Direct measurement of chemical composition of shock-induced gases from calcite: indirect greenhouse effect of CO after an impact

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Shock-induced devolatilization in hypervelocity impacts has been considered to play important roles in the atmospheric evolution and mass extinctions in the Earth's history. Although shock-induced gas species from carbonates have been assumed to be CO_2 in the previous studies (e.g., O'Keefe and Ahrens, 1989; Pierazzo et al., 1998), CO may be produced in shock-induced devolatilization of carbonates if we consider the thermodynamical stability of CO at high temperature. If CO is released into the atmosphere by an impact on carbonates, the abundances of intense greenhouse gases sch as CH_4 and tropospheric O_3 may increase via photochemical reactions. Therefore, the chemical composition (CO/CO_2) of shock-induced gas species from carbonates is a key issue to understand the global environmental effect of shock-induced gases. However, the chemical composition of the shock-induced gas species is not investigated by the previous studies because direct measurement of shock-induced gas species has been difficult.

In this study, we investigate the chemical composition (CO/CO_2) of shock-induced gas species from calcite ($CaCO_3$) using laser gun method which enables us to measure the shock-induced gas species directly. Our experimental results show that shock-induced devolatilization starts at shock pressure of 20 GPa. The amount of shock-induced gases increases with shock pressure and target porosity. These results show that our experimental system well reproduces the previous experimental studies. Furthermore, the ratio CO/CO_2 in shock-induced gas species from calcite is measured to be 2.02 +- 0.41, indicating that the amount of CO is around 2 times that of CO_2, contrary to the previous assumption that shock-induced gas species is CO_2 only. This may suggest that heterogeneous heating of target during shock compression because CO may be formed at high temperature.

Using our experimental results and tropospheric one-box photochemical model, we estimate the indirect radiative forcing of CO after the Chicxulub impact by adding the radiative forcing of CH_4 and that of tropospheric O_3. The radiative forcing of tropospheric O3 is estimated to reach 2.0-11.3 Wm^{-2}, which is 1-2 orders of magnitude larger than that of CH_4 (0.02-0.20 Wm^{-2}). This indicates that the radiative forcing of tropospheric O_3 accounts for most part of indirect radiative forcing of CO. Consequently, a rapid (within a few years) and intense (up to +5K) global warming may have occurred after the Chicxulub impact due to the increase in abundance of tropospheric O_3. The increase in the Earth's surface temperature estimated in this study is significantly higher than that of previous estimates (less than 2K) which consider production of CO_2 gas only (e.g., Pope et al., 1997; Pierazzo et al., 1998). It is possible such a rapid and intense global warming can significantly damage the biosphere and contribute to the mass extinction at the K/T boundary in 65 Myr ago.