Contents lists available at ScienceDirect



Earth and Planetary Science Letters



www.elsevier.com/locate/epsl

Triple oxygen and multiple sulfur isotope constraints on the evolution of the post-Marinoan sulfur cycle



Peter W. Crockford^{a,*,1}, Benjamin R. Cowie^{b,1}, David T. Johnston^b, Paul F. Hoffman^{b,d}, Ichiko Sugiyama^a, Andre Pellerin^a, Thi Hao Bui^a, Justin Hayles^c, Galen P. Halverson^a, Francis A. Macdonald^b, Boswell A. Wing^a

^a McGill University and GEOTOP, 3450, University Street, Montreal, Quebec, H3A 0E8 Canada

^b Harvard University, 20, Oxford Street, Cambridge, MA 02138, United States

^c Louisiana State University, Howe Russell Kniffen, Baton Rouge, LA 70803, United States

^d University of Victoria, 3800, Finnerty Road (Ring Road), Victoria, BC, V8P 5C2, Canada

ARTICLE INFO

Article history: Received 28 October 2014 Received in revised form 20 October 2015 Accepted 16 December 2015 Available online 29 December 2015 Editor: G.M. Henderson

Keywords: triple oxygen barite sulfur cycle Neoproterozoic cap dolostone snowball earth

ABSTRACT

Triple oxygen isotopes within post-Marinoan barites have played an integral role in our understanding of Cryogenian glaciations. Reports of anomalous Δ^{17} O values within cap carbonate hosted barites however have remained restricted to South China and Mauritania. Here we extend the Δ^{17} O anomaly to northwest Canada with our new measurements of barites from the Ravensthroat cap dolostone with a minimum Δ^{17} O value of -0.75%. For the first time we pair triple oxygen with multiple sulfur isotopic data as a tool to identify the key processes that controlled the post-Marinoan sulfur cycle. We argue using a dynamic 1-box model that the observed isotopic trends both in northwest Canada and South China can be explained through the interplay between sulfide weathering, microbial sulfur cycling and pyrite burial. An important outcome of this study is a new constraint placed on the size of the post-Marinoan sulfate reservoir (\approx 0.1% modern), with a maximum concentration of less than 10% modern. Through conservative estimates of sulfate fluxes from sulfide weathering and under a small initial sulfate reservoir, we suggest that observed isotopic trends are the product of a dynamic sulfur cycle that saw both the addition and removal of the Δ^{17} O anomaly over four to five turnovers of the post-Marinoan marine sulfate reservoir. (\otimes 2015 Elsevier B.V. All rights reserved.

1. Introduction

The dramatic climate transition observed at the boundary between the Cryogenian and Ediacaran periods (635 Ma) is well documented but poorly understood. The Snowball Earth Hypothesis postulates that during this transition, Earth's oceans were frozen in a runaway ice-albedo feedback that was finally disrupted by the gradual, syn-glacial build-up of volcanogenic greenhouse gases (primarily CO₂) in Earth's atmosphere (Hoffman et al., 1998). The Snowball Earth event at the end of the Cryogenian period (the 635 Ma Marinoan glaciation) is marked by "cap carbonate" deposits and, in several regions of the world, thin intervals of barite (BaSO₄) (Hoffman et al., 2011; Macdonald et al., 2013). The recent discovery of large deficits in $^{17}O^{-16}O$ ratios, relative to those expected from the $^{18}O^{-16}O$ ratios in Snowball-associated barites,

¹ Both authors contributed equally to this work.

has drawn new attention to these deposits (Bao et al., 2008; Peng et al., 2011).

Stratospheric production of ozone preferentially concentrates the heavy oxygen isotopes (¹⁷O and ¹⁸O) in equal proportions relative to their lighter counterpart (¹⁶O) (Thiemens and Heidenreich, 1983), and isotopic exchange results in the enrichment of stratospheric gases, principally CO₂, in the two heavy isotopes of oxygen (Yung et al., 1991, 1997). Conversely, stratospheric O₂ bears the isotopically lighter fraction, and is anomalously enriched in ¹⁶O, and depleted in ¹⁷O (Luz et al., 1999). This stratospheric isotopic anomaly is mixed into the tropospheric O₂ reservoir, where it can lead to ¹⁷O depletions in tropospheric O₂. These ¹⁷O depletions are tempered in the troposphere by O_2 generated through oxygenic photosynthesis (Luz et al., 1999), which is sourced ultimately from the hydrosphere and carries no mass-independent ¹⁷O anomaly. Mass exchange between the stratosphere-troposphere seems to be relatively insensitive to changing atmospheric compositions (Butchart et al., 2006), therefore, the unique oxygen isotope signatures in post-Marinoan barites likely reflect perturbations to

^{*} Corresponding author. Tel.: +1 514 995 4397.

E-mail address: peter.crockford@mail.mcgill.ca (P.W. Crockford).



