GEOCARB III: A REVISED MODEL OF ATMOSPHERIC CO2 OVER PHANEROZOIC TIME

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and

A New Look at the Long-term Carbon Cycle

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excerpts

The Phanerozoic Eon is the current geologic eon in the geologic time scale, and the one during which abundant animal and plant life has existed. It covers 541 million years to the present, and began with the Cambrian Period when animals first developed hard shells preserved in the fossil record. Its name was derived from the Ancient Greek words φανερός (phanerós) and ζωή (zōê), meaning visible life, since it was once believed that life began in the Cambrian, the first period of this eon. Quelle: Wikipedia

ABSTRACT.
Revision of the GEOCARB model (Berner, 1991, 1994) for paleolevels of atmospheric CO2, has been made with emphasis on factors affecting CO2 uptake by continental weathering. This includes:

1) new GCM (general circulation model) results for the dependence of global mean surface temperature and runoff on CO2, for both glaciated and non-glaciated periods, coupled with new results for the temperature response to changes in solar radiation;
2) demonstration that values for the weathering-uplift factor $f_R(t)$ based on Sr isotopes as was done in GEOCARB II are in general agreement with independent values calculated from the abundance of terrigenous sediments as a measure of global physical erosion rate over Phanerozoic time;
3) more accurate estimates of the timing and the quantitative effects on Ca-Mg silicate weathering of the rise of large vascular plants on the continents during the Devonian (419 - 359 million years ago. Also informally known as the "Age of the Fish", the Devonian features a huge diversification in fish);
4) inclusion of the effects of changes in paleogeography alone (constant CO2 and solar radiation) on global mean land surface temperature as it affects the rate of weathering;
5) consideration of the effects of volcanic weathering, both in subduction zones and on the seafloor;
6) use of new data on the delta13C values for Phanerozoic limestones and organic matter;
7) consideration of the relative weathering enhancement by gymnosperms versus angiosperms; (gymnosperms = naked-seed plants, e.g. conifers, ginko, angiosperms = fruit producing plants)
8) revision of paleo-land area based on more recent data and use of this data, along with GCM-based paleo-runoff results, to calculate global water discharge from the continents over time.

Results show a similar overall pattern to those for GEOCARB II:

- very high CO2 values during the early Paleozoic,
- a large drop during the Devonian and Carboniferous,
- high values during the early Mesozoic, and
- a gradual decrease from about 170 Ma to low values during the Cenozoic.

However, the new results exhibit considerably higher CO2 values during the Mesozoic, and their downward trend with time agrees with the independent estimates of Ekart and others (1999). Sensitivity analysis shows that results for paleo-CO2 are especially sensitive to:

- the effects of CO2 fertilization and temperature on the acceleration of plant-mediated chemical weathering;
- the quantitative effects of plants on mineral dissolution rate for constant temperature and CO2;
- the relative roles of angiosperms and gymnosperms in accelerating rock weathering; and
- the response of paleo-temperature to the global climate model used.

This emphasizes the need for further study of the role of plants in chemical weathering and the application of GCMs to study of paleo-CO2 and the long term carbon cycle.

run GEOCARB-Model for a CO2 spike:
http://climatemodels.uchicago.edu/geocarb/

APPENDIX 1

Equations used in GEOCARB modeling

$$F_{wc} + F_{mc} + F_{wg} + F_{mg} = F_{bc} + F_{bg}$$

$$\delta_c(F_{wc} + F_{mc}) + \delta_g(F_{wg} + F_{mg}) = \delta_{bc}F_{bc} + (\delta_{bc} - \alpha_c)Fbg$$

$$Fwc = f_{BB}(T, CO_2)f_{LA}(t)f_{AD}(t)f_E(t)k_{wc}C$$

$$Fwg = f_R(t)f_{AD}(t)k_{wg}G$$

$$F_{mc} = f_G(t)f_C(t)F_{mc}(0)$$

$$F_{mg} = f_G(t)F_{mg}(0)$$

$$dC/dt = F_{bc} - (F_{wc} + F_{mc})$$

$$dG/dt = F_{bg} - (F_{wg} + F_{mg})$$

$$d(\delta_cC)/dt = \delta_{bc}F_{bc} - \delta_c(F_{wc} + F_{mc})$$

$$d(\delta_gG)/dt = (\delta_{bc} - \alpha_c)F_{bg} - \delta_g(F_{wg} + F_{mg})$$

$$F_{wsi} = F_{bc} - F_{wc} = f_B(T, CO_2)f_R(t)f_E(t)f_{AD}(t)^{0.65}F_{wsi}(0)$$

click on set of equations to enlarge

Definitions

F_{wc}; F_{wg} = rate of release of carbon to the ocean/atmosphere/biosphere system via the weathering of carbonates (c) and organic matter (g)
F_{mc}; F_{mg} = rate of degassing release of carbon to the ocean, atmosphere, and biosphere system via the metamorphic, volcanic, and diagenetic breakdown of carbonates (c) and organic matter (g)
F_{bc}; F_{bg} = burial rate of carbon as carbonates (c) and organic matter (g) in sediments
F_{wc} = rate of uptake of CO_2 via the weathering of Ca and Mg silicates followed by precipitation of Ca and Mg carbonates (Ebelmen-Urey reaction). $F_{wc}(0)$ represents rate at present.
$f_{BB}(T, CO_2)$ = dimensionless feedback factor for carbonates expressing the dependence of weathering on temperature and on CO_2
$f_B(T, CO_2)$ = dimensionless feedback factor for silicates expressing the dependence of weathering on temperature and on CO_2
$f_{LA}(t)$ = carbonate land area(t)/carbonate land area(0) derived from $f_A(t)$ = land area(t)/land area(0) times [carb/total land(t)]/[carb/total land(0)]
$f_{AD}(t)$ = river discharge(t)/river discharge(0) due to changes in paleogeography. It is obtained from the product of $f_A(t)$ and $f_D(t)$ = runoff(t)/runoff(0). The power of 0.65 in the expression for F_{wsi} reflects dilution at high runoff.
$f_R(t)$ = mountain uplift factor = mean land relief(t)/mean land relief(0)
$f_E(t)$ = factor expressing the dependence of weathering on soil biological activity due to land plants ($f_E(t) = 1$ at present)
$f_G(t)$ = global degassing rate(t)/global degassing rate(0)
$f_C(t)$ = dependence of degassing rate on the proportions of carbonate in shallow water and in deep sea sediments
δ = $\delta^{13}C$ value (‰); subscripts are c for average of all carbonates, g for average of all organic matter and bc for the burial of carbonates at each past time
α_c = carbon isotope fractionation between organic matter and carbonates during burial
k_{wc}; k_{wg} = rate constants for weathering of carbonates and organic matter
C; G = masses of carbon present as carbonates and organic matter

click on set of definitions to enlarge

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