Jason Sanford received his B.Sc. degree in geology and Spanish from Middlebury College (Vermont). He then worked for a year with an independent petroleum exploration company in Midland, TX. He is currently working in his M.Sc. at the University of Texas (Austin); Drs. John Snedden and Sean Gulick are his advisors.

The Cretaceous-Paleogene boundary unit, Gulf of Mexico: Character, distribution, and relation to the Chicxulub impact

SUMMARY

The Chicxulub asteroid impact initiated a global catastrophe that drastically altered the Earth's climate and ecology at the start of the Cenozoic (e.g., Alvarez el al. 1980, Hildebrand et al. 1991, Schulte et al. 2010). Due to its proximity to the impact site, the Gulf of Mexico basin was likely the most severely affected locale, suffering extreme geologic and marine processes (e.g., seismogenesis, tsunamigenesis, platform collapse, mass transport) that yielded a geologically instantaneous transformation of the basin.

A thick (hectometer-scale) carbonate deposit located at the Cretaceous-Paleogene (K-Pg) boundary has been observed in seismic reflection and borehole data in the Gulf Mexico, and is believed to have resulted from the Chicxulub impact and associated processes (e.g., Bralower et al. 1998, Scott et al. 2011, Denne et al., in press). My research aims to characterize this boundary unit throughout the Gulf of Mexico using seismic reflection and borehole data, and to use these results to infer the impact-related processes that produced the deposit. Finally, I plan to use my results to illustrate the paleotopography of the Gulf at the start of the Cenozoic and its control on deposition in the Paleogene.

Key questions:

- Is the Chicxulub impact responsible for the thick carbonate deposit located at the K-Pg boundary in the Gulf of Mexico?
- What is the distribution of this boundary unit from the Chicxulub crater to the deep Gulf?
- What marine and geologic processes occurred in the basin as a result of this impact, and how are they recorded in the stratigraphic record?
- How did the impact redefine paleotopography and consequently influence subsequent deposition at the start of the Cenozoic?

If awarded an Ed Picou Fellowship, I will dedicate funding to field and laboratory work that would aid my study on the K-Pg boundary unit. Work would include observation and description of Deep Sea Drilling Project, Ocean Drilling Program, and Integrated Ocean Drilling Project (DSDP/ODP/IODP) cores penetrating the K-Pg boundary; known K-Pg boundary outcrops proximal to the Chicxulub crater; and two previously unidentified cores penetrating the K-Pg boundary in shallow-water and onshore Gulf of Mexico. This work would bolster my basin-wide perspective of boundary unit deposition and allow me to better couple associated deep-marine, shallow-water, and onshore processes.

