The CO_2 content of the Carboniferous atmosphere derived from high resolution $\delta^{13}C$ records of brachiopod calcite – Implications for the transition from greenhouse to icehouse

P. Bruckschen

Institut für Geologie, Ruhr-Universität Bochum, 44780 Bochum, Germany,

The CO_2 content of the past atmosphere is a key parameter for any palaeoclimatic modelling. This parameter can be modelled from the $\delta^{13}C$ record of marine carbonates (Berner, 1991, 1994). Such models were originally constructed as sensitivity tests for a variety of input scenarios for various forcing factors, such as variations in land area, runoff, degassing rates etc. (Berner, 1991). However, the sensitivity to $\delta^{13}C$ input was tested only by assuming a constant signal of 1‰ throughout the entire Phanerozoic, which resulted in a huge feedback on the modelled CO_2 content, particularly for the early Carboniferous atmosphere, (Fig. 15 in Berner, 1991). The aim of this study is to utilize two different Carboniferous $\delta^{13}C$ records, from Europe and North America, and to test their impact on the sensitivity of CO_2 modelling. The Carboniferous is a particular interesting period of Earth history, because it represents the transition from greenhouse to icehouse.

Sampled material and geologic setting

The records are based on well preserved internal 'secondary' layers of articulate brachiopod shells, the material that is of exceptional utility for isotope studies of the Palaeozoic (e.g. Veizer *et al.*, 1997 and literature therein). The Carboniferous $\delta^{13}C$ record is based on samples from western Europe and the former USSR (Bruckschen and Veizer, submitted) and the mid-continent of North America (Mii *et al.*, submitted). Palaeogeographically, the former belonged to the northwestern shelf of the Palaeotethys, while the American counterpart was a part of the Phantalassian province. Both datasets are characterised by unusually high stratigraphic resolution, enabling testing of 'short term' oscillations ($\times 10^6$ years) and their meaning in terms of organic carbon burial rates, atmospheric CO_2 levels, and ultimately the climate.

The model

We have employed the GEOCARB I model of Berner (1991) because of its mathematical simplicity and more detailed documentation. In addition, in terms of Carboniferous atmospheric CO_2 content this model does not differ significantly from GEOCARB II (Fig. 18 in Berner, 1994). Except for the new $\delta^{13}C_{carbonate}$ data all other parameter are as in the original model. The $\delta^{13}C$ input is based on formational means for the European Carboniferous. The North American $\delta^{13}C$ record was extracted from the overall trends in Mii *et al.* (submitted), but corrected for taxonomic effects in the Pennsylvanian.

The Carboniferous $\delta^{13}C$ records

Both Carboniferous $\delta^{13}C$ records are characterised by a dominant peak in the late Tournaisian, a second, less pronounced, early to mid Visean maximum, a late Visean minimum and a Serpukhovian rise to a Pennsylvanian plateau, at about 4 and 5‰. The European record, due to its higher stratigraphic resolution, shows higher frequency fluctuations, and its Pennsylvanian plateau is roughly 1‰ higher than is the case for North America. This difference may be related to changes in the oceanic circulation pattern caused by the closure of the western terminus of the Palaeotethys during the formation of Pangea.

Another marked aspect of the European record is a rapid drop in $\delta^{13}C$, of about 6‰, at the Moscovian-Kasimovian transition that coincides with a warm phase within the late Carboniferous icehouse. This drop took place within the Suvorovskaya Formation, that is, within less than one biozone (*Obsoletes obsoletus* zone). The drop has not been detected in the North American record perhaps due to duration and due to the lack of samples for a portion of the lower Missourian. Alternatively, the anomaly may only be of local significance.

Modelled CO_2 level and glaciations

The present model results yield the atmospheric CO_2 contents that, except for the late Tournaisian, are significantly higher than those of Berner (1991). The main phase of Permo-Carboniferous glaciation commenced at the latest at the Visean/Namurian transition but large late Visean sea level oscillations, reflected in the cyclothems, suggest that in Europe it may have commenced already at the base of the Asbian stage (Wright, 1997, pers. comm.). If so, the results of the present modelling excercise indicate that the onset of glaciation may have been initiated at CO_2 levels of 6.5 to 8 PAL.

For the European record, the modelled atmospheric CO_2 content is characterised by 1) large fluctuations during the Tournaisian and early Visean, 2) significant drop at the Visean/Namurian transition, and 3) short lived peak at the Moscovian/Kasimovian boundary. Due to lower stratigraphic resolution, the North American data show less fluctuations in the Visean and the peak at the Westphalian/Stefanian boundary is missing, probably due to the previously discussed reasons. Although the American trend generally follows the European one, some differences do exist. At this stage, it is not if these small discrepancies could be a consequence of differing stratigraphic resolution, uncertainties in the stratigraphic correlation or to regional factors. The curves should be therefore regard only as possible end members.

Accepting 7 PAL as a threshold level for survival of summer snow cover, hence glacial conditions, the model yield three additional pre-Asbian intervals for the European record with and, therefore, glacial conditions, the model indicates for the European record three pre-Asbian intervals with CO_2 contents below this potential threshold. This is consistent with at least three distinct phases of early Carboniferous glaciation proposed recently by Garzanti and Sciunnach (1997) from sedimentological evidence in southern Tibet. The North American run yields two potential glaciation intervals during the mid to late Tournaisian and the Meramecian, a proposition in accord with the $\delta^{18}O$ record (Mii *et al.*, submitted).

Conclusions

The modelled scenarios of Carboniferous climate are consitent with a picture emerging from other climatic records, such as the distribution of glacial deposits or oxygen isotope data. They provide a theoretical background for at least two distinct periods of widespread, if not global, early Carboniferous glaciation, in the upper Tournaisian and mid Visean.

Acknowledgements

This study has been financially supported by a 'Habilitations Stipendium' grant (Br 1543/3-1) of the Deutsche Forschungsgemeinschaft (DFG) and is also a contribution to IGCP Project 386.

References

Berner, R.A. (1991) *Amer. J. Sci.*, **291**, 339–38.

Berner, R.A. (1994) *Amer. J. Sci.*, **294**, 56–36.

Bruckschen, P. and Veizer, J. (submitted), *Chem. Geol.*

Garzanti, E. and Sciunnach, D. (1997) *Earth Planet. Sci. Lett.*, **148**, 359–7.

Mii, H.-S., Grossman, E. and Yancey, T.E. (submitted), *GSA Bull.*

Veizer, J., Bruckschen, P., Pawellek, F., Diener, A., Podlaha, O.G., Carden, G.A.F., Jasper, T., Korte, C., Strauss, H., Azmy, K. and Ala, D. (1997) *Palaeogeogr. Palaeoclim. Palaeoecol.*, **132**, 159–14.