

Supplementary material DR1: Degassing during contact metamorphism as an explanation of the negative carbon isotope excursion associated with the emplacement of the Emeishan LIP

Our measurements of the $\delta^{13}\text{C}$ of dolostones from the Sinian formation range from +4.7 to -1.1, values which are consistent with Jacobsen and Kaufman's (1998) estimate of $\delta^{13}\text{C}$ in Neoproterozoic seawater (+4 to -4 ‰, with most of the data between +2 and -2 ‰). If we assume that (1) end-Guadalupian seawater contained ~40000 Gt C with $\delta^{13}\text{C} = +5$ ‰ (Berner, 2005), (2) end-Guadalupian atmosphere contained ~2850 Gt C (Rothman 2002) with $\delta^{13}\text{C} = -2$ ‰ (7 ‰ more negative than seawater (Mora et al. 1996)), then the average $\delta^{13}\text{C}$ of the ocean-atmosphere system was +4.5.

After the addition of 16800 Gt of magmatic CO_2 (4580 Gt C with $\delta^{13}\text{C} = -6$), 62500 Gt of CO_2 from destabilized Sinian dolostone (17000 Gt C with $\delta^{13}\text{C} = 0$) and potentially 84000 Gt CO_2 from the metamorphism of organic carbon (=22900 Gt C with $\delta^{13}\text{C} \sim -22$), the bulk composition of the ocean-atmosphere system is changed to between $\delta^{13}\text{C} = +2.6$ ‰ (if no organic contribution) and -3.9 (if 22900 Gt C from the metamorphism of organic carbon was added with $\delta^{13}\text{C} \sim -22$). If we then assume that ocean-atmosphere equilibrium is rapid (flux ~90 Gt/y as current estimation) and the difference between the carbon isotope compositions of ocean and atmosphere is fixed at the timescales we consider ($\delta^{13}\text{C}_{\text{atm}} = \delta^{13}\text{C}_{\text{ocean}} - 7$ ‰), as supposed by Mora (1996) and Beerling et al. (2002), then the effect of emplacement of the Emeishan LIP in the Sinian Basin is a negative carbon excursion for the ocean-atmosphere system from an average of $\delta^{13}\text{C} = -2$ before the degassing to an average of $\delta^{13}\text{C} = -4.4$ to -10.9 after degassing.

References cited

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Supplementary material DR2: An overview of reactions in a metamorphic aureole in a sedimentary basin

The amount of gas released during metamorphism depends on the type of sediment and its chemical composition, and on the conditions (P,T, Xfluid) of metamorphism.

- At the highest temperatures, calcite melts incongruently to CaO and CO₂. Solid or liquid calcite is assimilated into the magma where it reacts to Ca which is absorbed in the magma or overlying rocks and CO₂, which degasses.
- Thermal decomposition of pure anhydrite ($\text{CaSO}_4 = \text{CaO} + \text{SO}_2 + \frac{1}{2} \text{O}_2$) begins at 1100°C and reacts readily only at temperatures around 1400 °C. Impure anhydrite containing clay, graphite or carbon monoxide reacts at temperatures well below 1000°C ($2\text{CaSO}_4 + \text{C} = 2\text{CaO} + \text{CO}_2 + 2\text{SO}_2$ and $\text{CaSO}_4 + \text{CO} = \text{CaO} + \text{CO}_2 + \text{SO}_2$). Kuusik et al. (1985) report thermal decomposition of anhydrite in CO/N mixtures at 900 °C. Impurities such as SiO₂ lower the decomposition temperatures by up to 100 °C. West and Sutton (1954) report decomposition of anhydrite with 20% added carbon at 615°C in a nitrogen atmosphere.
- Thermal decomposition of pure limestone ($\text{CaCO}_3 = \text{CaO} + \text{CO}_2$) strongly depends on the water content. In the absence of water, decomposition starts only at high temperature, around 1200°C; when aqueous fluid is present, the temperature is lower (~700°C).
- Dolomite reacts to calcite, periclase and CO₂ ($\text{CaMg}(\text{CO}_3)_2 = \text{CaCO}_3 + \text{MgO} + \text{CO}_2$) at 700°C. In the presence of aqueous fluid the temperature decreases to below ~450°C
- Calc-silicates containing forsterite and diopside form from impure limestones and marls. These reactions release considerable CO₂ and proceed at relatively low temperatures, between 450 and 500°C.

26 • Organic matter in carbonates or shales releases CH₄ and/or CO₂. Cracking of
27 hydrocarbons starts at ~100°C and reaches a maximum around 550 °C.

28 • Other gases are released from specific sediment types. Salts break down to
29 halogens; pyrite in sulfide-rich shales oxidises or breaks down to Fe-oxide releasing
30 sulfur oxides; coal burns to release CO₂.

31 The reactions within an aureole thus release a series of greenhouse or toxic gases,
32 including CO₂, SO₂, CH₄, and halogens, as summarized in Figure 2.

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34 References cited

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