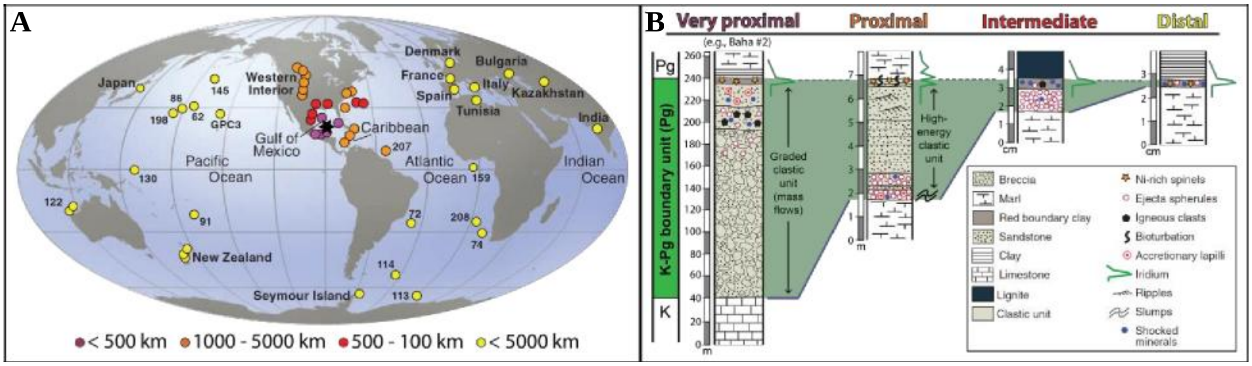

Figure 1. Global distribution and lithology of key K-Pg boundary unit locations. (**A**) World map illustrating the distribution of key K-Pg boundary unit penetrations, colored by distance from the Chicxulub impact crater (asterisk). (**B**) Schematic lithologic sections of K-Pg boundary deposits, illustrating how they vary significantly with proximity to the crater. Color of global locations and lithologic sections correspond between (**A**) and (**B**); with increasing distance from the crater, deposit thins from hundreds of meters to less than a centimeter. AC 557 (Baha) #2 typifies the boundary unit in the Gulf of Mexico with an approximate thickness of 200 m; see Figure 3 for well location. Modified from Schulte et al. (2010).

OVERVIEW

Since it was described at Gubbio, Italy, and El Kef, Tunisia, the K-Pg boundary unit has been posited as the product of a catastrophic extraterrestrial impact responsible for one of the largest mass extinctions in the fossil record (Alvarez et al. 1980; Perch-Nielsen 1980; Raup and Sepkoski 1982; Smit and Hertogen 1980). With the 1991 publication of Glen Penfield's discovery of an impact crater on the Yucatán Peninsula more than a decade prior, the ideal candidate for hypothetical impact was found (Hildebrand et al. 1991). Since then, locales throughout the world have been found to contain the K-Pg boundary unit (Fig. 1A), which ranges from a thin (< 5 mm) clay layer rich in platinum-group elements (PGE) and impact ejecta material in distal (> 5000 km) areas to a thick (> 100 m) carbonate sequence in areas very proximal (< 500 km) to the crater (Fig. 1B; Bralower et al. 1998, Claeys et al. 2002, Schulte et al. 2010).

Given its proximity to the impact site and marine setting, the Gulf of Mexico is the ideal locale for deposition and preservation of the K-Pg boundary unit. Nevertheless, the geological result of the impact in the Gulf remains poorly understood, and the submarine setting and depth of the K-Pg boundary unit has thwarted scientific interest until very recently (e.g., Scott et al. 2011, Denne et al. 2011a).

Recent exploration for oil and gas has expanded into deeper and/or sub-salt stratigraphy, revealing objectives in the lower Cenozoic (e.g., Paleogene Wilcox) and Mesozoic strata. Borehole and seismic data that penetrate the K-Pg boundary can be utilized to better understand the effect of the Chicxulub impact in the area (e.g., Scott et al. 2011, Denne et al. 2011a, Gulick et al., in press, Whalen et al., in press). If the prevailing hypothesis of an impact origin for the K-Pg boundary unit is true, then the Chicxulub impact must have initiated catastrophic submarine sedimentary processes in the Gulf of Mexico that drastically altered paleotopography and defined subsequent depositional systems, including that of the Wilcox and other potential hydrocarbon reservoirs (Denne et al. 2011b).

CURRENT PROGRESS & PLANNED WORK

My interest in the K-Pg boundary unit in the Gulf of Mexico is equally sedimentologic and stratigraphic. First, I seek to employ the stratigraphic record to understand the deformational and depositional processes initiated by the impact and resulting in the boundary unit. Second, I intend to apply this knowledge to evaluate how the impact redefined the ancient seascape for subsequent deposition in the Cenozoic. For these purposes, I am using seismic reflection and borehole data throughout the Gulf of Mexico to

