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A field guide to the lithostratigraphy of the Cretaceous/Tertiary boundary sequence at Brazos River, Falls County, Texas

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by

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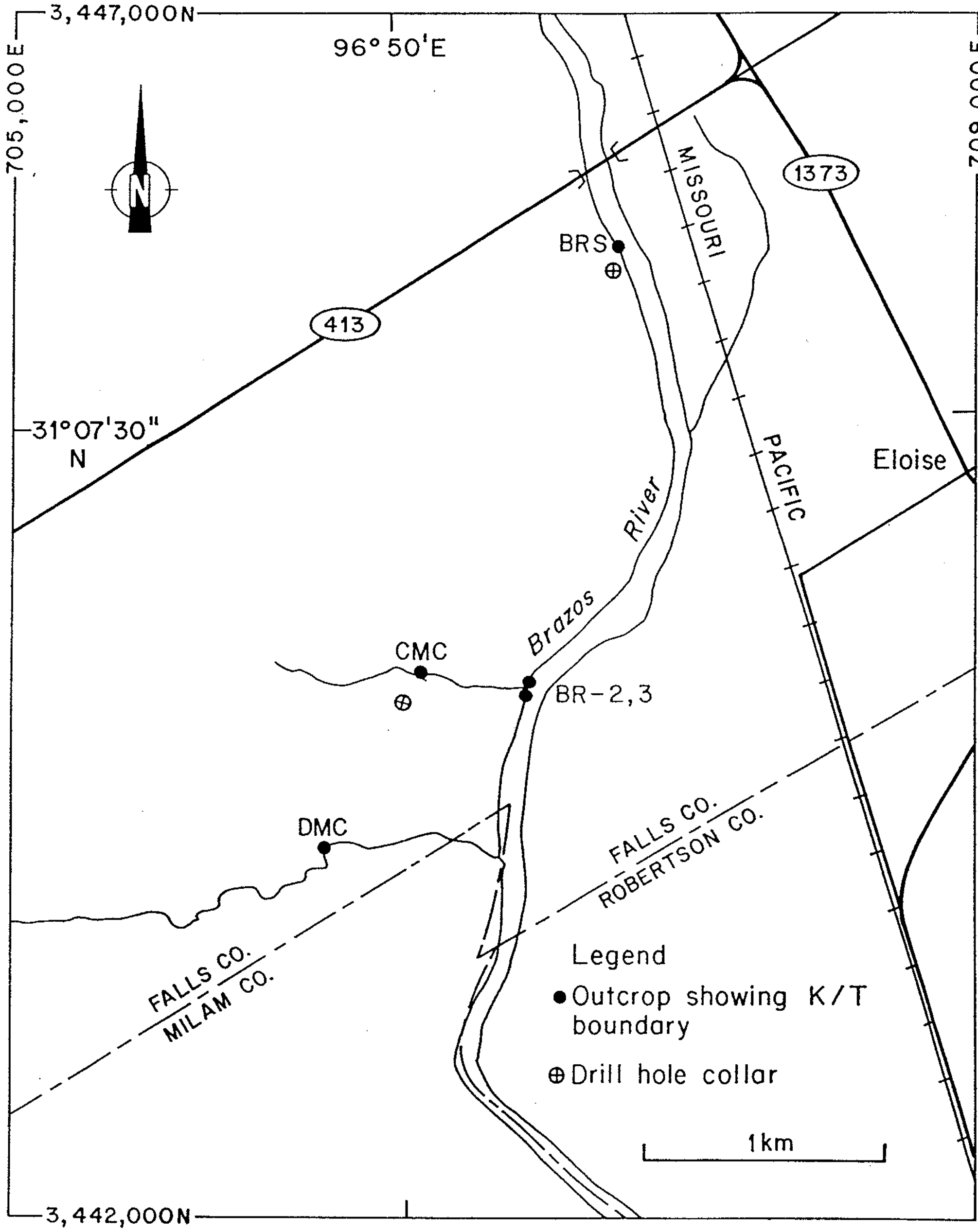
A FIELD GUIDE TO THE LITHOSTRATIGRAPHY OF THE CRETACEOUS/TERTIARY BOUNDARY SEQUENCE AT BRAZOS RIVER, FALLS COUNTY, TEXAS

