

## Control of atmospheric CO<sub>2</sub> and climate through Earth history

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The geochemical and paleobiological records from sediments document a spectacular climate transition from the persistent warm climates of the Cretaceous and early Cenozoic to the cold, semi-glaciated climates of the Plio-Pleistocene. Climate reconstructions for the earlier Mesozoic and Paleozoic are less precise, but quasi-periodic oscillations between warm, ice-free climates, such as the Silurian and Devonian, and partly glaciated climates, such the Ordovician and Permian, appear to be a general feature of the entire Phanerozoic. Over the last two decades, a variety of theories and models for the causes of climate change over these time scales have been developed, most involving long-term changes in the carbon cycle and atmospheric CO<sub>2</sub>. A prominent series of contributions followed seminal work by Berner et al. (1983) (BLAG), developing a model known as GEOCARB. In the BLAG and GEOCARB models, the primary control on the evolution of atmospheric CO<sub>2</sub> over Phanerozoic time is the rate of volcanic outgassing of CO<sub>2</sub>. As there are no direct measures of the rate of volcanic outgassing, it is calculated from estimates of changes in the average rate of sea floor spreading, as this controls both the rate of mid-ocean ridge volcanism and the rate of subduction. This, in turn, is calculated from the Phanerozoic eustatic sea level curve. A re-examination of the modern rate of volcanic outgassing as well as estimates of the calcium carbonate budget suggest that the sea floor spreading rate is likely a very poor proxy for volcanic outgassing rate through time. In the modern ocean, more than 10 times as much calcium carbonate is being buried as is being subducted. This severe imbalance in the geochemical cycle cannot be maintained over the Phanerozoic. An alternative explanation is explored that considers the site of calcium carbonate deposition and the quasi-periodic destruction of ocean basins. The warmth of the Cretaceous is explained by subduction of the carbonate-rich Tethys, which ended in the Eocene when Cenozoic cooling commenced. The current cool climate will remain until the carbonate-rich Atlantic is subducted. A natural oscillation is proposed to explain the quasi-periodic oscillations over the Phanerozoic. When subduction and metamorphism of calcium carbonate is high, elevated CO<sub>2</sub> produces a warm climate and high sea level, leading to preferential deposition of carbonate on shallow-water cratonic areas. Eventually, this will starve the ocean floor of carbonate deposition, leading to reduced subduction of carbonate and a cooler climate. Cooler conditions in turn lead to the exposure of continental shelves and high rates of carbonate weathering (like today), reloading the ocean floor with carbonate to be subducted in the future. The quasi-periodicity of the climate oscillations is the result of this natural cycling of calcium carbonate between the continents and the ocean floor, and also by the quasi-periodic nature of continent-continent collisions.

## Bacteriogenic lead-zinc mineralization in the Bleiberg deposit, Austria

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The world-class Bleiberg, Austria, lead-zinc deposit has been interpreted by concepts ranging from the syngenetic-sedimentary to the epigenetic. A reef-back reef position has been postulated for the Triassic host sediments, and there has been general agreement on a shallow-water depositional environment. The actual causes of mineralization, however, have not been determined. New data and observations are presented here.

Reflected light microscopy has been employed in the search for all discernable textural features, and in preparation for microprobe analysis. Oil immersion, crossed polars, and etching techniques have been used in this context. Two distinct groups of textures have emerged in the process: Firstly, a wide spectrum of bacterial relics and, secondly, various low-reflectance phases which do not appear to be gangue minerals. Microprobe analyses of the latter have been performed to check for peak splitting and, indeed, there is evidence of peak shift related to sulphur valencies ranging from -2 to +5, similar to valencies observed in the laboratory during sulphate sulphur reduction by bacteria. These indicate the presence of oxysulphides, products of stepwise reduction of sulphur by sulphate-reducing bacteria. Sulphur isotope data obtained previously (Schroll et al 1983) support this observation: these range from -3 to -31 and point to a sedimentary environment of deposition and bacterial reduction of sulphur. Finally, Leco analysis of ore-bearing members of the Triassic stratigraphy at Bleiberg reveals the presence of significant amounts of C-Org.

Thus four independent lines of evidence have been presented, each of which provide convincing proof for the significant role played by bacteria in ore deposition at Bleiberg. The geological conditions summarized above can easily be accommodated within the shallow-water environment postulated by earlier workers. Fallick et al. (2001) have recently stressed the important role of bacteria in the formation of large lead-zinc deposits such as Navan, Ireland.

### References

- Fallick A.E., Ashton J.H., Ellam R.M and Russell M.J. (2001). *Econ Geol.* **96**. 885-890.  
Schroll E., Schulz O. and Pak E., (1983). *Min. Dep.* **18**. 17-25