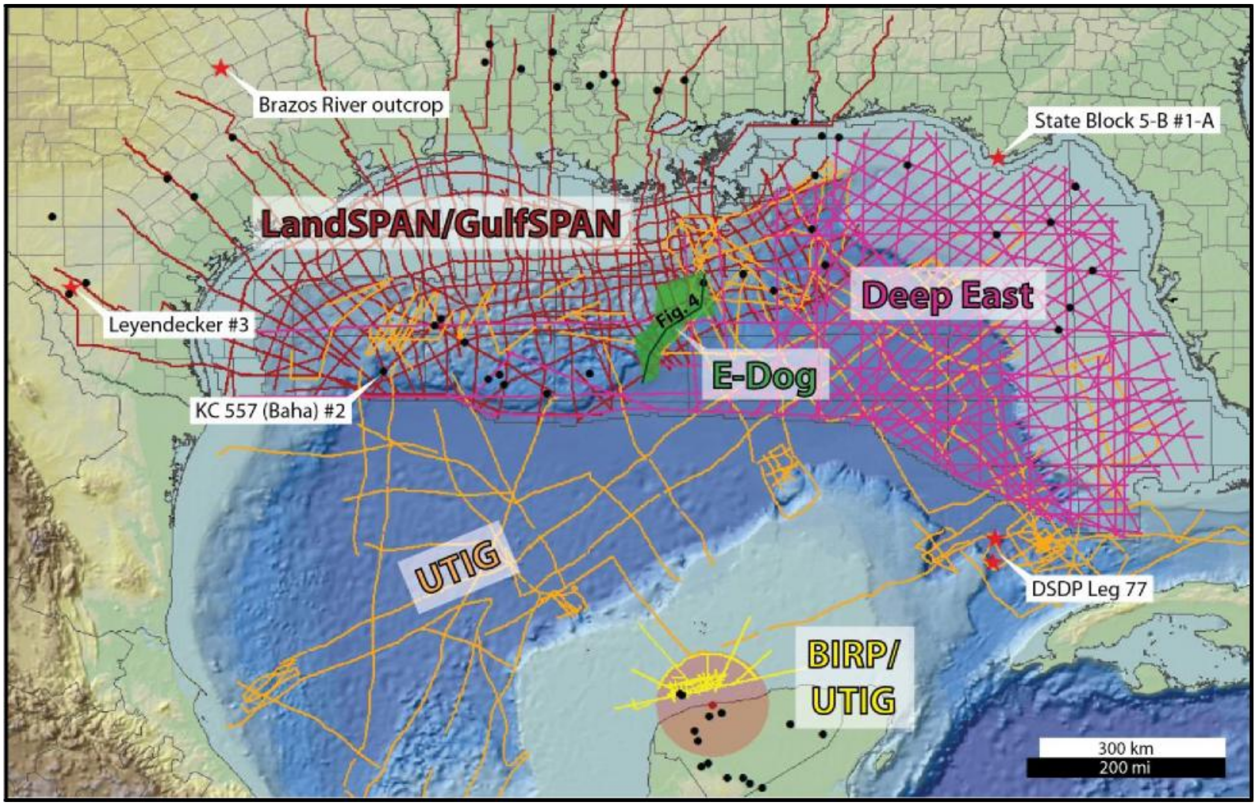

Figure 2. Map of the Gulf of Mexico, illustrating Gulf-wide seismic reflection and borehole dataset being used for this study. Black dots represent the location of complete or partial penetrations of the boundary unit, and seismic lines are colored by survey. Center and extent of the Chicxulub crater are indicated by red dot and shading, respectively. Note the location of the KC 557 (Baha) #2, the type well for the K-Pg boundary unit in the deep-water Gulf (Fig. 3), and the seismic transect through E-Dog shown in Figure 4. Red stars indicate the location of wells and field sites for proposed field and laboratory work DSDP/ODP Legs 44 and 171 (North American Atlantic margin) and Leg 165 (Caribbean Sea) are out of the bounds of this map. LandSPAN and GulfSPAN 2-D data are courtesy of IonGeoventures; Deep East 2-D data are courtesy of Fugro; E-Dog 3-D data are courtesy of WesternGeco.

characterize the boundary unit and to correlate it from the basin center to the Chicxulub crater on the Yucatán Peninsula.

Borehole dataset and character

Though Cretaceous well penetrations are scarce in the Gulf of Mexico, borehole data can greatly facilitate identification and characterization of the K-Pg boundary unit. To date, the dataset includes 25 offshore boreholes that penetrate the boundary unit, 14 onshore boreholes that penetrate the boundary unit in or near the Chicxulub crater on the Yucatán Peninsula; and 13 onshore boreholes that penetrate the boundary unit on the Gulf Coast of the continental United States (see Fig. 2). Of the 25 offshore boreholes, 12 are considered “deep-water” (> 500-m water depth), where the K-Pg boundary unit is thickest. Of these 12 boreholes, six penetrate the unit completely.

