N89-21293

CARBON DIOXIDE CATASTROPHES: PAST AND FUTURE MENACE

Mario E. Baur, Department of Chemistry, UCLA, Los Angeles, CA 90024

CO_2 is uniquely important in its role as coupler of the terrestrial biosphere to inorganic chemical processes and as the principal greenhouse gas controlling Earth's surface temperature. The hypothesis that atmospheric CO_2 levels have diminished with time, with the resulting cooling effect offsetting an increase in the solar constant, seems firmly established, and it has been shown that feedback mechanisms exist which can maintain the terrestrial surface in a relatively narrow temperature range over geological time[1]. However excursions occur; epochs of glaciation may result in part from decreases in atmospheric CO_2. During the most recent glacial advance, atmospheric CO_2 estimated from air trapped in Antarctic ice may have been as low as 160-200 ppm[2]. This figure is relevant in its implications for primary production; photosynthesis rate in C_3 plants, at least is sensitive to $P(CO_2)$ and exhibits a threshhold at 50-100 ppm below which the process ceases[3]. Thus the amount of CO_2 in the atmosphere during the glaciation may not have been much more than twice that at which a global biosphere collapse would have resulted. Of the factors involved in such CO_2 variation, the oceanic reservoir appears the most important; at present, in units of 10^{16} moles, the oceans contain a total CO_2 inventory (including HCO_3^- and $CO_3^=$) of 290, compared with about 6 in the atmosphere, and about 5 units of C combined in biomass with 25 additional units of C as organic debris in soils and hydrosphere.

Surface waters are probably in approximate equilibrium with regard to CO_2 exchange with the ambient atmosphere in most regions, but data from deep-ocean water sampling[4] indicates that such waters are somewhat undersaturated in the sense that they would tend to absorb CO_2 from the atmosphere if brought to the surface without change in composition or temperature. The total absorptive capacity of the present ocean for CO_2 is probably 10-30 units, small relative to total oceanic CO_2 but greater than the total atmosphere inventory. That the oceans are, therefore, potential net sinks for CO_2 is consistent with the observation that almost half the anthropogenic CO_2 generated in recent decades has vanished from the atmosphere, presumably by ocean uptake. This uptake has been a gradual one, but were some event to produce a rapid turnover of a substantial portion of the ocean, a significant drawdown of atmospheric CO_2 into the oceanic reservoir could result; this would be a kind of reversed Lake Nyos phenomenon (the reference is to a lake whose bottom waters became supersaturated with CO_2 and whose subsequent overturn resulted in a degassing catastrophic for nearby inhabitants). An agency capable of producing such an overturn is the impact of a large extraterrestrial object into the ocean, and in this connection we note that such an impact event may have occurred just prior to the onset of the Pleistocene glaciation epoch.

If major impacts into the ocean can result in loss of a substantial portion of the atmospheric CO_2 reservoir, then any such future event could imperil the continuation of most higher forms of life on Earth; for the margin of security between present CO_2 levels in the atmosphere and the minimum needed to maintain primary production is, from this perspective, perilously thin. Indeed, solar warming has narrowed the "window" between CO_2 levels high enough to produce an intolerable greenhouse heating and those too low to permit continuation of primary production to a degree which merits some concern.

The most likely candidate for an inverse Nyos global event in previous Earth history, other than onset of the Pleistocene, and possibly earlier, glacial epochs, is the Cretaceous-Tertiary terminal extinction event. That the latter was provoked by the impact of a massive extraterrestrial object seems beyond reasonable question, but the precise character of the impacting object is unclear and the proximate mechanism of biosphere injury remains controversial[5]. The Cretaceous was characterized by warm, equable temperatures presumably indicative of relatively high CO_2 levels and an intense greenhouse heating. Isotopic evidence indicates a pronounced cooling at the end of the Cretaceous, but this seems not to have been accompanied by a large transfer of CO_2 to the oceanic reservoir[6]; the most reasonable interpretation is that CO_2 was being withdrawn from the atmosphere into biomass and carbonate deposits in shelf seas. Cooling of the oceans in absence of massive transfer of CO_2 to the oceanic reservoir in itself would promote a condition of CO_2 undersaturation in abyssal waters, and this may have been made even more extreme by the pattern of ocean water circulation, dominated by movement off continental shelves, in the late Cretaceous. Thus it is possible to envision a situation in which deep ocean waters were at least occasionally profoundly undersaturated with regard to CO_2. Turnover of a major fraction of such an ocean would then remove, on a very short time scale, as much as 90% of the atmospheric CO_2 inventory. A possible mechanism for such turnover is the multiple impact of a number of 1-km diameter objects resulting from the breakup of a weak impactor[5]. The result of such a sharp in CO_2 in the atmosphere, and resulting from it, of total dissolved CO_2 in surface waters as well, would be the elimination of photosynthetic activity or its reduction to levels too low to sustain much of the existing biota, especially the larger fauna. Cooling and darkening resulting from the lowered greenhouse effect and the impact-generated dust cloud would compound the severity of the crisis. However, it would not necessarily be prolonged, if the pre-extinction biomass were great enough and dieoff sufficiently extensive; for then rapid oxidative recycling of much of this biomass would largely restore the atmospheric CO_2 inventory.

[1]Walker, J. C. G., Hays, P. B. and Kasting, J. F. (1981), J. Geophys. Res. 86, 9776-9782

[2]Delmas, R. J., Ascencio, J.-M. and Legrand, M. (1980), Nature 284, 155-157

[3]Körner, Ch., Farquhar, G. G. and Roksandic, Z. (1988), Oecologia 74, 623-632

[4]Takahashi, T., Broecker, W. S. and Bainbridge, A. E. (1981), in: Carbon Cycle Modelling, SCOPE 16, Bolin, B., ed., John Wiley, New York, 271-286

[5]Silver, L. T. and Schultz, P. H., eds. (1982), Geological Implications of Impacts of Large Asteroids and Comets on the Earth, Special Paper 190, Geological Society of America

[6]Douglas, R. G. and Savin, S. M. (1975), DSDP Initial Reports 32, 509-520