed at 64 Ma to 66 Ma, these dates indicate that 4 to 6 Ma are missing from the section at Littig Pit. This work confirms and helps to define the extent of the unconformity at this exposure. An equivalent amount of section is likely to be missing from the stratigraphically similar section at Walker Creek. Paleontologic dating at the Brazos River section will probably show that a shorter period of time is missing from that exposure.

Table III presents a compilation of all radiometric age determinations on glauconites from Littig Pit which are found in the literature. These closely coincident results were determined by three separate investigators (Obradovich, Ghosh, and Gammill) in three different laboratories (Berkeley, Rice, and Teledyne). The concordance of these dates is striking in view of the low percentages of potassium found in these glauconites. The most reliable radiometric ages obtained in this thesis (L20, L21) agreed well with those reported by both Obradovich (1964) and Ghosh (1972). These findings refute the view of Odin (1982), who suggests that dates derived from all low potassium glauconites are suspect.
TABLE III

POTASSIUM-40/ARGON-40 AGE DETERMINATIONS
ON GLAUCONITES FROM LITTIG PIT

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>K IN %</th>
<th>%Ar-40</th>
<th>AGE IN MEGAYEARS</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>KA-1318</td>
<td>4.43</td>
<td>73.6</td>
<td>(59.8)</td>
<td>Obradovich (1964)</td>
</tr>
<tr>
<td>KA-1315</td>
<td>4.54</td>
<td>75.5</td>
<td>(59.8)</td>
<td>Obradovich (1964)</td>
</tr>
<tr>
<td>KA-1315US</td>
<td>5.16</td>
<td>72.6</td>
<td>(58.8)</td>
<td>Obradovich (1964)</td>
</tr>
<tr>
<td>KA-1314</td>
<td>4.19</td>
<td>78.4</td>
<td>(59.2)</td>
<td>Obradovich (1964)</td>
</tr>
<tr>
<td>KA-1314</td>
<td>4.19</td>
<td>76.2</td>
<td>(59.8)</td>
<td>Obradovich (1964)</td>
</tr>
<tr>
<td>E1103</td>
<td>4.23</td>
<td>75.5</td>
<td>58.3 (59.8)</td>
<td>Ghosh (1972)</td>
</tr>
<tr>
<td>L20</td>
<td>2.33</td>
<td>41.5</td>
<td>(57.1)</td>
<td>This work</td>
</tr>
<tr>
<td>L21</td>
<td>2.38</td>
<td>47.0</td>
<td>(59.1)</td>
<td>This work</td>
</tr>
</tbody>
</table>

NOTES:

1. Odin and Worsley in their NDS 55 (Odin (1982), p.712-14) recalculated the analytical data on potassium and radiogenic argon-40 from Obradovich (1964) and Ghosh (1972), using the decay constants and isotopic abundance of potassium-40 recommended by the IUGS Subcommission on Geochronology (Steiger and Jaeger, 1977). Ghosh's original calculation is given with the recalculation in parentheses for comparison. The ages for the present work are also shown in parentheses because the same IUGS constants were used.

2. The small superscript numbers are not considered significant, as our operational precision is generally ± 1 or 2 megayears.
Ghosh (1972) reported dates of 60 and 59.5 Ma for glauconites at the K-T contact in Alabama and Mississippi, respectively. These dates were in close agreement with his dates from the Littig Pit. Ghosh considered the possibility of a marked unconformity at the contact but concluded that the K-T boundary was simply younger in the Gulf Coast than in other areas. He suggested that the Navarro-Midway contact of the Gulf Coast was not exactly correlatable with the European Maestrichian-Danian boundary. The Maestrichian-Danian contact is considered to be 65 Ma (Berggren, 1971). The possibility should be considered that the uppermost Navarro of the Gulf Coast may be partially Danian in age (Ghosh, 1972).

The fact that the iridium layer of Alvarez et al. (1980, 1982) is missing at Littig Pit (Table I) strongly suggests that this section is unconformable. The sedimentology and paleontology at Littig Pit were studied in order to investigate this hypothesis. This work is presented in the following chapters.
VII. Sedimentology

Introduction

Three problems were identified for sedimentologic study. These problems included the question of possible size sorting of glauconite near the K/T transition and the mechanics of transport which resulted in deposition of the Littig Member. In addition, the prominent siltstone units within the Late Cretaceous were studied in an attempt to distinguish their original environment of deposition.

Several samples which were originally collected for radiometric analysis of included glauconites were re-examined. It was felt that there was a possibility of size-sorting of the silt-sized and coarser fraction. Size-sorting would indicate that these sediments had been reworked and, thus, diminish the validity of the calculated ages.

Sample L07 was taken within the Littig Member. The radiometric date obtained for L07 is questionable since the original sample was somewhat weathered, as discussed earlier. Furthermore, sedimentary evidence at the outcrop (clay rip ups, shell hash, numerous chert pebbles) indicate that this unit may have been deposited as a lag over a considerable length of time. If the Littig Member is a lag deposit, then the glauconite here cannot be considered authigenic for this setting, but may be detrital. Kocurek and Hansen (1982) interpret the Littig Member to represent a condensed zone formed during a rapid regional transgression. According to this view, such a rapid transgression would result in a shelf which was "starved" for terrigenous sediment and, thus, the Littig Member contains a large amount of coarse debris such as shell hash and chert pebbles.
Textural analysis of the sediments was undertaken in order to distinguish between these two interpretations. If the Littig Member formed during a transgression, then some grading should be apparent in these sediments. Sorting of the sediments would result from reworking by currents during the transgression. If the Littig Member is a lag deposit, then the sediments should be markedly unsorted.

Lastly, a brief study was made of two prominent Late Cretaceous siltstone units in an attempt to recognize the depositional environment prior to the K/T transition. Kocurek and Hansen (1982) felt that the sedimentary structures within these units indicated rapid deposition on a muddy substrate. They interpret the siltstone units as deltaic frontal splays deposited on the prodelta during storm events. However, the sedimentary structures observed within the siltstones of the Kemp Clay Fm. at Littig are not necessarily confined to the deltaic environment. These hummocky sands may well represent lower shoreface deposits. The sands of such an environment would be rapidly deposited below fair weather wavebase but within the storm wavebase. A consistent southeasterly transport was observed on the low angle troughs. In light of the regional geologic picture, the southeasterly transport is taken to imply strong offshore transport during storms. Textural analysis should indicate that the lower shoreface deposits consist of very fine, well sorted sands. If, on the other hand, these sands were deposited as deltaic frontal splays, then transport should be multidirectional and the sediments should be coarser, siltier, and probably graded. Samples were collected at the base and top of each siltstone unit in order to study the textural indicators of environment.
Sample Preparation

Samples were prepared for analysis on the Rice University Automated Sediment Analyser (RUASA) system. The design and procedures of this method were detailed by Anderson and Kurtz (1979). Briefly stated, the method is based on the hypothesis that textural variations in sedimentary hand samples are directly related to the sediments' hydrodynamic properties. In turn, these hydrodynamic properties reflect the original mechanics of transport. The system utilizes settling tubes which are equipped with basal weighing pans. The weighing pans electronically sense impinging material. An associated microcomputer translates the known length of water column traveled versus time spent in the settling column into an equivalent grain size distribution. The microcomputer performs these calculations using accepted standard hydrodynamic equations for sand-sized and silt-sized material and produces a statistical output. The data meaningful to this thesis were the percent sand, silt, and clay for each sample and the frequency and cumulative weight percent for each 0.25 phi increment of grain size for each sample. Calculations for this data were based on originally inputed dry weight values.