In deep-water boreholes, the K-Pg boundary unit is a thick (> 100 m) interval that exhibits a blocky gamma ray response with very low counts (~30 GAPI) and a strong resistivity response relative to adjacent stratigraphy (~2-20 ohm-m deep resistivity; Fig. 3). Resistivity response often registers a sharp “kick” at the base and faintly decreases upwards, occasionally accompanied by an increasing-upward gamma ray

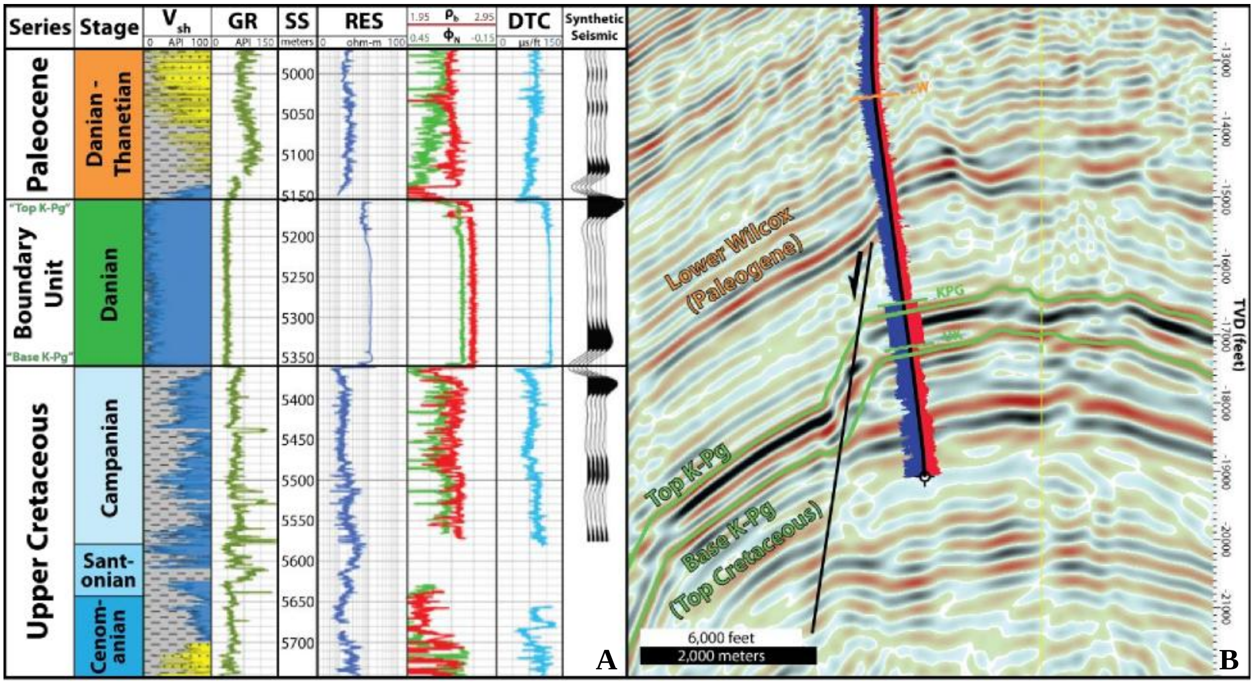

Figure 3. Typical well-log and seismic response of the K-Pg boundary unit in the Gulf of Mexico. (**A**) Type log of the K-Pg boundary unit and adjacent stratigraphy in AC 557 (Baha) #2 in the deep Gulf of Mexico (modified from Denne et al. 2013). Note the characteristic log response and synthetic seismogram, suggesting that the boundary unit is resolvable in both borehole and seismic data. (**B**) Small (~ 6.5 km) portion of GulfSPAN line 2400 overlain by gamma ray and deep resistivity curves from the nearby Baha # 2 well. The seismic data illustrates the characteristic response of the boundary unit in seismic reflection data due to the high impedance contrast between the overlaying Wilcox sands and the hard carbonates of the boundary unit. Well-log and seismic signature of the boundary unit clearly correspond. The Baha #2 borehole is approximately 3 km from the location of the seismic transect, resulting in the apparent mistie of borehole and seismic data. See Figure 2 for seismic line and well location.

response, characteristics suggestive of a fining-upwards clastic sequence. In shallower waters (< 500 m) and onshore, the boundary unit thins significantly, ranging from tens of meters to less than a meter. Due to its minimal thickness in shallow-water and onshore wells, as well as its compositional similarity to sub- and superjacent sediments in areas (e.g., carbonates of the Florida Platform), biostratigraphic data becomes increasingly diagnostic.

