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Massive Cretaceous-Paleogene boundary deposit, deep-water Gulf of Mexico: New evidence for widespread Chicxulub-induced slope failure

Richard A. Denne1, Erik D. Scott2, David P. Eickhoff1, James S. Kaiser1, Ronald J. Hill3, and Joan M. Spaw1

1Marathon Oil Corporation, 5555 San Felipe, Houston, Texas 77056, USA
2Talisman Energy USA Inc., 9320 Lakeside Boulevard, The Woodlands, Texas 77381, USA
3Noble Energy, 1625 Broadway, Suite 2200, Denver, Colorado 80202, USA

ABSTRACT

The single largest-known mass wasting deposit has been identified at the Cretaceous-Paleogene (K-Pg) boundary in the deep-water Gulf of Mexico, in 31 industry-drilled wells and on seismic data, corresponding to the “MCU” (middle Cretaceous unconformity) horizon. The deposit has an average thickness of 10–20 m on the upper slope and 90–200 m on the lower slope and basin floor, and is on an unconformity that represents 9 m.y. to 85 m.y. The deposit contains the distinctive association of lithic fragments, impact-derived material, and reworked microfossils (i.e., the Cretaceous-Tertiary boundary “cocktail”) associated with the Chicxulub impact, and is predominantly composed of graded pelagic carbonates. These new findings substantiate widespread slope failure induced by the Chicxulub impact and provide further evidence of a single impact coincident with the K-Pg mass extinction.

RESULTS

Thirty-three (33) industry wells with publicly available petrophysical data have penetrated Cretaceous sediments in the deep-water (>300 m) northern GOM. The biostratigraphic data comprise studies of foraminifera and calcareous nannofossils from cutting samples, typically at ~9 m intervals. Nine of the industry K-Pg boundary penetrations and samples from DSDP Sites 536, 538A, and 540 were examined for calcareous nannofossils by one of us (Denne). The biostratigraphic top of the K-Pg boundary deposit was placed at the highest sample dominated by Cretaceous species; the first evolutionary occurrences (bases) of Danian species are not reliable because of possible downhole contamination in cutting samples. Assemblages were compared against those described as the Cretaceous-Tertiary boundary cocktail by Bralower et al. (1998). The ages of biostratigraphic datums are from Ogg et al. (2008).

The study used natural gamma ray (GR), resistivity (RES), bulk density (RHOB), thermal neutron porosity (NPHI), and compressional sonic (DTC) petrophysical logs. Sample descriptions were used to verify the lithology when available. The layer containing the biostratigraphically defined K-Pg boundary has a distinctive petrophysical signature, characterized by low GR and an elevated RES relative to the bounding lithology. The RHOB and NPHI logs indicate a low-porosity carbonate material. These characteristics were used to determine the position of the K-Pg boundary deposit in wells for which biostratigraphic data have not been released.

The compressional velocity of the deposit is significantly higher than the surrounding shales, producing a large impedance contrast. This unambiguous tie to a seismic signature allows for mapping on proprietary seismic lines in the northern GOM and publicly available seismic lines from the University of Texas Institute for Geophysics (www.ig.utexas.edu /sdc/) in the southern and eastern GOM to ascertain the extent and variability of the deposit. Poor imaging beneath salt sheets and stratigraphic disruptions caused by salt tectonics precluded detailed regional mapping of the deposit.
species, indicating post-depositional mixing. That no typical succession of age-diagnostic biostratigraphic events, such as extinctions, evolutionary first occurrences, or assemblage changes, is discernible within the deposit is further evidence that it contains a mixture of redeposited fossils. This microfossil assemblage is identical to the Cretaceous-Tertiary boundary cocktail described and interpreted by Bralower et al. (1998) to be a result of the Chicxulub impact, implying that the K-Pg boundary deposit discussed here is also associated with the impact. Foraminiferal assemblages are dominated by Maastrichtian and Campanian planktonic forms, with rare deep-water benthic foraminifera.

The deposit is 10–67 m thick on the upper slope and ancient structural highs (Fig. 2A), where it is typically a lime mudstone (calcilutite) composed predominantly of pelagic carbonate particles, with the exception of the AT 336 #1 well, where it is a cross-bedded lime wackestone containing shallow-water fossils (Dohmen, 2002). Although thicker, these deposits are similar in composition to K-Pg boundary layers described from bathyal outcrops in northeastern Mexico (Smit et al., 1996) and DSDP sites from the southeastern GOM (Alvarez et al., 1992; Bralower et al., 1998).

