An evolving biosphere reflected in the dampening of carbon isotope variability

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One of the principal aspects of life is that it resists equilibration with its surroundings. Preservation of this disequilibrium is a costly process, and this is achieved by organisms through the harnessing of redox reactions. Energy efficiency is another key feature to achieve maximum benefit from these reactions, where the energetically favourable light isotopes are preferentially used during metabolism. Combined, these physiological processes exert a major control on ambient chemistry and create micro-scale isotope gradients. In addition, metabolism is a prime driver of large-scale biogeochemical cycles, and can alter the isotopic composition of the exogenic reservoirs. Both micro- and macro-scale isotopic imprints can be channelled to the rock record by mineral formation, which can as well be controlled to varying extends by organisms. We assess trends in $\delta^{13}C$ variability of marine carbonate rock throughout Earth history, by looking at the frequency of high-amplitude stratigraphic-confined $\delta^{13}C$ oscillations. Part of these stratigraphic-confined $\delta^{13}C$ oscillations are unlikely to be forced by the carbon cycle, based on steady-state calculations. Instead this $\delta^{13}C$ variation (>5 ‰ VPDB) might be explained by authigenic and diagenetic carbonate mineral additions, which carry metabolic C isotope signatures created in the vicinity of cells and secluded (sub-)seafloor micro-environments. It can be envisioned that compartmentalization (membrane enclosed regions), the accumulation of extracellular polymeric substances (biofilms), and restricted fluid exchange in the early diagenetic environment can create a heterogeneous C isotopic micro-environment that leads to a high-order of micro-scale carbon isotope variability being imprinted in carbonate rock. The frequency of the high-amplitude variation diminishes in the Phanerozoic, but is temporarily re-instated in the aftermath of the end-Permian mass extinction, coupled to an >80% loss of marine metazoan species. Hence dampening of $\delta^{13}C$ variability could be related to the development of more complex life in the Phanerozoic (metazoan-dominated biosphere); presumably through the dispersing action of bioturbation, increased grazing pressure and the advent of obligate enzymatic-controlled biomineralization. This conceptual model can therefore explain both the amplitude of stratigraphic-confined $\delta^{13}C$ oscillations as well as long-term trends in $\delta^{13}C$ variability. If correct, these observations can help improve the extraction of $\delta^{13}C$ signals relevant to the operating of the deep-time carbon cycle as well as for stratigraphic purposes, whereas the stratigraphic-confined $\delta^{13}C$ oscillations might be used as a palaeontological tool.