PALEONTOLOGICAL AND MINERALOGICAL EVIDENCE FOR A SINGLE K/T EXTINCTION IMPACT AT CHICXULUB. D. S. Ebel[1,4], M-M. Mac Low[2,5], and N. H. Landman[3,6]. [1]Department of Earth and Planetary Sciences, [2]Department of Astrophysics, [3]Division of Paleontology (Invertebrates), American Museum of Natural History, Central Park West at 79th St., New York, NY 10024. [4](debel@amnh.org), [5](mordecai@amnh.org), [6](landman@amnh.org).

Introduction: The sharp boundary between the Cretaceous and Paleogene (formerly Tertiary [1]) periods (K/T) is contemporaneous with the second-largest impact crater on the Earth's surface, at Chicxulub, Yucatan Peninsula [2]. It marks the mass extinction of ~70% of species, including non-avian dinosaurs [3, 4].

The impact is represented by two spherule layers: a lower, Ir-poor, macro-spherule layer, thick near the Gulf of Mexico and thinning to nothing in Pacific drill sections; and an upper, global, Ir-rich layer of microspherules containing Ni-rich spinel crystals [5]. These lower 'tektite' and upper 'condensate' layers are separated by meters-thick hydraulically deposited sands near the Caribbean [6], but by not even a single leaf in Colorado [7]. On the New Jersey coastal plain, 2500 km from the impact, the two layers appear in the Bass River core [8], but spherule deposition relations have not been rigorously determined in outcrop [9].

The primary killing phenomenon was a pulse of infrared radiation lasting hours to days produced by global re-entry of the impact fireball condensate spherules into Earth's atmosphere [10,11]. Radiation from the reentering debris likely incinerated flora and fauna alike [6], with surface heat fluxes reaching 10-100 kWm^{-2} (cf., the solar constant of 1.37 kWm^{-2}) depending on location relative to the impact [10, 11]. The global heterogeneity of this effect is caused by plume asymmetry and local clumping [12].

The Chicxulub impact appears to be the only post-Proterozoic impact to have exceeded in size the threshold required for its ejecta to ignite global fires [12,13]. However, in the absence of fire (e.g., desert or sparsely-vegetated regions), local air temperature rises were only of order 10 K, so organisms sheltered from direct radiation flux by vegetation, earth or water could breathe safely [4]. The persistence of faunal ensembles in particular, sheltering ecological niches is an interesting cross-disciplinary topic [4,14].

Recent paleontological evidence from the New Jersey coastal plain [9] allows us to interpret a scenario for the fate of life at 20-30m water depth immediately after the K/T impact. We also consider the minerals calculated to condense from vapor plumes expected from large asteroid impacts into continental crust, oceanic crust, and shelf sediments [15]. Observations and calculations strongly support the scenario of a single impact at Chicxulub, and are not consistent with scenarios imagining an Ir-poor Chicxulub impactor, followed many years later by the 'real' K/T killer [16].

Technique: Outcrops were studied in the Manasquan River Basin, Monmouth County, New Jersey. The litho- and biostratigraphy were examined in detail. A total of 37 sediment samples spanning the K/T boundary were analyzed for iridium.

Calculations as described in [15] postdict equilibrium (high-temperature, $P^{tot} > 10^{-5}$ bar) condensation in cooling rock-vapor plumes expected for d=10 km chondritic impactors into granitic (continental), basaltic (oceanic), and shelf (Chicxulub sequence) targets.

Results: Two distinct lines of evidence are presented: *Paleontology:* A schematic illustration of strata (Fig. 1) illustrates an iridium anomaly or spike (average concentration=520 pg/g) with no evidence for Ir remobilization. This is overlain by an extremely fossiliferous unit (the *Pinna* Layer) containing approximately 110 species, including ammonites. Most of the bivalves are filter feeders. There are many indications that this layer represents an in situ community that was rapidly buried. Most bivalves are in life position. In addition, there are monospecific clusters of scaphites and baculites, which could not have been produced by hydraulic sorting, but represent instead accumulations of dead shells following mating or spawning. The faunal community may have persisted for tens of years after the impact. The *Pinna* Layer is unconformably overlain by the Hornerstown Formation. The lowermost unit of this formation is thin (20 cm thick) and contains very few fossils, none of which is in situ. This is overlain, in turn, by a slightly more fossiliferous unit, dominated by a single small oyster species. *Mineralogy:* Calculations show that the abundance and compositions of spinels in the global K/T boundary layer are similar to those predicted for impact of a ~10 km chondritic asteroid into the thick carbonate-sulfate sedimentary pile known to be the target rock of the Chicxulub impactor [1,15]. Further calculations, substituting granitic crust, or basaltic (oceanic) crust as the target rock, yield vapor clouds that are insufficiently oxygen-rich to allow the condensation of magnesio-ferrite spinels with compositions or abundance like those observed in the K/T boundary layer (Fig. 2). These compositions are reduced due to the lack of available oxygen in the vaporized sulfate- and carbonate-rich target rock.