In accordance with the RUASA method, it was necessary to mechanically separate the sands, silts, and clays in each of the original samples. The samples which were collected for glauconite study (L06, L08, L20, L21, and L22) had been previously prepared for radiometric analysis and paleontologic study. Therefore, the sediment acquired from these samples required little additional preparation for settling tube analysis. The samples studied from the Kemp Fm. and Littig Member required more lengthy laboratory preparation.

Each raw sample was broken down to approximately gravel size using a hammer and/or porcelain mortar and pestle. Samples were treated with
thirty percent hydrochloric acid (HCl) to break down the carbonate cement. This treatment was repeated until effervescence ceased. Samples were wet-seived through a -1 phi (10 mesh) metal screen to remove residual acid and separate any remaining gravel. A large percentage of the original gravel consisted of carbonate fossil casts which dissolved in the acid. Chert which remained was dried at low temperature (150°C) in an electric oven to remove adsorbed water. Following drying, the chert was weighed as gravel and archived. The total of sand, silt, and clay was similarly filtered, dried, and weighed.

Due to the large amount of clay in this material, it was necessary to soak each sample in a dispersant. A mild commercial soap dispersant (Calgon) was somewhat effective in separating the clay particles. Samples were soaked for twenty-four hours in this solution. Clays were not measured on the hydraphotometer for this thesis but were separated from sand-sized material using a 4 phi (230 mesh) metal screen. Authigenic minerals were removed at 1 phi (35 mesh) since the sedimentologic study concentrated on only those particles involved in the original deposition. Medium and fine sand was set aside to be treated separately from the silt and clay at this point.

Clay and silt were allowed to settle in beakers for twenty minutes, then the clay was carefully decanted. Sediments were then transferred to large test tubes designed for pipetting away excess water and its included clay. The large test tubes were filled with water, mixed, allowed to settle, and pipetted each eight minutes until the water column was no longer cloudy. At this point, most of the clay-sized material should have been removed. The vails were allowed to settle for fifteen minutes before sediment was transferred to pre-weighed dry beakers and allowed to settle an additional ten minutes.
Excess water and clay were gently pipetted away without disturbing the remaining silt. Each beaker was then slowly dried in an electric oven at approximately 150°C and reweighed. Subtracting the known dry weight of the beaker yielded the dry weight of silt which remained from the original dry samples. These silts were then ready for introduction to the small settling tube.

The sands were again treated with thirty percent hydrochloric acid (HCl) to further dissimulate the larger sand particles into their smaller constituents. This material was then filtered, dried, and reweighed to compare the dry sand weight with the original total dry weight of the sample. The sands were mechanically split until a workable amount of sample (0.5gm-2gm) was obtained for introduction into the large settling tube.

Grain-size, degree of cementation, and mineralogic maturity of each sample analysed with the settling tubes were also studied using reflected light microscopy. Particular attention was given to the effectiveness of dispersant and acid treatments for disseminating clay clumps and quartz agglomerates. Grain counts of at least three hundred grains per sample were conducted on those samples prepared to study possible size-sorting of glauconites.

**Settling Tube and Microscope**

Figure 3 illustrates the result of settling tube analysis of those samples selected for study of possible size-sorting of glauconites. The individual graphs are arranged in descending stratigraphic order. Stratigraphic locations of all samples are shown in Appendix A. Hand sample descriptions of all original samples are listed in Appendix B.

Samples L06, L08, and L22 occur within the Littig Member. Samples L21 and L20 lie within the overlying Pisgah Member and were radiometrically
Figure 3. Grain Size Curve for Glauconite Study.
dated. The third sample which was radiometrically age dated, L07, was not available for this study. Therefore, L06 and L08 were analysed since these samples were the nearest stratigraphic equivalents.

Glauconite contained in these samples was commonly encrusted with phosphates or quartz, and thus was not suitable for dating. In addition, a large percentage of the clean glauconite was either too small or poorly formed to be considered usable for radiometric dating. It is noteworthy that, of all the samples prepared for radiometric dating, samples L20 and L21 proved to be the richest in usable glauconite. However, glauconite composed only five percent of these original samples by weight and datable glauconite comprised merely 0.3 percent of the original samples. Therefore, a distinction was made between well-formed, large, unfractured (datable) glauconite and unusable glauconite in grain count totals. That is, since the question of study dealt with minerals which were actually dated—whether the dated glauconite was sorted—then care was taken to make counts of only datable minerals. Separate counts were taken of poor quality glauconite and all other particles. Table IV lists the results of the mineralogic grain counts. Grain-size ranges on the table are arranged for direct comparison with the modes of the frequency curves shown on Figure 3.

Grain-count analysis shows that glauconite is distributed across all size ranges and is not clearly concentrated in any one mode relative to all other materials. Phosphates, unbroken foraminifera, and angular quartz accompany glauconite in all size ranges in roughly equal proportions.

Nevertheless, there does appear to be a slight tendency for glauconite, especially datable glauconite, to occur in the 2 to 3 phi size range. These
## Average of All Grain Counts

<table>
<thead>
<tr>
<th>Sample</th>
<th>Particle Size Ranges</th>
<th>Datable Glauconite (%)</th>
<th>Other Glauconite (%)</th>
<th>Other Material (%)</th>
<th>Total Glauconite (%)</th>
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</thead>
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<tr>
<td>L20</td>
<td>&lt;2 phi</td>
<td>6</td>
<td>32</td>
<td>62</td>
<td>38</td>
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<td></td>
<td>2-3 phi</td>
<td>11</td>
<td>42</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>&gt;3 phi</td>
<td>3</td>
<td>33</td>
<td>64</td>
<td>36</td>
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<tr>
<td>L21</td>
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<tr>
<td></td>
<td>2-3 phi</td>
<td>5</td>
<td>60</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>3-3.5 phi</td>
<td>1</td>
<td>37</td>
<td>62</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>&gt;3.5 phi</td>
<td>0</td>
<td>38</td>
<td>62</td>
<td>38</td>
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<tr>
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<td>&lt;2.5 phi</td>
<td>6</td>
<td>72</td>
<td>22</td>
<td>78</td>
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<tr>
<td></td>
<td>2.5-3.5 phi</td>
<td>4</td>
<td>54</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>&gt;3.5 phi</td>
<td>1</td>
<td>19</td>
<td>80</td>
<td>20</td>
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<tr>
<td>L06</td>
<td>&lt;2.5 phi</td>
<td>18</td>
<td>34</td>
<td>48</td>
<td>52</td>
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<tr>
<td></td>
<td>2.5-3.5 phi</td>
<td>4</td>
<td>27</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>&gt;3.5 phi</td>
<td>0</td>
<td>20</td>
<td>80</td>
<td>20</td>
</tr>
</tbody>
</table>

Table IV. Grain Counts on Glauconite
glauconites generally infill foraminiferan tests which for a variety of environmental and biologic reasons tend to form within the 2 to 3 phi size range. Therefore, the glauconite appears to be preferentially concentrated within this size range.