The deposit on the GOM lower slope is as much as 200 m thick (Figs. 2A and 3), and was penetrated by 17 wells; 5 of these wells penetrated the deposit on top of salt sheets that have moved basinward. These salt carapace deposits are thinner than other lower slope deposits because the salt sheets were structurally high at the time of deposition. On the lower slope the deposit is a single massive graded bed composed of pelagic carbonate particles, comparable to the massive limestones found at the K-Pg boundary on Cuba (Tada et al., 2003). The deposit correlates to a laterally continuous couplet of parallel, high-amplitude reflections.
found throughout the lower slope and basin floor of the GOM (Fig. 4). The upper reflection corresponds to the seismic horizon mapped as the MCU, or middle Cretaceous unconformity (e.g., Faust, 1990). Smit and Alvarez (1991) speculated that the MCU horizon is the K-Pg boundary; this was confirmed by Dohmen (2002). The lower reflection truncates underlying reflections in the vicinity of preexisting structures; this is indicative of erosion. On regional seismic lines, the deposit is 100–200 m thick on the lower slope and basin floor, thins on structural highs and salt, and thickens to >1000 m in salt-related minibasins.

An unconformity occurs underneath the K-Pg boundary deposit at all locations that drilled into underlying in situ section, representing an age gap ranging from 9 m.y. to 85 m.y. (Fig. 2B; Table DR1 in the Data Repository), corroborating the erosion seen in seismic data. The youngest sediments beneath the deposit are Campanian calcareous shales containing a *Globotruncanella havanensis* Zone (ca. 74 Ma) foraminiferal assemblage in the MC 379 #1 well and a CC22 Zone (ca. 76 Ma) calcareous nannofossil assemblage in the AC 557 #1 and KC 596 #1 wells. The oldest sediments are Jurassic shales (ca. 150 Ma) underneath the deposit in the AT 337 #1 well. The largest hiatuses were found beneath thin or missing K-Pg boundary deposits on the upper slope and structural highs, particularly in the northeastern portion of the study area, probably due to a condensed Upper Cretaceous section.

A typical sequence of biostratigraphic events was found in the rocks below the K-Pg boundary in those wells that drilled through the basal unconformity. The AC 557 #1 well penetrated the most complete Cretaceous section on the lower slope, where 480 m of middle Campanian–Hauterivian (ca. 132 Ma) calcareous shales are interbedded with thin-bedded limestones and sandstones (Fig. 3). Comparison of the rocks penetrated by the AC 557 #1 indicates that the K-Pg boundary deposit is unique; no other interval in the well exhibits a similar petrophysical response.

**DISCUSSION**

**Deposit Volume**

Norris et al. (2000) suggested that the mass wasting deposits identified at the K-Pg boundary in the western North Atlantic represent the most
Evidence for a Single Impact

A contrasting hypothesis to the link between the Chicxulub impact and the K-Pg mass extinctions proposed that the Chicxulub impact predates the K-Pg boundary by 300 k.y. (Keller et al., 2004), and that there were multiple impacts, including an impact larger than Chicxulub, at the K-Pg boundary (Keller, 2005). A second smaller crater, 24 km in diameter, has been identified in Ukraine, but this impact is unlikely to have caused significant devastation (Jolley et al., 2010). Keller et al. (2003, p. 365) stated that the single impact scenario “suffers from a lack of evidence of large-scale slumping” produced by Chicxulub; however, the well and seismic data presented here provide evidence of unprecedented large-scale slumping caused by Chicxulub, refuting this argument for multiple impacts. Conversely, if there had been a bolide impact bigger than Chicxulub at the K-Pg boundary, as posited by Keller (2005), the evidence that originally pointed to the GOM–Caribbean region as the impact site (e.g., Hildebrand and Boynton, 1990) should have pointed toward this proposed impact and not Chicxulub. This purported impact would also be expected to have produced an immense deposit for which there is currently no evidence. Therefore, the existence of a single impact larger than Chicxulub at the K-Pg boundary is doubtful.

CONCLUSIONS

The well and seismic evidence presented here supports the conclusions of the majority of previous research that a large bolide hit the Yucatan Peninsula at the time of the K-Pg boundary (Schulte et al., 2010). This impact produced seismic shocks that caused the collapse of proximal carbonate platforms (Grajales-Nishimura et al., 2000; Tada et al., 2003) and unstable shelf margins into the deep-water GOM and proto-Caribbean as mass transport complexes. Unconsolidated Maastrichtian and Campanian sediments on the slope and basin floor were destabilized and suspended into the water column by the seismic shock, possibly augmented by hydrate dissociation, turbidity currents, and tsunamis, removing almost all of the Upper Cretaceous sediments at many upper slope locations. These sediments settled throughout the basin as massive graded marls or limestones containing the mixed Maastrichtian and Campanian microfossil assemblage, known as the Cretaceous-Tertiary boundary cocktail (Bralower et al., 1998). In the GOM, the resulting deposit ranges in thickness from tens of meters on the upper slope to hundreds of meters on the lower slope and basin floor, with the top of the deposit correlating to the seismic horizon originally mapped as the MCU. The overall deposit in the GOM, Caribbean, and the North Atlantic is the largest known submarine event deposit, and is an order of magnitude larger than any other known deposit. This new evidence does not preclude the possibility of other causal factors for the K-Pg mass extinction, but it does place doubt on assertions that there were multiple impacts, while providing crucial evidence of the impact’s destructive effects on the GOM region.

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