Introduction: Several K/T boundary sections are exposed on the banks of the Brazos River and two of its small tributaries in Falls County, Texas. Some of these sections have been the subject of numerous reports describing their bio- and lithostratigraphy (e.g. Smith and Pessagno, 1973; Sikora, 1984; Maddocks, 1985; Jiang and Gartner, 1986; Hansen et al., 1984, 1987, 1993; Bourgeois et al., 1988; Keller, 1989a, 1989b; Beeson, 1992; Hildebrand, 1992; Montgomery et al., 1992), stable isotopes (Barrera and Keller, 1990) and geochemistry (Ganapathy et al., 1981; Asaro et al., 1982; Huffman et al., 1989; Hildebrand, 1992), establishing the presence of an apparently near-complete section with a typical K/T boundary faunal turnover and the presence of iridium (Ir) and other elemental anomalies. Stratigraphic completeness for a section is defined as preserving the recognized fossil and magnetozones with no significant missing intervals. However, an atypical series of coarse sediments is preserved at the boundary, and the origin of these is the subject of continuing controversy.

Section locations: The stratigraphy of the 5 best-exposed and most-studied outcrops (Figure 1) that include the K/T boundary sequence is described here (with mention of other sections such as those exposed only at low water in the river bed). Because of spring floods some "outcrops" may be deeply buried by river sediment (or water), but during the 1987 to 1993 interval all sections have been accessible for at least one field season. The study area straddles the boundary of U.S.G.S. 1:24,000 topographic map quadrangles Reagan and Baileyville. Two aerial photographs that cover the study area are 48145 178 44R & 44L, which are available from the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Aerial Photography Field Office, 2222 West, 2300 South - P.O. Box 30010, Salt Lake City, Utah 84130-0010.

The boundary exposure, located on the west bank of the Brazos, ~300 m south of the Route 413 bridge (U.T.M. Zone 14: 3446025 N, 707510 E) previously described as the Brazos River section (BRS; e.g. Smith and Pessagno, 1973) or Brazos 1 (Hansen et al., 1987), is the best exposed, tectonically undisturbed, and least weathered (See Figure 1). Unless someone else has recently uncovered this exposure it must be dug out; this is a 2-day job for one person if the spring flood was severe, but attempting to study the exposure without doing this will yield an incomplete picture and will possibly lead to misinterpretation of this section. The boundary stratigraphy exposed at the Brazos 2 (BR2; 3444170 N, 707150 E), Brazos 3 (BR3; 3444200 N, 707160E), Cottonmouth Creek (CMC; 3444240 N, 706710 E), Darting Minnow Creek (DMC; 3443520 N, 706320 E) are discussed here as well (Figure 1). Two localities are downstream from the Brazos River locality at the mouth of a small tributary; the other two are located on informally-named tributaries of the Brazos, located southwest of the BRS locality. The CMC exposure is apparently mislocated by Keller (1989b) as no good outcrop could be located at the

Figure 1: Location of K/T sections, Brazos River, Texas. The base maps used in drafting this figure were U.S.G.S. 1:24,000 quadrangles Reagan and Baileyville. The course of the Brazos river near the Brazos 2 and 3 sites has changed considerably since these topographic maps were made. Other K/T boundary outcrops occur in the Brazos River bed and Cottonmouth and Darting Minnow creeks but are not shown here.



described position (an exposure most closely matching the outcrop description and that of Bourgeois et al. (1988) is found at the position indicated on Figure 1) and the core near BRS is apparently mislocated by Hansen et al. (1984, 1987) as a drillhole collar is found at the position indicated. The core described by Keller (1989a, b), labelled Brazos Core, is also probably mislocated as it reportedly occurs ~150 m southwest of the CMC exposure (T. Hansen, pers. commun.) although its collar has never been found to verify the location.

Stratigraphy: Figures 2 and 3 show the stratigraphy of the boundary sequence, which is composed of a series of unusually coarse-grained and carbonate-rich lithologies enveloped in calcareous mudstones of Upper Cretaceous and Lower Tertiary age (e.g. Smith and Pessagno, 1973; Jiang and Gartner, 1986; Hansen et al., 1987; Keller, 1989a).