The frequency curves obtained for samples L20 and L21 indicate that these samples are moderately well sorted, and that the dominant transport mechanism is saltation. However, the sorting is not pronounced since very fine sand (3-4 phi) remains. The curves do not show distinct sorting of sand-sized particles and glauconite is not clearly concentrated in any single mode. Therefore, it is concluded that these sediments are not reworked to any significant extent and the radiometric dates obtained from them are reliable.

The frequency curve for sample L22 (Figure 3) again depicts moderate sorting with a peak near 2.75 phi. The presence of fine and very fine sands indicates very slow current velocity over time. The presence of glauconite has been shown to be indicative of slow deposition (Cloud, 1955). This implies that velocities were low during the time that these sediments were exposed to erosion. The similarity of frequency curves obtained for samples L20, L21, and L22 indicates a constant energy across this section. Paleontologic evidence, discussed in the next chapter, supports this hypothesis. Also, it is interesting to note that the paleontologic data places samples L20 and L21 in 190 meters and 174 meters water depth, respectively. In the modern Gulf of Mexico, the continental shelf break is commonly placed at 135 meters water depth. In all likelihood, samples L20 and L21 were deposited on the upper continental slope. Any reworking at this depth would be due to moderate "contour currents" paralleling the topography. Furthermore, the presence of
unbroken foraminifera, angular quartz, and fresh unfractured glauconite indicates a lack of extensive transport.

Samples L08 and L06 are less efficiently sorted than the overlying samples. This implies either that the sorting mechanism was active for a shorter period of time, sediments were not transported far from their source, or current velocities were very slow. The abundance of chert in this section implies an accumulation of sediments over a long period of time. Nevertheless, the entire unit is rather thin (approximately eighteen inches), indicating extremely slow deposition or a large amount of missing section. The presence of glauconite suggests very slow deposition (Cloud, 1955). Furthermore, roughly seventy percent of the glauconite in these samples is found to be finer than 2.5 phi. The diminished nature of these glauconites may reflect an influx of argillaceous material (Cloud, 1955; Bentor and Kastner, 1965). This view is consistent with paleontologic evidence for this section presented in the following chapter. It appears then that the Littig Member represents the very slow accumulation of material over a long period of time.

Outcrop observation suggested that the source for material comprising the Littig Member lay outside of the immediate area. Pebbles and sand found within the Littig Member did not occur in strata directly underlying the unit and, thus, immediately younger strata were not eroded to produce the Littig Member. Evidence indicates that this unit was deposited during a transgression (Kocurek and Hansen, 1982; Paleontology, this thesis). The source for the Littig Member was, therefore, probably facies equivalent strata which were present at a distance from this outcrop.

In order to study the Littig Member itself, samples were collected and analysed on the RUASA system of the base (L47) and top (L48) of the unit.
Appendix A shows the exact stratigraphic locations of these samples relative to the samples discussed above. The results of textural analysis are shown in Figures 4 and 5. Due to the difficulty in obtaining a workable volume of sand from these clayey samples, two different types of curves were constructed. The frequency curves on Figure 4 illustrate the actual proportions of sand to silt found in the raw samples. The sand/silt/clay ratio for each original sample is noted on its corresponding graph. The curves shown on Figure 5 were obtained by processing large amounts of original sample solely for the sand-sized content. It was hoped that a larger volume of sand sample, when split into a workable volume, would produce a curve more closely representative of the actual sample collected. The sand/silt/clay ratios are those of the original raw samples. Comparison of these two sets of graphs shows that the results are identical using both small and large volumes of sample. This consistency proved valuable in analysing samples L41 and L42, which contained so little sand in the original samples that processing the samples in the standard manner resulted in insufficient volumes of sand for settling tube analysis. Concentrating the sand resulted in enough sediment to create the curves shown in Figure 5 for samples L41 and L42. The results obtained for samples L47 and L48 give credence to the validity of this technique. Microscopic descriptions of these samples are given in Table V.

Samples L47 and L48 are essentially stratigraphically equivalent to samples L06 and L22, respectively, discussed above (see Appendix A). It has been determined that L06 and L22 were deposited very slowly over a long period of time and that their source area probably lay outside of the study area. Figures 4 and 5 illustrate a more complete picture of these sediments. It is apparent from the sand/silt/clay ratios that silt and clay form a large
Figure 4. Grain Size Curve for Littig Member.
Figure 5. Grain Size Curve for Sand Sorting Study.
TABLE V

Microscopic Sample Descriptions

Samples listed in descending stratigraphic order

| Sand % | | |
|--------|------------------|
| L48 :  | Moderately sorted fine grained quartz sand; glauconite small, not well formed, and frequently encrusted with silt; little muscovite; iron concretions (removed by hand); 60-70% glauconite. |
| L47 :  | Very unsorted fine quartz sand; some glauconitic sand; very few silt agglomerates; little muscovite; iron concretions (removed by hand); 50% glauconite. |

<table>
<thead>
<tr>
<th>Silt %</th>
<th>Degree of sorting is not apparent at this magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td>L48 :</td>
<td>Very fine grained clean quartz silt; sparse feldspar, roughly 5% glauconite</td>
</tr>
<tr>
<td>L47 :</td>
<td>Very fine grained clean quartz silt; less than 5% very fine grained glauconite</td>
</tr>
<tr>
<td>L42 :</td>
<td>Very fine grained clean quartz silt</td>
</tr>
<tr>
<td>L41 :</td>
<td>Very fine grained clean quartz silt</td>
</tr>
<tr>
<td>L40 :</td>
<td>Very fine grained clean quartz silt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sand Sorting</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L48 :</td>
<td>Moderately sorted fine grained quartz sand; silt agglomerates and iron concretions (removed by hand); 60-70% glauconite.</td>
</tr>
<tr>
<td>L47 :</td>
<td>Poorly sorted fine grained quartz sand; some glauconitic sand; numerous silt agglomerates, phosphate crystals, and iron concretions (removed by hand); 20-25% glauconite.</td>
</tr>
<tr>
<td>L42 :</td>
<td>Very well sorted fine grained quartz sand; quartz is angular to subangular; a few fine grained flakes of biotite and muscovite, sparse fine grained K-spar; sparse silt agglomerates; less than 2% glauconite fragments.</td>
</tr>
<tr>
<td>L41 :</td>
<td>Poorly sorted micaceous silty sand; angular quartz, feldspar, biotite, and muscovite; no glauconite; a few silt agglomerates.</td>
</tr>
</tbody>
</table>
part of the sediments. Current velocities were not sufficient to remove these fine materials or even produce any definitive sorting. More importantly, the presence of such large fractions of fine sand is unusual at these depths of greater than 150 meters. (Assuming a gradient of six feet/mile, this depth is equivalent to 75 miles offshore.) This observation strongly suggests a source at a distance from the study area. The angularity of the quartz grains indicates that the sands were not windblown, and therefore frosted, or carried at length by water, and thus rounded. The possibility exists that these coarse sediments were plant rafted out to these depths. However, all evidence indicates that the Littig Member represents a residual lag formed by winnowing through the water column. Current velocities after deposition were not sufficient to produce efficient sorting. The slight sorting observed was the result of water column winnowing prior to deposition and bioturbation after deposition which did not effectively entrain the sediment.

