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Review

The silicon and oxygen isotope compositions of Precambrian cherts: A record of oceanic paleo-temperatures?

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ABSTRACT

Oxygen and silicon isotopes in cherts have been extensively used for the reconstruction of seawater temperatures during the Precambrian. During the past decade, the advance of in situ analysis of Si isotopes has enhanced the interest on cherts as a paleo-environmental proxy. The coupled O and Si isotope composition variations show secular and correlated trends that have been interpreted as a progressive cooling of the ocean. However, this reconstruction has been challenged because cherts can have various origins (hydrothermal, sedimentary, volcanic silicification) and their isotopic compositions might have been reset by metamorphic fluid circulation. In this case, the secular oxygen and silicon isotope variation are considered as reflecting a mixing between seawater and hydrothermal sources. A key point in this discussion deals with the origin of cherts: sedimentary, hydrothermal or chemically silicified? Therefore, several petrographical and geochemical criteria are proposed to recognize the pristine sedimentary origin of a chert. Namely they are: (1) the occurrence of microquartz, (2) a ^{18}O-rich bulk oxygen isotopic composition, (3) the occurrence of large δ^{18}O ranges at a micrometer scale, (4) variation of trace element compositions coupled with δ^{30}Si, (5) the occurrence of large ranges of δ^{30}Si in pure microquartz. These criteria should be regarded as guides to the identification of pristine diagenetic cherts in order to better constrain seawater paleo-temperature reconstructions by taking into account the effect of diagenesis. This article will review the different interpretations about O and Si isotope variation and propose a model of formation based on ancient and modern chert studies.

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1. Introduction

Knowledge of the past environmental conditions of the hydrosphere and especially the temperature evolution of the ocean is crucial to better understand circumstances of life origin. To obtain this information from the past, proxies that record chemical and isotopic signatures of past environmental conditions are used. A common proxy for oceanic temperature is the oxygen isotope composition of sedimentary rocks. Cherts, which are siliceous sedimentary rocks, are used as an important record for paleo-environmental conditions because they can retain primary information about surface conditions, i.e., ocean temperatures. Therefore, the curve of temperature evolution through time has been defined from the oxygen isotope composition of cherts (e.g., Fig. 1 Knauth and Lowe, 1978). This paleo-temperature reconstruction (Fig. 1) suggesting a hot ocean during the Archean with oceanic temperature around 70 °C (Knauth and Lowe, 1978), is highly debated (e.g., Kasting et al., 2006). Controversies are about the origin of chert, the initial oxygen isotope composition of the ocean (Jaffres et al., 2007) and the preservation of the isotopic signatures after the deposition of cherts (e.g., Perry and Lefticariu, 2014). The goal of this article is not to review the various hypotheses about the oxygen isotope composition of the ocean since it has been extensively covered in the literature (Holmden and Muehlenbachs, 1993; Jaffres et al., 2007; Kasting et al., 2006; Knauth, 2005; Muehlenbachs, 1986). In the following, we will consider that the oxygen isotope composition of the ocean was constant through geological times as suggested by the study of oxygen isotope composition of 2 Ga old ophiolites (Holmden and Muehlenbachs, 1993).