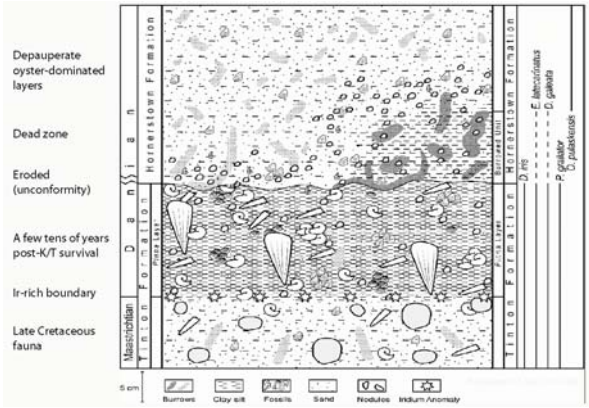

Fig 1: Simplified stratigraphic section in the Manasquan River Basin, central Monmouth County, New Jersey, showing the upper part of the Tinton Formation and the lower part of the Hornerstown Formation. The *Pinna* Layer unit at the top of the Tinton Formation contains a rich assemblage of fossils and represents an autochthonous deposit. (The fossils are not as abundant as illustrated.) A concentration of siderite nodules at the base of the Hornerstown Formation is associated with a hiatus. A ''Burrowed Unit'' is present at some downdip sites and is sandwiched between the top of the *Pinna* Layer and the overlying part of the Hornerstown Formation. Biostratigraphic ranges of five key species are shown at right.

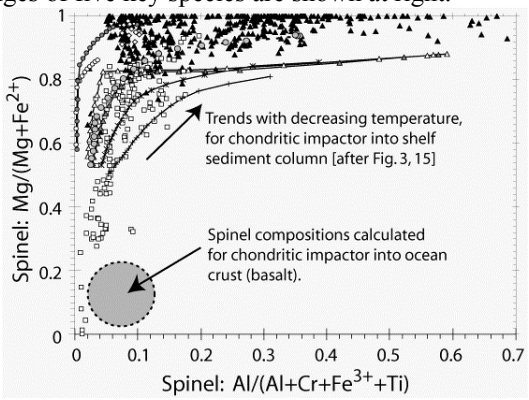

Fig 2: Spinels predicted for impact plumes.

Discussion: These observations and calculations lend support to the theory of a single K/T impact, supported by a preponderance of other evidence [17]. Paleontology of the K/T in the New Jersey coastal plain is consistent with survival of a diverse community including ammonites at 20-30 m depth. These fauna may have survived and even flourished for a short duration (tens of years) after impact, possibly due to an influx of dead material from the surface. The community was rapidly buried, perhaps as the result of enhanced weathering of the land following widespread fires. The overlying stratigraphic unit with few fossils suggests a dead zone. A gradual repopulation of the coastal plain is indicated by the development of a depauperate community dominated by a single oyster species.

The mineralogy of *both* K/T spherule layers is consistent with a single impact, with all the properties known or inferred for that at Chicxulub [5]. If the Chicxulub impact deposited *only* the Ir-poor 'tektite' layer, the impactor was neither a chondrite nor an iron, and it lacked the metals (Mg, Fe, Ti, Ni, Al) necessary to condense spinel in an oxidized plume. An imagined second (larger) impactor, responsible for the global K/T condensate layer, would have to have chondritic Ir, Ni, and Co, and impact km-thick CO_2-, SO_2-rich sediments to produce a plume consistent with observed condensate mineralogy. It would have to be just like Chicxulub except in its identity. Continental shelf comprises only ~5% of the Earth's crust, with basaltic oceanic crust ~55% and continental crust ~40 %. A non-chondritic Chicxulub impactor, followed by another, chondritic or metallic shelf-impactor within less than 500 M years is a very low probability scenario.

The paleontology of the New Jersey coastal plain provides a detailed record of the delayed death of Cretaceous filter-feeders and ammonites, and of the return of life in the Paleogene. Progress in understanding the record preserved in these stratigraphic sections will require combined micropaleontological examination and chemical and isotopic microanalysis, as well as consideration of the local terrestrial dynamical setting and climate following the impact event.

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