Fig. 1. (a) Exposed Neoproterozoic stratigraphy in the Mackenzie Mountains in northwest Canada where barites from this study were sampled. (b) Stratigraphic log outlining barite occurrence at the top of the Ravensthroat cap dolostone, underlying the Hayhook Limestone. (c) Digital photomicrographs of barite fans taken in unpolarized light in \sim 3 mm-thick polished thin sections, where examples of the change in textures observed in the barite unit are observed with basal bladed crystal fans in the B1 horizon and digitate groups with widely spaced laminations in the B3 horizon.

either biospheric productivity (Sansjofre et al., 2011), atmospheric CO_2 levels (Bao et al., 2008), or possibly both (Cao and Bao, 2013; Wing, 2013).

Transfer of the atmospheric isotope signal to marine sulfate starts with oxidative weathering of sulfide minerals, producing aqueous sulfate with up to 25% of its oxygen from tropospheric O_2 (Balci et al., 2007; Bao et al., 2008; Kohl and Bao, 2011). Rivers transport this sulfate to the oceans where it, and the isotopic anomaly it carries, is diluted into the standing stock of marine sulfate. Sulfate also fuels microbial sulfur cycling (MSC) in marine environments. The sulfide produced along the reductive branch of MSC can be re-oxidized to sulfate (Jørgensen, 1990), leading to a flux of isotopically normal ($\Delta^{17}O = 0$) sulfate back into the marine pool (Peng et al., 2011). This same set of processes (sulfide weathering and MSC) carry sulfur isotope consequences for the marine sulfate reservoir, mediated by the fraction of sulfur that leaves the marine environment through pyrite burial. The sulfide produced from sulfate reduction will be enriched in ³²S, leaving a sulfate counterpart that is enriched in ³⁴S. As preserved in the sedimentary record, sulfur isotopic differences between sulfates and sulfides are related to both oceanic sulfate concentrations (Gomes and Hurtgen, 2015; Bradley et al., 2016) and organic carbon availability, as manifest through sulfate reduction rates in marine sediments (Leavitt et al., 2013). Re-oxidative sulfur cycling can amplify this isotopic difference between reduced and oxidized forms of sulfur (Canfield and Thamdrup, 1994) but it also produces characteristic ³³S-³²S fractionations that enable it to be distinguished from MSC's reductive branch (Johnston et al., 2005; Pellerin et al., 2015a; Wu et al., 2010). Coupled oxygen and sulfur isotope measurements from post-Marinoan barite, therefore, are a potentially powerful tool to resolve not only atmospheric compositions, but also the dominant metabolic contributions and critical fluxes into and out of the marine reservoir during this unique time in Earth history.

Although considerable attention has been given to the dynamics of the sulfur cycle across the Cryogenian–Ediacaran transition, many outstanding questions remain. For example, the initial size of the marine sulfate reservoir at the end of the Marinoan glacial episode, and the rapidity of its growth to typical Phanerozoic levels is still unknown. Sulfur isotope fractionations between sulfate and sulfide in different post-Marinoan sedimentary packages have been used to argue for an initial sulfate reservoir of late Archean proportions that grew to Phanerozoic levels over \approx 30 million years (Halverson and Hurtgen, 2007). Alternatively, large depletions in ³⁴S in sulfides from black shales have been interpreted to reflect a more immediate oxidative response, with the growth of a sizable sulfate reservoir occurring at a rate that was more than an order of magnitude more rapid (Sahoo et al., 2012). The microbial dynamics of the sulfur cycle over this interval are also uncertain, with the suggestion of a broad interval of enhanced re-oxidative sulfur cycling preceding the Marinoan glacial interval (Canfield and Teske, 1996) as well as a vigorous oxidative component of MSC drawing down marine sulfate levels in the earliest Ediacaran (Peng et al., 2011). Given the complicated relationship between atmospheric oxygen, marine sulfate levels, and the intensity of microbial sulfur re-oxidation, these conflicting results make it difficult to reconstruct the nature of the ocean - atmosphere system in the aftermath of the Marinoan glaciation.

In this study we provide new data and interpretation of the post-Marinoan sulfur cycle through the isotopic record within barite fans from the Mackenzie Mountains in northwest Canada (Fig. 1). This dataset includes the first paired triple oxygen and multiple sulfur isotope measurements from a Marinoan-aged barite. These data are interpreted within a time-dependent model of post-glacial sulfate cycling to explain observed isotopic trends and the environmental conditions accompanying barite deposition. By extending the record of the ¹⁷O anomaly in barite to another paleo-continent, we link these isotopic shifts to the global operation of the post-Marinoan sulfur cycle. Through this approach we make new estimates for the size of the post-Marinoan sulfate reservoir and the impact of re-oxidative sulfur cycling. These

Download English Version:

https://daneshyari.com/en/article/6427641

Download Persian Version:

https://daneshyari.com/article/6427641

Daneshyari.com