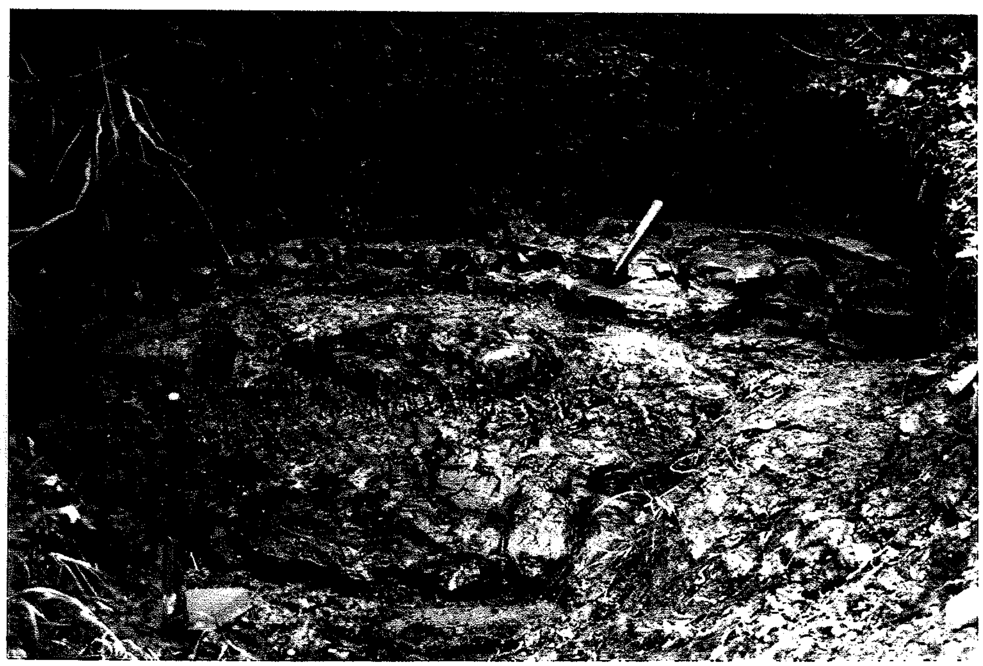
The boundary sequence overlies an irregular surface eroded into latest Cretaceous (Maastrichtian), grey, fossiliferous, glauconitic and calcareous mudstones of the Corsicana Formation. The Corsicana mudstones contain slightly less than 10% carbonate. These rocks are often referred to as the Kemp Clay (e.g. Jiang and Gartner, 1986), which is a junior synonym for the uppermost Corsicana in this area (see Smith and Pessagno, 1973). Smith and Pessagno (1973) and Keller (1989) did not recognize the Upper Maastrichtian planktonic foraminiferal index fossil A. mayaroensis, but its absence has been attributed to unfavourable environmental (i.e. shallow-water) conditions, as at El Kef, Tunisia (Keller, 1989a). However, Montgomery et al. (1992) disagree, interpreting its absence as indicating substantial missing section due to erosion. Jiang and Gartner (1986) studied the calcareous nannoplankton of this sequence and found the Prediscosphera quadripunctata Acme Zone, representing the uppermost part of the Micula murus Zone which marks the top of the Maastrichtian. This indicates that no significant amount of section is missing and that the lack of A. mayaroensis is probably due to environmental conditions. Hansen et al. (1987) report an upper Cretaceous molluscan assemblage in the Corsicana mudstone.

The first unit of the boundary sequence is a multi-shaded grey, coarse, generally matrix-supported, calcareous-mudstone sedimentary breccia containing clasts as large as 80 cm in longest dimension. The $CaCO_3$ content is ~10%. Natural exposures reveal this unit also occurs at the DMC and CMC localities with thicknesses of approximately 30 and 75 cm, respectively. This unit is not present at the BR2 and BR3 sections where the rest of the coarse boundary sequence pinches out to the south. The sedimentary breccia thickens from ~30 cm at the sampling line across the BRS to ~60 cm only 2 metres to the south, indicating the irregularity of its base. When this section was first visited and sampled by this worker the exposed outcrop was not large enough to reveal this somewhat cryptic breccia, although larger exposures, such as the one pictured in Figure 2, clearly reveal clasts of the breccia. The breccia had not been described by previous investigators, although Hansen et al. (1987) noted that large mudstone clasts occurred at the base of the overlying skeletal sand and that the uppermost Cretaceous (their unit A) had possibly been disturbed by the event which produced the coarse sediments. Dark-gray, calcareous mudstone clasts containing occasional macrofossil fragments are supported in a slightly lighter gray calcareous mudstone matrix with more abundant macrofossil