Very little sand was available from samples L40, L41, and L42. By concentrating a large amount of sample, frequency curves of the sand fraction were compiled for samples L41 and L42 (Figure 3). The silt fractions for these three Cretaceous siltstones are shown in Figure 6. The sands contained in these samples are indeed very fine and apparently well sorted as would be expected in the environment of the lower shoreface. However, the large amount of silt is more indicative of a prodeltaic environment, as suggested by Kocurek and Hansen (1982). Neither the sedimentary structures observed at the outcrop nor the frequency curves presented here resolve the question of depositional environment for the Cretaceous siltstones.
Figure 6. Grain Size Curve for Kemp Clay Formation.
Conclusions

Textural analysis was performed on samples from the Kemp and Kinkaid Fms. at the Littig Pit. A study was made of sediments containing glauconite within the Pisgah Member of the Kinkaid Fm. Lack of pronounced grain size sorting in these sediments indicated that the sediments were not reworked to any significant degree. The lowermost Pisgah Member was deposited during a period of consistently low current velocities. Radiometric age dates derived from samples collected from this unit (L20, L21) were thus shown to be reliable. The ages are viable since these glauconites were not transported following their formation.

Sedimentary analysis of the Littig Member suggested that this unit did not form as the result of a rapid transgression as proposed by Kocurek and Hansen (1982). The Littig Member was found to represent the very slow accumulation of material over a long period of time. The source of sediments was outside of the immediate area and the coarse particles were probably plant rafted to this site. This investigation strongly suggests that the Littig Member represents a lag formed by winnowing of these particles through the water column. Slight sorting was produced by this winnowing prior to deposition and some bioturbation after deposition. Sample L07, which was collected from the Littig Member, is thought to yield an anomalously low age which does not represent the time of deposition of the Littig Member.

It is not clear from observation of sedimentary structures and textural analysis of the siltstones within the Kemp Clay Fm. whether these siltstones represent a deltaic or lower shoreface environment.
VIII. Paleontology

Introduction

Samples which were originally collected for radiometric analysis were re-examined for their paleontologic content. The planktonic foraminifera and calcareous nanofossils which were identified were assigned to previously published standard fossil zones. Published age ranges for these zones were compared to the calculated radiometric ages for the same sediments. These age correlations pointed to the possibility of missing sedimentary section at or near the K-T transition in Littig Pit. Missing section would be reflected in missing fossil zones. This thesis is, thus, an attempt to correlate directly from a radiometrically dated sediment to its biostratigraphic content. This work is an original contribution for the study of the K-T boundary in Texas.

The microfossils were also studied in an attempt to identify the original depositional environment of the sediments in conjunction with the sedimentologic work discussed in the previous chapter. It was deemed to be particularly important to study those sediments which were dated radiometrically to identify evidence of reworking. Reworking of the sediments would effect the validity of the calculated dates.

Sample Preparation

Loosely broken samples were dried at very low temperature (70°C) on electric hot plates to remove absorbed water. The wettest clays required 17–36 hours of drying. One-half of each sample was archived while the remaining half was weighed to the nearest gram on a Mettler balance.

Each sample was then boiled in a mixture of water and thirty percent hydrogen peroxide ($\text{H}_2\text{O}_2$) to oxidize the organics. This treatment was
continued until most or all of the effervescence ceased or until a syrupy liquid was obtained.

Wet-seiving through a 63-mesh nylon screen removed the clay-sized fraction of each sample. Several clayey samples, particularly those low in the section, required three separate dryings and washings to remove the clays. The sand and gravel-sized separate was allowed to settle overnight. The water was then decanted and the samples redried and reweighed. Gravel was removed using a 32-mesh seive and returned to the sample bags.

Smear slides of calcareous nannofossils were prepared from the clay-sized fraction of the selected raw samples. The section of interest included those samples directly underlying and immediately overlying the K-T contact. Oil immersion microscopy was utilized.

**Planktonic Foraminifera**

The cleaned and dried samples were studied microscopically in the form of dissegregated grains. The samples studied were those originally collected to obtain concentrations of glauconite for radiometric dating. Collecting was thus concentrated in the Littig Member near the Cretaceous-Tertiary contact and within two meters above the contact where glauconite was the most abundant. However, samples were also collected from the underlying Kemp Clay Formation as well as throughout the Cretaceous to the top of the highest quarry wall. Thus, samples were examined from the entire section exposed in the quarry. Appendix A illustrates the stratigraphic locations of all samples collected. A map view of the entire quarry depicting all collecting stations is shown in Figure 2.

Microscopic examination revealed that fossil preservation in the Kemp Formation was generally very poor. The badly weathered samples contained
very few foraminifera. These sparse foraminifera were frequently worn or covered with phosphatic particles. In some cases, the fossils were even replaced by phosphates. Secondary iron minerals – probably hematite – also indicated weathering in the lower section. The lack of preservation made species identification unfeasible and foraminiferal counts difficult and very suspect.

Fossils were found to be most abundant in the samples within the first one meter of the base of the Tertiary. This increase in abundance was accompanied by a marked increase in the amount of glauconite and phosphate in the section. The presence of the mineral glauconite indicates a period of very slow sedimentation (Cloud, 1955). The lack of detrital influx concentrated and apparently encouraged an increase in the abundance of fauna. Therefore, the sparsity of fossils in the lower section was probably due not only to weathering but was also the result of an originally unfavorable, sediment clogged environment. Kellough (1959) noted a similar coincidence of glauconite increase and foraminiferal abundance increase within the lower Midway Group.

Paleontologic interpretation across the exposed section was based on the number of species of foraminifera per sample, the species assemblage of foraminifera and calcareous nannofossils for each sample, and the relative ratio of planktonic foraminiferans to benthonic foraminiferans per sample. Figures 7 and 8 summarize the results of this study. Poor fossil preservation hampered identification and interpretation of the lower exposures within the Cretaceous. However, fossils found in the uppermost Cretaceous sediments were sufficient in quantity and quality to bracket the suggested K-T contact and identify missing fossil zones. Numerous Tertiary fossils were studied from the samples at and surrounding the horizons which were dated radiometrically.
Figure 7. DISTRIBUTION OF FORAMINIFERA AND CALCAREOUS NANNOFOSSILS AT LITTIG PIT.

