Collaborative Research: Evaluating Climate Change and Kill Mechanisms Associated with the End-Cretaceous Mass Extinction: A Model-Data Comparison Approach

Overview: Paleontological evidence confirms that approximately 75% of all species on Earth went extinct across the Cretaceous-Paleogene (K-Pg) boundary (66 Ma). Although most experts agree that the K-Pg mass extinction was primarily a result of the Chicxulub impact, associated forcings and feedbacks have largely been approached qualitatively, limiting mechanistic understanding of the causes for extinction. Moreover, existing proxy data do not constrain environmental changes well during the first years to millennia of the Paleogene. With a diverse team of researchers, the proposed study will combine new and existing proxy records with Earth system model simulations to elucidate the processes leading to the K-Pg mass extinction and subsequent environmental recovery.

Using a customized, state-of-the-art Earth system model, the PIs propose a series of K-Pg simulations that mimic forcings from the Chicxulub impact. The model contains an explicit aerosol resolving scheme and high-top atmosphere, both of which are essential for capturing the processes associated with these extreme perturbations. Further, development and implementation of an ocean biogeochemistry module will allow for direct comparison with paleontological, chemical, and isotopic records across the K-Pg boundary. Using a variety of model configurations, these simulations will capture the temporal and spatial responses of the Earth system in the days to multi-millennia after impact. The proposed experiments will be the first to simulate the coupled responses of Earth's climate, depositional, and biotic systems to these K-Pg events within a consistent modeling framework.

To constrain and validate the K-Pg simulations, the PIs will collect high resolution soot, temperature, and biomarker records. Several studies suggest that if the asteroid impact produced widespread fires, then soot emission could drive the impact winter. However, evidence for impact-driven fires remains controversial. Therefore, additional samples will be analyzed for soot to confirm or refute the widespread fires hypothesis as well as provide additional constraints for the simulations. Proxy records that capture climate evolution across the K-Pg boundary are also scarce and implications of the existing data are often disputed. The PIs propose generating new estimates for surface temperature change using phosphatic microfossils, a paleotemperature archive widely used with Paleozoic samples, but previously applied to the K-Pg boundary only once with provocative results, and TEX_{86}, a paleotemperature archive previously shown to capture abrupt climate change across the K-Pg boundary. These records will provide sub-millennial scale constraints on marine temperature, and in combination with simulations, a means to backout CO_2 emissions associated with the impact. Finally, additional high resolution biomarker work will shed light on the rate of marine recovery and discrepancies between organic and inorganic carbon isotope records after the asteroid impact, which again can and will be directly compared with simulations. Data from these measurements will provide novel, and much needed, perspective on the possible temporal patterns of climatic change in the millennia bounding the K-Pg. From model-proxy comparisons, this study will help determine which combination of emission magnitudes, timings, and durations best explain patterns of response across the K-Pg boundary.

Intellectual Merit: The results of this project will provide a systems-level understanding of the mechanisms responsible for the K-Pg extinction and help settle several longstanding debates within the geological sciences, including if the impact caused 1) widespread fires and soot emission, 2) CO_2 release and warming, 3) ocean acidification, and 4) increased UV exposure. In addition, the findings will help inform several present-day environmental issues. First, emissions from the Chicxulub impact potentially led to a rapid atmospheric CO_2 increase. Therefore, studying these events will provide a better understanding of the short- and long-term Earth system responses to current anthropogenic CO_2 emissions. Second, the ocean biogeochemistry model will help determine biological response and resilience to large climate forcings, delivering insight into potential drivers of another mass extinction. Finally, model development associated with this project will provide a tool for studying asteroid and volcanic emissions during other periods in Earth's history as well as the consequences of nuclear conflict.

Broader Impacts: Mass extinction is a topic that excites and engages both specialists and the general public, presenting an opportunity to educate a broad audience on the methods scientists use to study and predict the earth system. The PIs will partner with Science Discovery at the University of Colorado to develop and disseminate a STEM learning module and teacher professional development program, with Hickman High School to develop a paleothermometry lecture and lab experiment, and with the University of Connecticut's State Museum of Natural History to create an exhibit that presents the data, methods, and findings of this study. Given general interest and accessibility of the topic, the methods and results will be incorporated into undergraduate and graduate level courses. Finally, this work will help support two early career scientists, train four graduate students and one postdoc, and engage a number of undergraduate students at a minority serving institution.