Figure 2: The Brazos River section outcrop (looking west) showing the K/T boundary sequence; note pick and shovel (foreground) for scale. The pick head lies on the top of prominent-weathering, rippled calcareous sandstone. This unit is underlain by a coarse, pebbly, calcareous, skeletal, sandstone with an irregular base. It is draped over the boulders of a sedimentary breccia which is 30 cm thick at the center of the outcrop. In the center of the photo an 80-cm-diameter, 20-cm-thick, disc-shaped clast of dark-grey mudstone is visible in the sedimentary breccia. The breccia's underlying contact is irregular and the unit thickens to the left (south). The underlying massive, medium-grey Corsicana mudstone represents the top of the Maastrichtian sequence; some uppermost Maastrichtian was probably eroded by the event, probably giant, impact-induced waves, which produced the sequence of coarse and carbonate-rich lithologies.

Above the pick head, a competent, polygonal-jointed, muddy micrite is succeeded by a calcareous mudstone. Earliest Paleocene fossils appear at a 2-cm-thick sandy layer ~15 cm above the top of the micrite.

At the pick head, immediately on top of the rippled sandstone is a 2-3 cm thick calcareous mudstone with associated weak Ir and Au anomalies and reported rare shocked minerals, which may contain the coarse fraction of the fireball layer. The coarse units below the rippled sandstone contain occasional pseudomorphed tektites representing the coarse fraction of the ejecta layer. Immediately beneath the sandy layer ~15 cm above the top of the micrite is a 0-7 mm dark, calcareous claystone with associated siderophile (Ir, Au, Re) and chalcophile (As, Sb, Se) trace-element anomalies which is probably the equivalent to the fine fraction of the fireball layer.