This figure illustrates the results of paleontologic study of the Littig samples.

The planktonic foraminifera zones are those of Stainforth et al. (1975). The calcareous nannofossil zones of the Cretaceous were defined by Cepek and Hay (1969). Hay and Mohler (1967) correlated the Tertiary calcareous nannofossil zones.

Approximate water depth at the time of deposition for each sample was calculated from the data of Pflum et al. (1976). Their estimates of water depth versus percent of planktonic foraminifera was presented on their Figure 22.
<table>
<thead>
<tr>
<th>LATE CRETAKEOUS</th>
<th>GLOBOROTALIA TRINIDADENSIS ZONE</th>
<th>PLANKTONIC FORAM. ZONES</th>
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<td>KEMP FM.</td>
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<td>Heterohelix striata</td>
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<td>X</td>
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<td>BENTHONIC FORAMINIFERA</td>
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<td>X x x x</td>
<td></td>
<td>Cristellaria midwayensis carn.</td>
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<tr>
<td>X</td>
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<td>Cristellaria psuedocostata</td>
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<tr>
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<tr>
<td>LOWER CHIASTO-ZYGUS INITIALIS</td>
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<td>Arkhangeliskiell cymbiformis</td>
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2 Planktonic foraminiferal zones missing (Stainforth et al., 1975)

2 1/2 Calc. nanno, zones missing (Cepek and Hay, 1969).

1 Calcareous nannofossil zone missing (Hay and Mohler, 1967).

Figure 7.

WATER DEPTH

100

200

(lm)
Figure 8. Estimated Water Depth of Sample Deposition.

(A) After data presented on Fig. 22 of Pflum et al. (1976).

(B) After Tipsworth et al. (1966).
Cleaned and dried samples were split into successively smaller portions to obtain workable volumes of material. Each sample was placed on a scored petri dish. The grids on the petri dish were used as a visual aid when counting specimens. Only intact foraminifera were counted within each grid since the inclusion of broken specimens in the data would have created errors in the results. Planktonic foraminiferans were distinguished from benthonic foraminiferans and each morphologic type was counted separately for each sample. A total of at least one hundred foraminiferans – the total of the planktonic and benthonic counts – was counted for the most poorly preserved samples. A minimum of three hundred foraminiferans, representing three separate counts of one hundred foraminiferans, was counted for the samples with better preservation. In several cases, totals of four hundred and five hundred foraminiferans were obtained. All foraminifera totals were then normalized to ratios of one hundred in order to compare these results with the planktonic/benthonic ratios obtained by Pflum et al. (1976).

Pflum et al. (1976) demonstrated that a direct correspondence exists between percent planktonic foraminifera in the benthic population and water depth – planktonic foraminifera become increasingly abundant with increasing water depth. Their samples were collected in sediment core traverses of the northern continental slope and abyssal plain of the present-day Gulf of Mexico. The data of Pflum et al. was used for this thesis since the present-day Gulf of Mexico seems to be a suitable analogue of the shallow epicontinental seas of the Cretaceous Gulf of Mexico. Assuming that the present-day sedimentary environment is analogous to that of the Tertiary and Cretaceous, planktonic percents calculated for the Littig Pit samples were converted to depths using the counts of Pflum et al. (1976). The data of the Pflum et al. study is
tabulated in their Appendix E and presented on their Figure 22. The results of this thesis are shown in Figure 8. The bathymetric zonation used is that proposed by Tipsword et al. (1966).

The uppermost Late Cretaceous sample, L04, contained very few planktonics and these were of a diminished size. This indicates a shallow nearshore environment, an environment unsuited to planktonic fauna. Indeed, the very high number of benthonics (95%) indicates a middle neritic environment of 30m (100 ft) water depth. Hansen (1982b, 1983) studied the macrofauna of the Upper Cretaceous sediments at Littig Pit, concluding that the assemblage represents an inner shelf facies. He found a diverse, mixed deposit- and suspension-feeding fauna giving way upsection to a low diversity, deposit-feeding fauna of reduced size. An oxygen content of 1.0 ml/l, about 10-20 percent of the normal level, was suggested to be representative of this oxygen deficient basin. Thus, the findings of Hansen (1982b, 1983), using macrofauna, are in close agreement with the interpretations from foraminiferan evidence given in this thesis.

The lowermost early Tertiary sample collected, L06, contains a foraminiferal assemblage indicative of the Globorotalia trinidadensis Zone as used by Stainforth et al. (1975). This zone was originally defined by Bolli (1957, 1966) as the interval from the first occurrence of Globorotalia trinidadensis to the first occurrence of Globorotalia uncinata. Bolli's zonation was mainly derived from warm water marine sediments of Trinidad. The lowermost Tertiary planktonic foraminiferal zone of Stainforth et al. (1975) which is missing at Littig Pit is the Globorotalia pseudobulloides Zone. The succeeding and younger zone, the Globigerina triloculinoides Zone, is also not found in the Littig Pit samples. Berggren (1971) suggested an average estimated
length of 1.8 my for each Paleocene zone. These averages, therefore, suggest that approximately 3.6 my of the early Paleocene is missing. More accurately, Berggren's correlation of these two zones with calcareous nannoplankton zones originally defined by Hay et al. (1967) indicate that a gap of about 2.5 my exists in the lower Tertiary at Littig Pit.

All of the Tertiary samples collected at Littig Pit are within the *Globorotalia trinidadensis* Zone, as *Globorotalia uncinata* was not encountered in the samples. The occurrence of *Globorotalia uncinata* would indicate the end of the *Globorotalia trinidadensis* Zone and the beginning of the *Globorotalia uncinata* Zone as defined by Bolli (1957, 1966). According to Berggren (1971), the *Globorotalia trinidadensis* Zone occupies the interval of the stratigraphic column from 61.5 my to 62.5 my. This implies that the uppermost Tertiary sample studied, L30, is greater than 61.5 my of age. Therefore, less than one million years of the early Paleocene may be represented in the section at Littig Pit. This fauna is characteristic of the mid-early Paleocene strata of Danian age (Hardenbol and Berggren, 1978).

Figure 7 illustrates the fauna found to be present in these Paleocene strata. Despite the probable long length of time as sediment slowly accumulated in the Littig Member (Stanton, 1982), samples across this unit contain closely identical microfossil assemblages. This consistency implies a stable environment over this period. The relatively small size of the sparse foraminifera of the samples indicates a stressful environment consistent with the oxygen deficient basin suggested by Hansen (1982b, 1983).

While the species assemblages suggest stability in the overall nature of the environment, the planktonic foraminiferal counts indicate marked sea
level shifts during this period (Figure 8). These fluctuations were probably more gradual than indicated by the stratigraphy since the amount of time represented in the condensed Littig Member is ambiguous. The lower Littig was deposited at approximately 100-175 ft (30-53m) water depth. The sea later deepened to 540 ft (165m) in middle Littig time followed by a slight drop to 412 ft (125m) near the close of Littig deposition. These results coincide well with the findings of Kellough (1959, 1965). This study of Midway foraminifera concluded that the Littig Member was deposited in the marine environment, probably mid- to outer neritic (60-600 ft). Kellough further notes that the Littig Member is entirely marine and, therefore, never subaerially eroded. Glauconite in the section was, therefore, not exposed to subaerial weathering for some time after deposition.