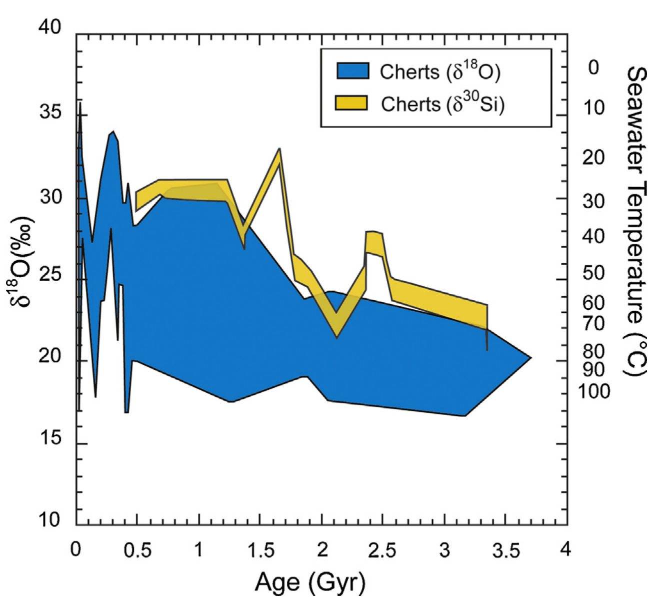

Fig. 1. Variations in $\delta^{18}O$ values of cherts with geological ages and variations in past oceanic temperatures modeled from the $\delta^{18}O$ (blue) and $\delta^{30}Si$ (yellow) values of cherts. These reconstructed temperatures evolution curves have been proposed to explain the secular $\delta^{18}O$ – $\delta^{30}Si$ correlations observed in chert through time (Robert and Chaussidon, 2006). This oceanic temperature reconstruction is still highly debated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Cherts are sedimentary rocks formed either by direct precipitation from hydrothermal fluids or seawater (C-cherts) or by silicification of precursor material (S-cherts, van den Boorn et al., 2007). They are composed mostly of silica under various forms of quartz (Calvert, 1977; Folk and Weaver, 1952; Knauth, 1994). They are abundant, widespread and found continuously over geological times from the Archean to present day. However, if chert is an ubiquitous rock through time on Earth, there is a fundamental difference between Precambrian and modern cherts. Modern cherts are formed via biological mediation of siliceous organisms like diatoms, radiolarian or sponges (De La Rocha et al., 1997; DeMaster, 2003; Hildebrand, 2008), while Precambrian cherts are mostly formed via inorganic pathways. Siliceous organisms, which appeared around 500 Ma (Porter et al., 2000, Maliva et al., 2005), maintain a low level of silica in the ocean by promoting the formation of opal A. Opal A is an hydrated amorphous silica phase relatively soluble. During diagenesis, opal A is converted to opal CT over a period of thousands to ten of millions of years (Bohrmann et al., 1994). Opal CT is then converted by dissolution-precipitation reactions to crystalline silica in the form of microquartz to make the chert (Knauth, 1994). Thus a fraction of modern cherts still contain opal A or opal CT, implying that the dissolution was not complete. In Precambrian cherts, so far, no trace of this amorphous silica precursor has been found and this is why the diagenesis pathway of these ancient rocks is not well understood still (Fig. 2). Thus, Knauth and Lowe (1978) have decided to base their temperature reconstructions on the maximum oxygen isotope composition and have attributed the large oxygen isotope variations observed in Precambrian cherts at a given age to diagenesis.

The recent development of silicon isotope analysis at high precision by MC-ICP-MS and SIMS techniques has renewed the studies of Precambrian cherts and brought new constraints on their formation and their origin (Marin et al., 2010; Marin-Carbonne et al., 2011, 2012; Robert and Chaussidon, 2006; van den Boorn et al., 2007). In situ analysis has revealed that the major silica phase constituting

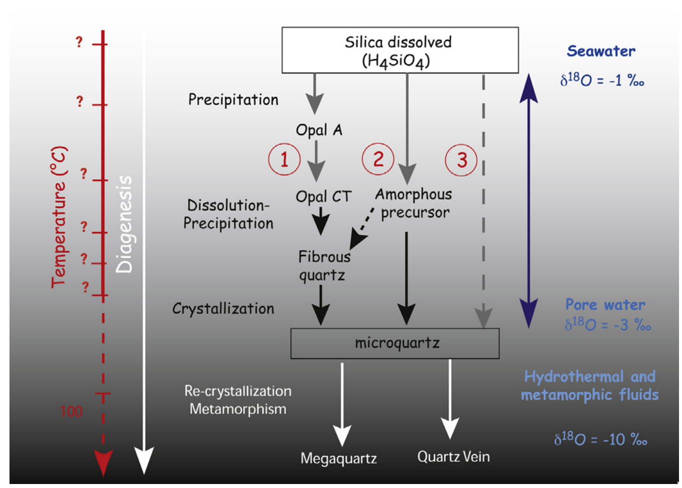

Fig. 2. Diagenesis model of cherts modified after Knauth (1994). Pathway 1 represents formation of biological mediated chert, pathway 2 represents the diagenesis of Precambrian chert while pathway 3 is still a possible pathway but not demonstrated yet.