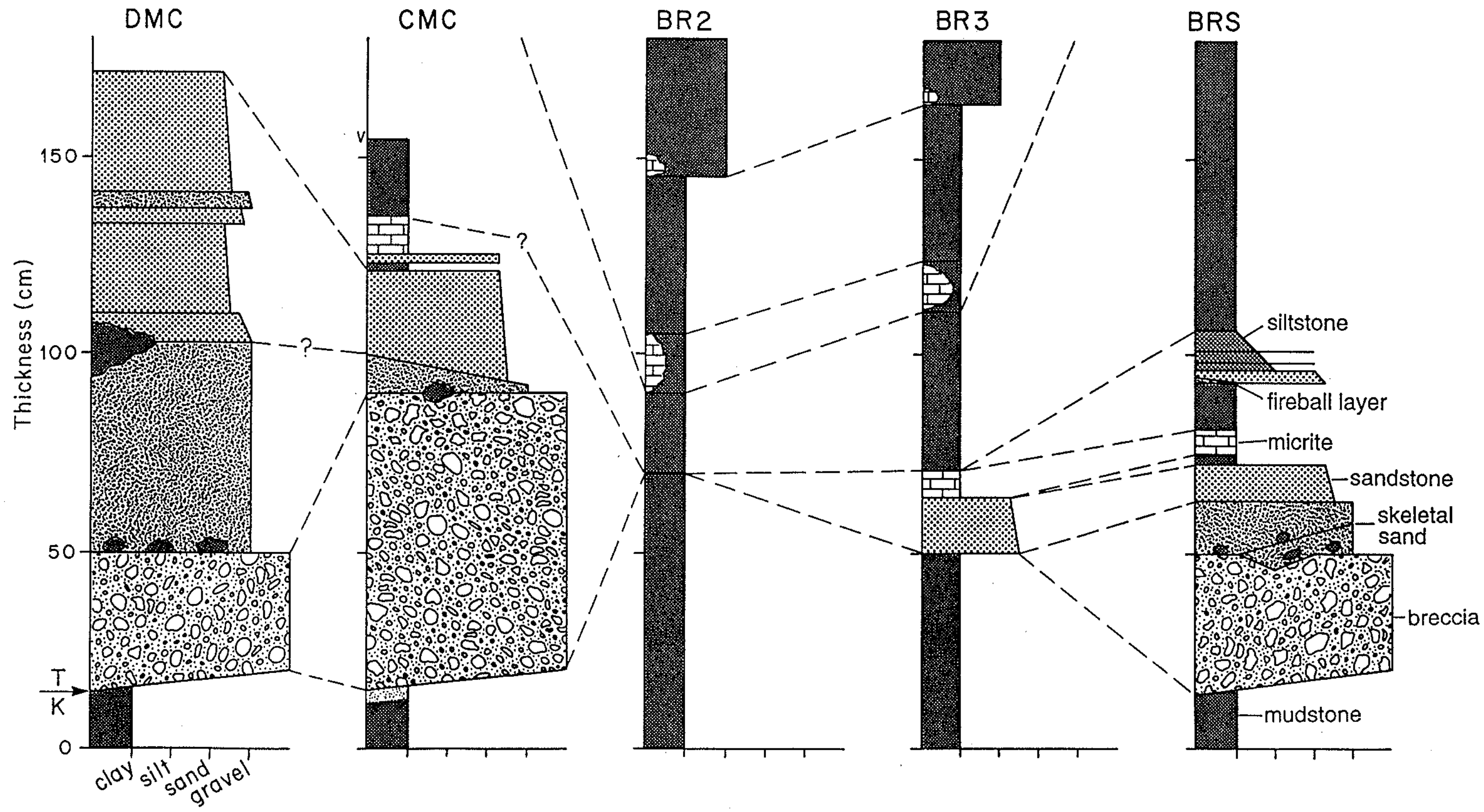


Figure 3: Stratigraphic columns of the K/T boundary interval. The vertical scale shows measured section; the horizontal scale shows grain size. The dashed lines show correlations between the sections which were made on the basis of lithology, biostratigraphy and composition. Note that the BR2 and 3 sections are condensed compared to the other three and that the DMC and CMC sections are truncated by a lack of exposure. The BRS and nearby river bed outcrops best show the boundary stratigraphy.

fragments, possibly Hansen et al.'s (1987) "crude shell laminations". At BRS the darker mudstone clasts are concentrated at the top of this unit and may represent a distinct depositional event of a boulder lag developed on the sedimentary breccia. Hansen (1982) described a sparse molluscan fauna in the large dark mudstone clasts in contrast to that in the underlying Corsicana mudstones, suggesting that these clasts were transported from a significantly different environment. At DMC, the breccia has a higher clast/matrix ratio than at BRS and is mostly clast-supported. The underlying massive Corsicana mudstone is medium gray and distinctly lighter than the sedimentary breccia on well-lit, clean surfaces. Rare, ~10 cm silicified mudstone clasts also occur in this unit, and a few similarly sized disc-shaped impure limestone clasts occur at CMC. The smaller clasts are frequently rotated, but the largest clasts, such as the 80-cm-diameter clast pictured in Figure 2, are disc-shaped and flat-lying. Clasts may be subangular to subrounded, although typically only cross sections may be seen so estimated shapes are tentative. At both DMC and CMC the mudstone clasts have colors similar to those of the matrix and underlying Corsicana mudstones but some variation may also be present. At the CMC locality a 1 to 2 cm-thick, discontinuous gypsiferous kaolinitic clay layer underlies the sedimentary breccia. The bed may be the result of a ground-water effect (secondary gypsum is common in the area), as the CMC section is the most weathered and similar patches are found in the overlying breccia. However, W. Alvarez noted that the layer is pure clay at some spots indicating that it might represent a distinct depositional event. Because such a thin layer corresponds to the base of an irregular, high-energy, erosive deposit, a secondary origin seems more probable.