Moving upsection into the Pisgah Fm., there is an increase in both diversity of species and percentage of planktonic foraminifera in the samples (Figure 7). Berggren and Aubert (1975) also noted a decrease in the number of individual benthonic foraminifera in the lower Kincaid Fm. which was accompanied by an increase in the specific diversity of species. They cite the correlative work of Kellough (1959) in interpreting the foraminiferal assemblage of the Pisgah Member as representing a maximum water depth of 200m. The depths calculated in this thesis agree with this interpretation, ranging from a low of 541 ft (67m) to a maximum depth of 675 ft (206m). These depths occur within the mid- to outer neritic zones or mid- to outer continental shelf.

It is interesting to note from Figures 7 and 8 that there is a sharp rise in relative sea level following Littig time, reaching a depth of 622 ft (190m) by L20 time. Samples L20 and L21 were radiometrically dated at 57.1 ±
2.9 my and 59.1 ± 3.0 my, respectively. Vail et al. (1977) indicate a marked rise in relative sea level at or near 60 my (Figure 9). This rise is the last indicated major transgression of the Paleocene and the dated samples in all probability correspond to this transgression. The foraminiferal assemblages of samples L20 and L21 do not contain reworked Tertiary fossils, indicating that samples L20 and L21 were not reworked. Therefore, the radiometric dates obtained on glauconitites for these samples are representative of the time of deposition of sediments during this transgression.

Relative sea level remained high through L12 time, then dropped to a low of 222 ft (67m) by L17 time followed by a sharp rise shown by foraminiferal counts in sample L30. As seen in the hand sample descriptions in Appendix B, samples L10 through L12 are composed of elements typical of a quiescent, low energy environment - glauconite layers, little sand, and an abundance of clay which may be faintly laminated. While samples L13 and L14 contain these same elements, microscopic examination reveals the presence of biotite and abundant Inoceramus prisms. Biotite indicates a short duration of transport while the Inoceramus prisms indicate that the sediment originated in the nearshore environment. Inoceramus (a nearshore benthic bivalve) ranged from Jurassic to Cretaceous time. Since planktonic foraminiferal counts reveal that these sediments were deposited in 170m to 138m of water, it is concluded that samples L13 and L14 are composed, in part, of reworked Cretaceous nearshore detritus. This detritus was deposited in deeper water as relative sea level dropped and sediments were transported offshore.

Samples L16 and L17 reveal small pebbles and clay clasts in hand specimens (Appendix B), implying reworking. Microscopic study shows that the included quartz is rounded, indicating windblown transport. Iron staining
Figure 9. Relative Sea Level Curve for Paleocene and Early Eocene.

Stratigraphic columns after Hardenbol and Berggren (1978).

Sea level cycles after Vail et al. (1977).
on the quartz grains suggests subaerial exposure. The presence of the Upper Cretaceous foram *Heterohelix striata* in sample L17 indicates reworking of older strata. Planktonic foraminiferal counts yield calculated depths of 116m and 67m for samples L16 and L17, respectively. These observations indicate continued reworking and offshore transport of sediments to deeper water with falling sea level. These sediments were originally derived from the beach environment, while samples L13 and L14 originated from near offshore sediments. The uppermost sample studied paleontologically, L30, reveals a diversity of species and high planktonic/benthonic foraminiferal ratio. By L30 time, waters had again deepened— foraminiferan counts imply a water depth of approximately 540 ft (165m). There is no indication in these samples of reworking of older deposits as occurred during the earlier rise of sea level.

**Calcareous Nannofossils**

Microscopic examination of calcareous nannofossils was concentrated on samples directly underlying and immediately overlying the K-T contact. Poor preservation hampered species identification in all but a few of these samples. The specific results of this study are shown on Figure 7.

The youngest Cretaceous sample collected, L04, contained examples of *Arkhangelskiell cymbiformis*, *Chiastozygus initialis*, and *Tetralithus obscurus*. This assemblage is representative of the lower portion of the *Chiastozygus initialis* Zone as defined by Cepek and Hay (1969). According to their zonation, the upper half of the *Chiastozygus initialis* Zone as well as two additional zones — the *Lithraphidites quadratus* Zone and the *Nephrolithus frequens* Zone — are missing from the sampled section. Jiang (1980) gives evidence for the presence of the *Nephrolithus frequens* Zone but also concludes that the younger *Lithraphidites quadratus* Zone is missing. Furthermore, Perch-Nielsen
1979) notes that a still younger zone, the *Micula prinsii* Zone, may be missing from many Maastrichtian sections. The delicate nature of this fossil prevents its preservation in poorly preserved strata such as the Littig section. The absence of the *Micula prinsii* does not in itself indicate missing stratigraphy. Nevertheless, the absence of this zone along with the indication of two additional missing nannofossil zones in this thesis implies a marked hiatus.

However, the identification of the key fossil *Chiastozygus initialis* is suspect since this fossil is easily confused with other forms (Hans Theirstein, personal communication). The absence of *C. initialis* would suggest that the sample should be placed in the older *Tetralithus aculeus* Zone (Cepek and Hay, 1969), indicating a greater hiatus. Moreover, a second key fossil in this assemblage, *Tetralithus obscurus*, is environmentally controlled. *T. obscurus* is a neritic or shelf form. Its absence in samples above or below L04 does not necessarily indicate that these samples represent other nannofossil zones, suggestive of varying lengths of hiatus. Therefore, an interpretation of absolute age for the top of the Cretaceous from this data is ambiguous, although there is a strong indication that some section is missing.

Examination of Tertiary nannofossils revealed the presence of *Cruciplacolithus tenuis* in sample L21, a sample which was also dated radiometrically. Hay and Mohler (1967) define the *Cruciplacolithus tenuis* Zone as the interval from the first occurrence of *C. tenuis* to the first appearance of *Fasciculithus tympaniformis*. Since *F. tympaniformis* does not occur in any of the samples from Littig Pit, L21 and all younger samples belong to the *Cruciplacolithus tenuis* Zone.

L21 was radiometrically dated to be from 56.1 my-62.1 my of age. Table 2 of Bukry (1975) lists an age range of 60 my-63 my for the
Cruciplacolithus tenuis Zone. The correlative foraminiferal zone is the Globorotalia trinidadensis Zone, as seen in this study and Hay and Mohler (1967). This zone is dated in the interval from 61.5 my to 62.5 my (Berggren, 1971) and 62 my–63 my (Hardenbol and Berggren, 1978). All of these age ranges coincide in part with the age range calculated radiometrically (Figure 10) and suggest missing section. According to these ages, at least 2 my of section is missing from the Tertiary of Littig Pit, assuming a K-T boundary of 65 ± 1 my.