Seismic dataset and character

While borehole data is vital to understanding the petrophysical attributes of the boundary unit, the limited amount of borehole penetrations frustrates efforts to characterize the unit. However, seismic reflection data throughout the Gulf images the boundary unit very clearly, and consequently are the focus of this study. The two-dimensional dataset in use for this study compiles data from several surveys throughout the Gulf of Mexico to achieve basin-wide seismic coverage: ION Geoventures' GulfSPAN and LandSPAN surveys in the western and central Gulf; Fugro's Deep East survey in the eastern Gulf; the University of Texas Institute for Geophysics' (UTIG) surveys throughout the Gulf, including two surveys of the Chicxulub crater, one of which was acquired in collaboration with the British Institutions Reflection Profiling Syndicate (BIRPS; Fig. 2). Furthermore, the seismic dataset includes data from a high-resolution three-dimensional survey (E-Dog) in the central Gulf, graciously donated by WesternGeco (Fig. 2). All data received from third-party donors (i.e., ION Geoventures, Fugro, and WesternGeco) are depth-converted.

For the purpose of this study, I have depth-converted all seismic data from UTIG/BIRP's Chicxulub crater

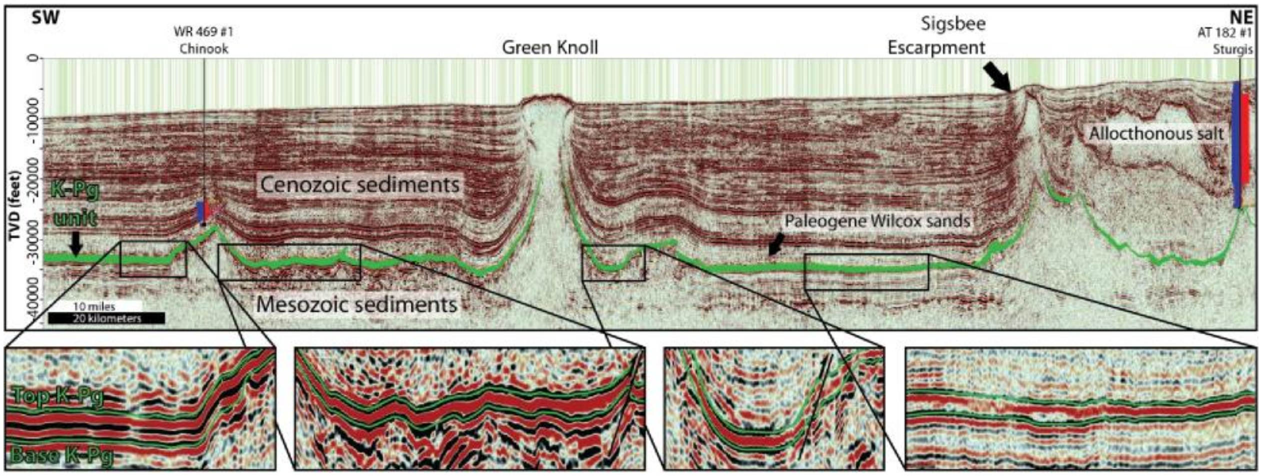

Figure 4. Seismic transect through the E-Dog survey area, demonstrating the structure and thickness of the K-Pg boundary unit in the central Gulf of Mexico. Northeast of the Sigsbee Escarpment, seismic imaging of the boundary unit degrades drastically as a result of overlying salt, though the three-dimensionality of the E-Dog data often allows interpretation despite this difficulty. Insets illustrate the variability in thickness and seismic character of the boundary unit, a focus of this study. Gamma ray (blue) and deep resistivity (red) curves for WR 469 (Chinook) #1 and AT 182 (Sturgis) #1 overlay the seismic profile. See Figure 2 for location of this transect and Sturgis #1; Chinook #1 is not displayed on Figure 2 because it does not penetrate the boundary unit.