The basal breccia is overlain by a medium greyish, distinct, laminated to massive, poorly-sorted coarse, pyritic, glauconitic, calcareous, upward-fining sand with abundant macrofossil (typically molluscan) fragments. It has occasional phosphatic and silicic nodules up to 10 cm in diameter concentrated at its base. Its top and bottom contacts are sharp. The $CaCO_3$ content averages ~20%, but decreases upwards through the unit. Occasional rounded mudstone clasts <10 cm across occur generally near the base of this unit (not as abundant as reported by Bourgeois et al., 1988) although one unique, ~100-cm-diameter dark-gray mudstone clast occurs near the top of this unit at DMC. This clast has a very flat disc shape and may have slid (i.e. be an olistolith) rather than rolled. This unit varies in thickness (BRS - 13 cm, DMC - 2 cycles - 60 cm and 4 cm, CMC - 10 cm) and contains at least 2 thick upwards-fining cycles at DMC. In the river-bed outcrops occurring ~50 m south of BRS this unit thins to only a few centimetres thick or pinches out. It does not occur at the BR2 and 3 outcrops. At DMC Smit et al. (1992) found scattered pseudomorphed tektites in the unit near its base. These occur with a "bubble in bubble" texture that is a presumed result of the alteration of the tektites. Also, their interior rim walls have the mammillary texture frequently observed in the pseudomorphed K/T tektites.

The coarse skeletal sand is overlain by 9.5 cm of light-gray, well-sorted, plane-parallel to ripple-laminated, fine, calcareous-cemented, quartz sand with abundant calcareous foraminifera. The $CaCO_3$ content is ~50%. This unit varies in width (BRS - 9.5 cm, DMC - 2 cycles - 27 cm and 30 cm, CMC - 25 cm, BR3 - 14 cm) and fines upwards in 2 major cycles at DMC with possible additional minor cycles superimposed (Fig. 3). Two cycles are also found in the river-bed outcrops south of BRS, the lower one capped by parallel ripples and the upper one by hummocky-shaped ripples apparently indicating a changing and sometimes multi-directional current regime. The bottom contact is sharp; the upper may be sharp to transitional with the overlying mudstone. At BR3 this unit pinches from north to south and is not present at BR2. The unit is sometimes very competent and is the most prominent-weathering unit in the boundary sequence, forming riffles and waterfalls in the Brazos and its tributaries.

A 2-3 cm thick, gray, calcareous, pyritic mudstone caps the coarse sequence. The unit contains ~45% $CaCO_3$ and scattered organics, and contains abundant, well-preserved microfossils (S. Gartner, pers. commun.). It weathers to soft clay, and its contacts are usually gradational, so its extent is difficult to trace. Keller (1989b) reported a similar unit at CMC, but the CMC exposure is so weathered at this level that this unit could not be seen definitively by this worker. This mudstone was not found at BR2 or BR3, and the base of its expected position marks the top of the exposed section at DMC. B. Bohor found 3 shocked quartz grains in samples of this unit as reported by Montgomery et al. (1992).

A 6-cm-thick, light-gray, competent, muddy micrite overlies the thin pyritic mudstone. The very fine-grained, massive unit contains ~ 80% $CaCO_3$ in particles only a few microns across; the remainder is composed of clay particles. It contains no coarse particles or macrofossils and contains only rare calcareous foraminifera and calcareous nannoplankton (S. Gartner, pers. commun.). Electron microscope studies reveal that recognizable carbonate clasts in the micrite are primarily coccolith fragments with occasional complete specimens and other skeletal debris (Z. Lasemi, pers. commun.). This unit has been described as a siltstone or calcitized siltstone (e.g. Bourgeois et al., 1988). It is well exposed in the river riffles south of the BRS section where polygonal jointing perpendicular to bedding is revealed and a uniform thickness is maintained. At CMC this unit is 9 cm thick, laminated (possibly cross-laminated at the base) and slightly contaminated with clay and skeletal debris, although still carbonate-rich. At BR3 it is 7 cm thick, but pinches out to the south over ~10 m across continuous exposure and is absent at BR2. In slightly weathered sections its contacts are marked by sharp colour changes (the micrite weathers a very light gray) but on fresh surfaces the contacts can appear gradational. Overlying the muddy micrite is 14 cm of gray, massive, calcareous mudstone averaging ~30% $CaCO_3$, with carbonate decreasing upwards. Petrographically the unit appears to be a mixture of the very fine-grained carbonate clasts similar to those of the underlying muddy micrite and clay particles similar to those found in the uppermost Corsicana. It contains no coarse clasts; organic particles are common. This unit and the overlying Paleocene Kincaid Formation are difficult to distinguish macroscopically, although the $CaCO_3$ content is diagnostic, being only ~5% in the basal Kincaid. The mudstone's top and bottom contacts vary in sharpness. The unit may occur at CMC based on the elevated $CaCO_3$ content reported by Keller (1989b) for the mudstone at this stratigraphic position, but severe weathering of that outcrop makes this conclusion uncertain. This unit, and the underlying, muddy micrite and rippled, calcareous sand contain burrows originating in the overlying Kincaid Formation, which contain Paleocene macro- and microfossils (Hansen et al., 1987). Both these units contain no

