
The occurrence of both shocked quartz grains at the K-T boundary [1] a low, possibly oceanic affinity $^{87}$Sr/$^{86}$Sr ratio [2,3], and the fact that sea level at the end of Cretaceous was some 300 m higher than at present suggests the possibility that this impact occurred on a shallow marine, probably carbonate-rich, sedimentary section.

A large impact onto such a terrane would result in large amounts of CO$_2$ to be released. The amount of CO$_2$ released upon impact can be estimated using the results of Lange and Ahrens [4] for the threshold pressures for CO$_2$ release (Fig. 1) and impact vapor scaling relations of O'Keefe and Ahrens [5]. The shock pressures required to vaporize CaCO$_3$ are almost an order of magnitude less than those required to vaporize silicates and are also more than an order of magnitude less than the expected peak impact pressures in the K-T event. The present model assumes that there are three layers, an ocean, a carbonate bed and an underlying silicate crust and mantle. The ocean was modeled as a 3 km thick layer and the carbonate-rich sequence was varied from 1 and 4 km. The impactor was assumed to be an asteroid having a density of 3 g/cc and a velocity of 20 km/s. The results of these calculations as a function of impactor size are shown in Figure 2. The mass of CO$_2$ released exceeds the present CO$_2$ budget in the atmosphere when the radius of the impactor is greater than 6 km for a 4 km-thick carbonate layer. It is clear that significant amounts of CO$_2$ can be ejected into the atmosphere for impactors having sizes in the range of those proposed for the K-T bolide [6,7].

In the case of impacts whose scales are equal or greater than the K-T event, the devolatilized CO$_2$ would dispersed rapidly and globally. The solid planet and atmospheric flow fields have been recently calculated for an impact that could be representative of the K-T event [8]. Examples of the flowfields for a 10 km diameter impactor at 20 km/s are given in Reference [8]. The flow of the devolatilized rock and CO$_2$ and the highly shocked air is upward and away from the impact site. The vapor flow velocities do not exceed the escape velocity, but the magnitudes and geometry are such that impact-produced CO$_2$ would be propelled to very high altitudes and distributed globally.

The sudden injection of CO$_2$ into the atmosphere will increase the earth's mean surface temperature as a result of the greenhouse effect [9]. The reequilibration time of the solid earth-ocean-atmosphere system to a sudden large increase in CO$_2$ in the atmosphere is unknown, but reaction times as great as $\sim 10^5$ years has been obtained by Berner et al. [10]. We have used the calculations of Kasting and Toon [11] to obtain the temperature rise at the Earth's surface as a function of CO$_2$ content to compute the temperature rise as function the size of the impactor from the conditions described in Fig. 2. Referring to Figure 3, the temperature change is significant for impactors greater than 5 km in radius. Emiliani et al. [12] have argued that a temperature increase of 10 K would be sufficient to account for the K-T extinctions. This temperature increase would result from impactors having radii from 10 to 30 km, which is consistent with the estimates of the K-T bolide radius. Emiliani et al. and McLean [13] have examined the geologic evidence at the K-T boundary and concluded that the mean temperature increased at, and after the event, and Hut et al. [14] have argued that the extinctions did not occur instantaneously but over an extended period of time. The present calculations indicate that an enhanced atmospheric greenhouse caused by a dramatic impact devolatilizing CO$_2$ event could produce a drastic extinction mechanism.
CO₂ PRODUCTION BY THE K-T BOLIDE

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Fig. 1. Fraction of CO₂ released in calcite as a function of impact pressure (from Lange and Ahrens [4]). TJAB87146SC

Fig. 2. Mass of CO₂ released from an oceanic impact from an underlying carbonate sediment. The impact velocity is 20 km/s and the density of the impactor is 3 g/cc. The ocean is assumed to be 3 km in depth and the carbonate thickness varies from 1 and 4 km. TJA88017SFD

Fig. 3. Mean atmospheric temperature rise as a function of impactor radius. Impact conditions are described in Fig. 2. TJA88018SFD