surveys, and plan to depth-convert select lines from the Gulf-wide UTIG profiles in order to interpret the K-Pg boundary unit from the crater to the deep Gulf. Furthermore, ION Geoventures is currently reprocessing and depth-converting the entire Gulf-wide UTIG dataset; portions of these data may become gradually available to me throughout the course of this study.

The K-Pg boundary unit is clearly distinguishable in seismic reflection data throughout the Gulf of Mexico (Figs. 3 and 4). Impedance contrast between the overlying, relatively slow sands of the Lower Wilcox and the hard and fast carbonates of the boundary unit yield high-amplitude reflectors that make recognition of the boundary unit straightforward, though not without exception. Where the salt canopy is substantially thick and/or complex, seismic penetration can be attenuated, significantly dampening the seismic reflection signature of the boundary unit (Fig. 4). Fortunately, the three-dimensionality of the E-Dog data allows for interpretation of the boundary unit even in areas of allochthonous salt, and has proved vital to developing sound criteria for interpreting beneath the salt canopy.

Consequently, the E-Dog survey area has served as an ideal "seed" from which to begin seismic interpretation of the K-Pg boundary unit. To date, I have interpreted the top of the boundary unit throughout the survey area (as well as other areas in the Gulf), revealing considerable variation in structure, thickness, and seismic character of the boundary unit (Fig. 5). Deposition of the boundary unit in the wake of the impact appears to have blanketed the deep-water Gulf of Mexico. Mobilized sediment deposited virtually everywhere throughout the basin, taking advantage of paleo-lows where present. Frequently, salt deflation of the Cretaceous salt canopy appears to have been an important post-depositional influence on the unit.

Moving forward, I plan to interpret the K-Pg boundary unit throughout this study's seismic dataset, applying the criteria for recognition of the boundary unit learned from interpreting E-Dog. Specifically, I will selectively depth-convert lines from UTIG's Gulf-wide dataset, using them to correlate from the Chicxulub crater seismic survey area to the central Gulf. Then, I will use the GulfSPAN and LandSPAN data to map the boundary unit within the central and western Gulf and the Deep East data to map to the eastern Gulf, onto the Florida Platform. Finally, I plan to use my findings to infer the various processes that contributed to the deposition of the boundary unit, and how it redefined the paleotopography in the wake of the event. In whole, I hope that my findings will adequately characterize the K-Pg boundary unit in the Gulf of Mexico, and in turn inform our current understanding of catastrophic impacts and associated sedimentary processes.

PLAN FOR PROPOSED FUNDS

If awarded an Ed Picou Fellowship, I will devote funds to field and laboratory work that would facilitate my understanding of K-Pg boundary unit deposition in the Gulf of Mexico. Such work would include description of two previously unidentified cores of the K-Pg boundary unit in the Gulf of Mexico basin. The first of these is the State Block 5-B #1-A core, held at the Florida Geological Survey Sample Repository in Tallahassee, Florida, the only known publically released core of the K-Pg deposit in the shallow-water Gulf of Mexico (Fig. 3). The second is the Leyendecker #3 core from Webb County, Texas, housed at ExxonMobil’s core facilities in Dallas, Texas (Fig. 3).

Laboratory work would also include observing and describing up to eight cores (Sites 390, 536, 538, 999, 1001, 1049, 1050, and 1052) from four legs (44, 77, 165, and 171) of the DSDP and ODP that penetrate the K-Pg boundary unit in areas near (< ~1600 km) to the Chicxulub crater, all housed at the DSDP/ODP/IODP Gulf Coast Repository at Texas A&M University in College Station, Texas (Fig. 3). Finally, work would include a trip to the Brazos River in Rosebud, Texas, to observe and describe a type outcrop of the K-Pg boundary unit proximal (~900 km) to the Chicxulub crater (Fig. 3)

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