Cretaceous macrofossils, only microfossils, reflecting the absence of any coarse grains of any origin.

The fine-grained units are overlain by a thin (0-7 mm), discontinuous, dark brown, sometimes-distinct, calcareous claystone. This unit is variably contaminated by the overlying sandstone and, if reworked, is finely laminated. It has not been described by most workers, presumably because it is relatively thin and occasionally absent, although Jiang and Gartner (1986) refer to a clay layer at approximately this stratigraphic position. It is discontinuous on the scale of metres, and varies in thickness partly because of selective reworking by the overlying coarser unit. At CMC the outcrop is too weathered and tectonically disturbed to differentiate the dark brown claystone and the overlying, thin, sandy unit. Neither the thin claystone or sandstone were observed at BR2 or BR3.

The dark-brown claystone unit is overlain by a 2 to 3-cm-thick, thinly laminated, fine grained, calcareous, quartzose and sometimes muddy sandstone. This rusty-weathering unit has $CaCO_3$ contents ranging from <5% up to 15% in its bottom and top halves, respectively (Hildebrand, 1992), but was weathered where sampled at BRS so that the variability could be secondary. On fresh surfaces this unit is gray, but on weathered surfaces it is a distinct rusty colour. This sandstone marks the base of the Paleocene section (which in this region is known as the Kincaid Formation) as determined on the basis of nannofossils (Jiang and Gartner, 1986) and foraminifera (Keller, 1989a; b). The fine sand is overlain by a dark-gray mudstone with a silty base and a few, discontinuous, millimetre-thick lenses of silty, fine sand in the first 10 cm. The $CaCO_3$ abundance is ~5% in the first 24 cm of this unit which is ~4 m thick at BRS. The silty and sandy base is 5-10 cm thick, and has been mapped as a separate unit by other workers (e.g. Huffman et al., 1989), but it may also be regarded as a transitional interval, grading into the massive mudstone above. This dark-gray mudstone is darker than the calcareous mudstones on top of the muddy micrite or the uppermost Corsicana. The basal Kincaid unit is much thinner at the BR2 and 3 localities where a coarser sandy unit with large burrows at its base overlies a thinner sequence of the dark-gray mudstone (Fig. 3). Also, see Hansen et al. (1987) for a description of the overlying sandy unit, but note that Hansen et al. apparently improperly correlated a carbonate nodule bed at the BR2 site to the micrite at the BR3 site as noted by S. Gartner (pers. commun.) and confirmed in the field.

Biostratigraphy: Most workers have reported evidence of the K/T boundary faunal turnover at the top of the sequence of atypical lithologies. The Kincaid mudstone lacks the white macrofossil fragments observed in the Corsicana and carries a Paleocene molluscan fauna together with some Cretaceous species at its base that may or may not have been reworked (Hansen et al. 1987). Jiang and Gartner (1986) describe a typical earliest Danian calcareous nannofossil "disaster" sequence characterized by the Markalius astropinorus zone divided into Thoracosphera imperforata, Biscutum romeinii, and Cruciplacolithus primus subzones. They note some Cretaceous nannofossils do carry into the Paleocene Kincaid sediments, and suggest that the Cretaceous nannofossils are probably redeposited. Keller (1989a, b) reports a complete sequence of earliest-Tertiary, calcareous foraminifera, beginning with the Gumbelitria cretacea

