CONSTRAINTS ON VOLATILE PRODUCTION BY THE CHICXULUB IMPACT. K.O. Pope[1], A.C. Ocampo[2], and K.H. Baines[2], [1] Geo Eco Arc Research, 2222 Foothill Blvd., Suite E-272, La Canada, CA 91011, kpope@primenet.com, [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109.

Vaporization of sulfates by the Chicxulub impact and the environmental effects resulting from atmospheric loading of sulfur dioxide are potential causes of the mass extinction at the Cretaceous/Tertiary (K/T) boundary. Recent advances in the study of the Chicxulub crater, impact simulations and experiments, and studies of acid rain at the K/T boundary provide new constraints on impact volatile production and help identify research areas where the greatest uncertainties lie. A conservativre estimate of global sulfur dioxide loading is 200 Gt. The nature of the projectile (asteroid or comet), the effects of impact angle on vaporization, and sulfuric acid production in the vapor plume are important sources of uncertainty and require more research.

Energy of the Chicxulub Impact. Prior to the discovery of the Chicxulub crater, estimates of the magnitude of the impact were based primarily on the meteoritic content of the K/T boundary clay [e.g. 1, 2]. Subsequent impact models improved these estimates by including the possibility that highly energetic impacts resulted in the loss of some meteoritic material to space [3]. We have carried this latter approach further by adding the constraints implied by the size of the Chicxulub crater. We use a transient crater diameter range between 110 km and 165 km. This range estimate follows transient crater reconstructions proposed by Croft [4], and the diameters of Chicxulub's peak ring (104 km) and inner most clearly defined terrace scarp (165 km) inferred from topography [5] and gravity [6]. Combining this transient crater estimate with crater scaling and calculations of impactor retention [3], and with the calculated mass of meteoritic material retained on Earth [2], we estimate the energy of the Chicxulub impact to between 6.7E30 and 3.4E31 ergs. This energy corresponds with 9.4-16.8 km diameter asteroids (velocity 20-25 km/s; density 2-3 g/cm^3) or 14.2-24 km diameter comets (velocity 25-45 km/s; density 1.5-2 g/cm^3). Projectiles outside of this range of diameters and velocities do not fit the constraints, given the densities noted.

Impact Simulations and Experiments. Hydrocode models of vertical impacts have now been used to simulate the vaporization of carbonates and sulfates in the 3 km thick surficial layer at Chicxulub [7,8]. These simulations demonstrate that most of the vaporized sulfates lie directly beneath the projectile. The ramifications of this are that the vaporization of sulfates is highly dependent on the diameter of the projectile and on the angle of the impact, independent of the overall impact energy. Similarly, recent experiments and applications of theory demonstrate that the mass of vaporized surficial sediments increases with decreasing impact angle (referenced to horizontal), but that the temperature of the vapor cloud decreases [9]. Analyses of the Chicxulub structure suggest that it may have been highly oblique (20-30 degrees) [10]. Hydrocode simulations of an oblique impact into a target with sulfate in the surface layers are still needed.

Sulfate Loading of the Atmosphere. Given the uncertainties in the nature of the projectile and its energy, as well as in the angle of impact, we estimate that between 100 and 1000 gigatons (Gt) of sulfur dioxide were deposited in the stratosphere. These estimates are based upon extrapolations from hydrocode models [8], anhydrite vaporization at 100 GPa [11,12], and 30% anhydrite in the target rocks at Chicxulub [13]. Our best estimate is 200 Gt, which is based on the most likely impact parameters, rather than the possible extremes. Similar masses of water were also injected into the stratosphere, an important factor in the conversion of sulfur dioxide to sulfuric acid aerosols. Most of the uncertainty lies in the angle of the impact and the percentage of sulfur dioxide and water that were globally deposited in the stratosphere, as opposed to rapidly condensing as aqueous solutions and raining out during vapor plume

expansion. Uncertainties in the total energy of the impact, within the constraints we propose, are less of a factor.

Sulfate vaporization experiments with lasers emphasize the potential for sulfur vapors to form sulfuric acid in the plume when it is cooled rapidly [8,14]. Recent discoveries in Montana of a rapid and severe pulse of acid rain with the first ejecta, followed by a second pulse after the fine ejecta had settled [15], may reflect the formation of sulfuric acid in the expanding plume. This scenario is made more plausible if the Chicxulub impact was oblique from the southeast as has been proposed [10], since such an impact may have focussed relatively "cool" vapors on this down range area, which then rapidly condensed to form sulfuric acid rain. The Montana data suggest about 500-1000 Gt of sulfur dioxide were converted to acid rain on a global basis. Since the initial pulse was probably localized, this estimate is excessive as a global average. The estimate of the mass of sulfur dioxide converted to acid in the second pulse is 200-700 Gt.

Conclusions. Recent studies of the Chicxulub crater help refine estimates of the impact energy, but a factor of 5 uncertainty remains. Current knowledge only weekly constrains the size and velocity parameters of the projectile and either an asteroid or a short period comet (<45 km/s) are possible. Determination of whether a comet or an asteroid impact produced Chicxulub is perhaps as important for estimating volatile production as a better estimate of the transient crater diameter. Even more important may be confirmation of whether or not the impact was highly oblique. Studies of acid rain at the K/T boundary in Montana suggest sulfuric acid production occurred in two pulses. The first was concurrent with the earliest ejecta, a scenario that is consistent with evidence for an oblique impact from the southeast and a relatively cool, rapidly condensing sulfuric acid-rich plume. The second pulse apparently began months later, after the fine ejecta had settled. This second pulse is probably the global pulse predicted by atmospheric models [7], and the 200-700 Gt of sulfur dioxide needed to produce it are in good agreement with our estimates of the mass of globally distributed sulfur dioxide produced by Chicxulub..

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