# ATMOSPHERIC $CO_2$ AND EARLY PALEOZOIC CLIMATES

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The carbonate-silicate geochemical cycle has been invoked to explain the remarkable stability of climate throughout Earth history. A high atmospheric $pCO_2$ would be expected during the Early Paleozoic in response to reduced solar luminosity (~95% of the Present-Day value).

The presence of terrestrial ice, an unequivocal paleoclimate indicator, is recognized only from the Late Ordovician in the Early Paleozoic. But numerical models of the carbonate-silicate cycle and isotopic proxies from goethite in a paleosol indicate that atmospheric $pCO_2$ levels were very high at this time (~14-16X present atmospheric level, PAL). This apparent inconsistency (even with a lower solar luminosity such a high $pCO_2$ would presumably imply a warm, ice-free climate) has challenged our understanding of the Earth's climate system. Energy balance model (EBM) studies have indicated that glaciation could exist at high $pCO_2$ if the pole was located close to the edge of a supercontinent. The ocean's thermal inertia would prevent summertime temperatures from rising above freezing, a major prerequisite for glaciation. This mechanism has been substantiated by a general circulation model (GCM) study, although an elevated topography was required.

Now, isotopic evidence has been produced that suggests the Late Ordovician glaciation lasted perhaps less than 1 Myr, consistent with the best stratigraphic evidence. Furthermore, geochemical models (typically run with 10 Myr timesteps) and the paleosol are probably unable to 'capture' such a short glaciation. Thus $pCO_2$ may well not be as high during the glaciation as the geochemical estimates seem to indicate. A reasonable hypothesis is that the Late Ordovician glaciation was caused by a drawdown of atmospheric $CO_2$ due to a short-lived increase in organic carbon burial.

We present results of a suite of GCM experiments that investigate the sensitivity of the Late Ordovician climate to atmospheric $pCO_2$ level. All experiments used a 4.5% lower solar luminosity value; a 440 Ma land-sea distribution; a uniform land elevation of 500 m, and a bare land surface with median values for soil color and texture. We performed experiments with atmospheric $pCO_2$ set at 18X, 14X, and 10X PAL.

The 10X experiment appears to be close to a runaway icehouse; substantial snow cover is present that continues to grow. In the 14X experiment only a small amount of snow survives each summer. Effectively no snow survives in the 18X experiment, which could be regarded as representing the rest of the ice-free Early Paleozoic. These results represent a very strong sensitivity to relatively modest changes in $CO_2$, under conditions of reduced solar luminosity.

Paleozoic climate modeling involves much larger uncertainties in boundary conditions than for later intervals. We are currently investigating sensitivity to a lower reduction in solar luminosity (3.5%) and to other paleogeographic reconstructions that remain consistent with paleomagnetic and biogeographic data.