P0 zone, in the same dark gray mudstone. Many Cretaceous species occur in the basal mudstone, and Keller (ibid.) concludes that many species persisted briefly into the Paleocene as is typical of most K/T sections (e.g. Smit and Romein, 1985). However, the number of species which do persist instead of reflecting reworking is currently controversial. Beeson (1992) reports that palynomorphs are present in the Brazos River sections and that a fern spore abundance anomaly appears at 3.5 cm above the top of the thin claystone or the level where Paleocene marine forms first appear. Although his study was not done with the same samples as any of the other paleontological studies this apparently establishes that the extinction levels in the marine and nonmarine environments are defining the same horizon which is also the stratigraphic equivalent of the K/T fireball layer (Hildebrand, 1992). This conclusion is based on the assumption that the fern spore abundance anomaly may be retarded for this 3.5 cm thickness due to a sedimentation or sampling effect; alternatively, the extinctions in the marine and nonmarine records would have to be diachronous by the time represented by this interval and the K/T boundary couplet could not be correlated from marine to nonmarine sections.

The biostratigraphic work of Montgomery et al. (1992) conflicts with that of the other studies discussed above with the exception of Smith and Pessagno (1973). Montgomery et al. (1992) placed the K/T boundary below the sequence of atypical lithologies on the basis of foraminifera and coccolith first appearances. Montgomery et al. also describe (and picture) a limestone (wackestone) below the coarse skeletal sand. However, this unit has not been observed by this author although some of the same exposures at CMC have been studied in detail. They did not record the presence of the basal sedimentary breccia. It may be that this limestone unit is equivalent to the impure limestone clasts observed in the sedimentary breccia, but resolution of these inconsistencies will have to await new joint field investigations. If the K/T boundary location of Montgomery et al. (1992) is valid then the K/T boundary as defined in marine and nonmarine sections is apparently diachronous by at least tens of thousands of years.

Mineralogy: The mineralogy of the boundary sequence has been studied petrographically and with X-ray diffraction by Butler (1983) in the BRS and by Barrera and Keller (1990) in the CMC core. Barrera and Keller report illite/smectite, calcite, quartz, feldspar, pyrite, glauconite and/or illite, kaolinite and sporadic mica throughout the section. They also report authigenic dolomite in the calcareous mudstones overlying the coarse units. These studies show that the impure micrite and immediately overlying calcareous mudstone unit at BRS have less clay and more calcite, and that the rippled calcarenite has more quartz and calcite than the Corsicana and Kincaid mudstones. Butler (1983) reports that the clay at the base of the rippled calcarenite is mainly composed of extremely poorly ordered smectite. This clay mineralogy is the same as found at the Beloc, Haiti marine K/T sections after alteration of tektite glass (e.g. Hildebrand, 1992) and may reflect a similar origin at BRS. In summary, mineralogical studies show that part of the boundary sequence has unusually quartz- and calcite-rich lithologies relative to the enclosing mudstones of the Corsicana and Kincaid Formations with unusual clay-mineral compositions.

Conclusions: The Brazos River K/T sequence, from the base of the sedimentary breccia to the top of the 2-mm-thick calcareous mudstone, represents a novel type of K/T boundary deposit. As discussed by Smit and Romein (1985), Bourgeois et al. (1988) and Hildebrand (1992) this deposit was probably produced by waves generated by a marine K/T boundary impact. The discovery of the K/T-age Chicxulub crater on the Yucatán Platform on the opposite side of the Gulf of Mexico (e.g. Hildebrand et al., 1991; Swisher et al., 1992; Sharpton et al., 1992) and many additional examples of impact-wave deposits (e.g. Hildebrand and Boynton, 1990; Smit et al., 1992; Alvarez et al., 1992) make a case for a large marine impact in the area between the Americas at K/T time. However, the identification of Chicxulub and its impact-wave deposits remains disputed with some workers interpreting the atypical lithologies as a consequence of a sea-level regression (e.g. Officer et al., 1992; Beeson, 1992; Keller et al., 1993; Stinnesbeck et al., 1993; Meyerhoff et al., 1994). By the definition proposed by Hildebrand (1992), the coarse K/T units preserved at the Brazos River would be regarded as part of the Chicxulub Formation and the K/T boundary would be located at the base of this coarse sequence as it is provisionally assigned here.

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