While foraminiferal data was obtained, no nannofossil data is shown within the Littig Member in Figure 7. Therefore, it is not clear whether the Cruciplacolithus tenuis Zone extends into the Littig Member. However, the correlative foraminiferal zone of Hay and Mohler (1967, 1969), the Globorotalia trinidadensis Zone, is shown to extend into the Littig Member to the base of the Tertiary. This strongly suggests that the Cruciplacolithus tenuis Zone extends into the strata below sample L21.

According to the correlations of Hay and Mohler (1967, 1969), the Markalius astroporus Zone may be missing from the Littig Member. Hay and Mohler (1967, 1969) define this zone as the interval from the first appearance of Markalius astroporus to the initial occurrence of Cruciplacolithus helius. For this thesis, C. helius can be considered to be equivalent to C. tenuis since the definition of the directly overlying Cruciplacolithus tenuis Zone begins with the first occurrence of C. tenuis (Hay and Mohler, 1967). They note that the species Markalius astroporus and Cruciplacolithus helius are wide-ranging nannofossils and should occur universally unless interrupted by a hiatus. That is, if deposition occurred at this time then these fossils will be present unless removed by later erosion. Interestingly, Hay and Mohler
Figure 10. TERTIARY AGE RANGES

This figure illustrates the coincidence of calculated radiometric age ranges (this thesis) with published standard fossil zonations.

K/Ar DATING

A  Sample L20 [57.1 + 2.9 Ma] (This thesis).

B  Sample L21 [59.1 + 3.0 Ma] (This thesis).

CALCAREOUS NANNOFOSSILS

C  Cruciplacolithus tenuis (Bukry, 1975).

D  Cruciplacolithus tenuis (Berggren, 1971).

PLANKTONIC FORAMINIFERA

E  Globorotalia trinidadensis (Berggren, 1971).

F  Globorotalia trinidadensis (Hardenbol and Berggren, 1978).
TERTIARY AGE RANGES (Ma)  

Figure 10.
(1967) studied samples of the Littig Member and Pisgah Member at Walker Creek. They found examples of *Cruciplacolithus tenuis* as close as six inches above the K-T contact and placed both members within the *Cruciplacolithus tenuis* Zone. Hay and Mohler (1967) did not describe this section in detail but felt that the missing *Markalius astroporus* Zone might be the result of mixing of fossils due to burrowing.

The interpretation of the findings presented on Figure 7 using the calcareous nannofossil zonation of Martini (1970, 1971) also implies that section may be missing beneath sample L21. Martini's lowest Tertiary nannofossil zone is the *Markalius astroporus* Zone. The *Markalius astroporus* Zone is synonymous with the *Markalius inversus* Zone or NP1 Zone (Martini, 1971). This zone is defined as the interval from the last occurrence of *Arkhangelskiella cymbiformis* and coincident Cretaceous species (Cretaceous extinction line) to the initial appearance of *Cruciplacolithus tenuis*. Thus, this zone is an interval zone; it is not defined by the assemblage present but is bracketed by species above and below the interval. Again, if *Cruciplacolithus tenuis* is found lower than sample L21 - as implied by the presence of the foraminiferal *Globorotalia trinidadensis* Zone - then the *Markalius astroporus* Zone is missing at Littig Pit.

It is frequently stated in the literature that conformable sections for the K-T contact are scarce. Perch-Nielsen, who has worked extensively on this problem, notes that the *Cruciplacolithus tenuis* Zone and the *Markalius inversus* Zone (syn. *M. astroporus* Zone) are often missing from Paleocene sections, even in the type area (Perch-Nielsen, 1977). This thesis contends that at least part of the *Cruciplacolithus tenuis* Zone is present at Littig Pit.
but the **Markalius astroporus** Zone may be missing. A recent study at the Littig Pit presented similar data but concluded the section is more conformable (Jiang, 1980).

Jiang (1980) places the first occurrence of **Cruciplacolithus tenuis** within the first glauconitic sand overlying the Littig Member. This position is equivalent to sample L21 of this thesis, where the lowest **C. tenuis** was found. Jiang (1980) reports an abundance of **C. tenuis** (40-60%) at its first occurrence. The large number of individuals of this species at its apparent initial appearance is atypical. It is likely that the **Cruciplacolithus tenuis** Zone actually extends farther down in the section, with the number of **C. tenuis** increasing from a time of lower abundance to the time of the apparent first appearance when Jiang notes a 40-60% abundance. Jiang (1980) himself questions his placement of the lower boundary of the **Cruciplacolithus tenuis** Zone.

The lower boundary of Jiang's (1980) **Markalius astroporus** Zone is, by definition, based on the last occurrence of **Arkhangelskiella cymbiformis** and associated Late Cretaceous nannofossil species. Jiang shows a decrease in abundance - but not complete disappearance - of **A. cymbiformis** at the base of the Littig Member. Numerous other Cretaceous fossils are also shown to dwindle but not vanish at the boundary. Perch-Nielsen (1977) notes that the boundary is difficult to identify since Cretaceous coccoliths are frequently reworked and occur in Tertiary sequences. These reworked fossils are impossible to distinguish from fossils in place. As the sedimentologic study in this thesis indicates, the Littig Member is indeed very likely a reworked deposit.

Perch-Nielsen (1977) suggests that the base of the **Markalius astroporus** Zone is marked by the initial appearance of **Biantolithus sparsus**.
This would place the lower boundary of \textit{M. astroporus} within one-half meter above the top of the Littig Member, resulting in a much smaller \textit{M. astroporus} Zone. Jiang (1980) based his K-T datum line chiefly on a sharp increase in the abundance of the opportunist form \textit{Thoracosphaera}, as suggested by Perch-Nielsen (1977). Nevertheless, the difficulties of recognizing both the lower and upper boundaries of the lowermost Tertiary nannofossil zone, the \textit{M. astroporus} Zone, make any definitive pick of the extent of this zone suspect.

\textbf{Conclusions}

The paleontologic evidence presented above corroborates the numerical radiometric age dates obtained for the Tertiary samples. Previously published age ranges for standard microfossil zonations applicable to the given data are coincident with the derived dates. This work is unique; this is the only study of the K/T transition in Texas to directly correlate the radiometric age dating of these sediments with the equivalent paleontologic age dating. While many authors state that a hiatus exists at Littig Pit, this thesis is the only study which presents evidence for the absolute amount of time missing. Paleontologic correlation of planktonic foraminifera and calcareous nannofossils shows that at least 2.5 and as much as 5 my is missing from the Tertiary. The absolute amount of time missing from the Cretaceous is indeterminate although section is clearly missing.

The foraminiferal work of Pflum et al (1976) is demonstratably applicable to this Gulf Coast section. Environmental interpretations based largely on Pflum et al agree with earlier studies on the Littig section using both microfossils and macrofossils. It is shown that the observations presented here strengthen the conclusions of Berggren and Aubert (1975) and Vail et al (1977) regarding the global applicability of their work. In addition, the
sedimentologic study discussed in the previous chapter is in agreement with the paleontologic interpretation given in this chapter. The radiometrically dated samples were not reworked and the dates obtained are shown to be both valid and workable.
IX. CONCLUSIONS

Radiometric, paleontologic, and sedimentologic evidence for the strata at Littig Pit are consistent with one another. Radiometric dates indicate that 4 to 6 Ma are missing from the lowermost Tertiary and paleontologic correlation limits the unconformity to 2.5 to 5 Ma. This work is unique in that it is the only study of the K-T transition in Texas, if not the Gulf Coast, to directly correlate these radiometrically dated sediments with their equivalent biostratigraphic content. Sedimentologic data helps to explain an apparently anomalous radiometric age date and suggests a mechanism for the unconformity at the K-T transition. The unconformity can be characterized as the result of a very long period of nondeposition rather than active erosion. Paleontologic study indicates that the unconformity represents a period of time of not less than 2.5 Ma and not more than 5 Ma. An undetermined amount of time is missing from the uppermost Tertiary at Littig Pit.

The work presented in this thesis can only lead to the conclusion that low potassium glauconites, even those with as little as three percent potassium in the glauconite separate, can be successfully used for radiometric age dating. It is of the utmost importance to carefully select, clean, and purify the glauconite separate. Interpretation of the apparent ages requires thoughtful application of the geologic history of the sediments dated.

The information discussed in this work has some very interesting implications for worldwide application. Foraminiferal work based largely on Pflum et al. (1976) proved to be useful for environmental interpretation and strongly indicated that the radiometrically dated sediments were deposited.
during the last major Paleocene transgression of Vail et al. (1977). There is a strong probability that the Midway Group elsewhere was also deposited during this transgression. Observations of the Midway fauna strengthen the conclusion of Berggren and Aubert (1975) that this fauna is correlatable globally. Lastly, the iridium layer of Alvarez et al. (1982) is missing at Littig Pit, which would be expected in the event of an unconformity. This observation illustrates that the iridium layer may be useful as a worldwide time marker.

Possibilities for future work include re-examination of glauconite-rich sections younger than the Late Cretaceous in the Gulf Coast which were previously overlooked due to the low percentage of potassium. It would be especially interesting to re-examine the exposures studied by Beck (1981) and Ghosh (1982) to correlate their age dates with the biostratigraphy. In particular, such a study of the Alabama and Mississippi locales might help to put numerical age dates on the timing of the progression of the Vail transgression across the Gulf Coastal Plain.
Appendix A. STRATIGRAPHIC COLUMN AT LITTIG PIT

Approximately sixteen meters of Cretaceous and Tertiary section are exposed at the Littig Pit. The section includes the clays and siltstones of the Kemp Clay Fm., the glauconitic sandy Littig Member of the Kinkaid Fm., and the clays and sands of the Pisgah Member of the Kinkaid Fm.

This column illustrates the stratigraphic location of all samples collected. The vertical scale is depicted in meters away from the Cretaceous-Tertiary contact.
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Appendix B

Hand Sample Descriptions

Samples listed in descending stratigraphic order

Littig Pit

Kincaid Fm. - Pisgah Member

L50  Sparsely fossiliferous yellow brown homogeneous clay; pelecypod and gastropod molds.

L30  Sparsely fossiliferous yellow brown homogeneous clay; pelecypod and gastropod molds; equivalent to L50.

L17  Poorly consolidated yellow brown clay containing numerous clay clasts.

L16  Fossiliferous black clay containing numerous small pebbles and clay clasts.

L14  Yellowish glauconitic sand along with unlaminated dark grey claystone.

L13  Glauconitic clayey very fine grained poorly consolidated yellowish sand; phosphatic.

L12  Faintly laminated light grey clay with no apparent fossils.

L11  Unlaminated light grey clay with no apparent fossils.

L20  Glauconitic grey green sand; clayey; highly phosphatic.

L21  Glauconitic slightly sandy grey clay; phosphatic; pelecypod molds.

L10  Glauconitic faintly laminated slightly silty fossiliferous grey claystone; pelecypod and gastropod molds; fauna is very small in size compared to other samples.
Kincaid Fm. - Littig Member

L48  Glauconitic loosely consolidated yellow brown clay with no apparent small scale structure; shell fragments, pelecypod molds.

L22  Highly glauconitic and fossiliferous clayey grey green sand; gastropod molds, pelecypod molds, and sharks' teeth.

L09  Phosphatic extremely finely laminated consolidated grey claystone; tiny inclusions of pyrite or glauconite.

L08  Glauconitic yellowish green claystone and siltstone; phosphatic; clay clasts less than 1mm in largest dimension; 1-2" micrite concretions.

L07  Glauconitic yellowish green claystone and siltstone; phosphatic; small clay clasts; no micrite concretions.

L06  Glauconitic loosely consolidated yellow brown clay; highly phosphatic; clay nodules; shell fragments; pelecypod molds.

L47  Glauconitic ferruginous yellow brown clay; pelecypod and small brachiopod molds.

Kemp Fm.

L46  Slightly glauconitic greenish yellow clay; faint parallel laminae; no apparent fossils.

L04  Yellow-brown claystone; pelecypod casts; possible silty laminae.

L45f Very sparsely fossiliferous massive black claystone; small shell fragments.

L41f  Yellow brown homogeneous clay; no apparent fossils.

L03  Unlaminated black claystone; equivalent to L45f.

L02  Unfossiliferous yellow claystone.

L01  Very fine grained light brown to yellow sandstone; no obvious impurities.
L42  Very fine grained slightly laminated clean buff sandstone; well indurated; equivalent to L01.

L41  Buff-yellow very fine grained massive sandstone; less indurated than L42.

L40  Extremely fine grained clean massive light grey claystone; well indurated.

L40f Massive dark grey claystone; no apparent fossils.

L39f Very light grey - light brown massive claystone; mottling indicated by small brown clay blebs within sample; lighter in color and more poorly consolidated than L40f; no apparent fossils.

Brazos River

Midway Group

B01  Extremely fossiliferous fine to coarse grained clayey dark green sand; phosphatic; clay clasts; shell fragments; pyritic; small pebbles; black claystone lenses.

Guadalupe River

Samples in approximate stratigraphic order.

Recent

SA 31  Pebbly black clay; poorly indurated; small (<.5mm) shell fragments; may be Quaternary in age.

SA 32  Pebbly black clay; poorly indurated, no apparent structure; may be Quaternary in age.
**Midway Group**

**SA1C** Fine to medium grained light pinkish brown clayey sand; no discernable structure; poorly sorted with 1/2"-1" pebbles; numerous gastropods - possible *Viviparus conradi*.

**Navarro Group**

**SA1D3** Yellowish gray homogeneous clay; no apparent fossils.

**SA1D1** Fossiliferous light grey mudstone; poorly sorted; no apparent structure; shell fragments; gastropods - including *Turritella*; pelecypods. including *Exogyra costata* and possible *Pholadomya*.

**SA1D2** Ferruginous olive grey un laminated clay; calcareous; no apparent fossils.
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