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6

Section-I

Possible Role of Sulfur on the Early Diversification of Life on Earth : Astrobiological Implications

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Abstract

The purpose of the present paper to review the possible role of sulfur on the early diversification of life on Earth, which has also influenced greatly, biogenic mineralization. Recently the significance of chemoautotrophs (microorganisms using inorganic or organic substances as energy source rather than light) has been discussed with special reference to the Jupiter's satellite Europa. The search for presence of sulfur in the core of Europan ocean, its chemistry and sulfur reducing bacteria (SRB) could be similar to the earth, especially in its early stages of crustal evolution. They have emphasized that the sulfur patches on the icy surface of the Europa might contain biomarkers and should be aimed to study in future Europa mission for extraterrestrial life in the universe.

Key words : Early life, Astrobiology, Europa, Extraterrestrial life sulfur reducing bacteria.

INTRODUCTION

Our aim is to ascertain certain aspects of the evolution of sulfur reducing bacteria that might suggest hints as to which biomarkers would be likely signatures of life on Europa. Fortunately, the question of distinguishing between signatures of past life and signatures of nonlife in the sulfur cycle of the Earth has been carefully discussed (Machel et al, 1995, Machel, 2001). Distinguishing criteria of bacterial and Thermochemical Sulfate Reduction (TSR) have been considered.

THE ROLE OF SULFUR IN LIFE

Sulfur is an important element for all microorganisms, animals and plants on Earth. The main source of sulfur are bacterial sulfate reduction, plants and soils. Sulfur isotopic ratios provide valuable clues regarding the presence of sulfur-based metabolic activity on the early earth.

The redistribution of the primordial isotopic mixtures can be followed up in terms of the appropriate parameter, namely:

$$\text{delta}\,{}^{34}\text{S} = [({}^{34}\text{S}/{}^{32}\text{S})_{sa}/({}^{34}\text{S}/{}^{32}\text{S})_{st} - 1] \times 10^{3}\,[{}^{0}/_{00}, \text{CDT}]$$

For simplicity this function will be referred to as the delta ^{34}S parameter, or simply as the delta parameter. Its value is close to zero when the sample coincides with the corresponding value of the Canyon Diablo triolite (FeS) that is a meteorite, abbreviated as CDT.

This parameter allows a comparison of a sample (sa) with the standard (st) CDT. The relevant terms are the dominant sulfur isotope (^{32}S) and the next in abundance (^{34}S). In fact, (^{34}S/^{32}S)st coincides with the average terrestrial fraction of the two most abundant isotopes of sulfur. We obtain positive values of the delta-parameter when by comparison we have a larger quantity of the less abundant isotope ^{34}S.

Sulfur isotopic values of delta ^{34}S for sulfide (pyrite) and sulfate (barite) minerals in the early Archaean display a relatively narrow spread around delta ^{34}S = 0± 3 $^{0}/_{00}$ for sulfides and delta ^{34}S = 4±1 $^{0}/_{00}$ for sulfates (Strauss, 2003). Archaean oceans at 3.5 billion years ago (Ga) were sulfate rich and sulfides were formed by sulfate reducing bacteria (Ohmoto, 1992). The average sulfate content of the mantle is about 300-400 ppm (Gehlen, 1992).

Sulfur isotope ratios in mantle sulfur are close to meteorites (delta ^{34}S = 0.5 $^{0}/_{00}$). Sulfur isotopic compositions of sulfides are enriched in ^{32}S and may be of biogenic origin.

THE ANTIQUITY OF SULFUR REDUCING BACTERIA

The presence of pyrite in black shales, chert and phosphorite association in Proterozoic and Early Cambrian formations with delta ^{34}S > + 4 $^{0}/_{00}$ indicate that sulfate and sulfide reducing bacteria were present in these depositional environments (Skyring and Donnelly, 1982, Tewari, 1984, 1996, Krajewski et al, 1994).

Precambrian-Cambrian boundary black shale-pyrite, stromatolite and small shelly fauna indicate highly reducing palaeoenvironment in lagoonal facies, where sulfate reducing bacteria must have flourished (Tewari, 1984, 1994, 1996, Tewari and Qureshy, 1985). Neoproterozoic carbonates (1000 - 540 million years before the present) of the world are characterized by positive delta ^{13}C values (Tewari and Sial, 2007, Tewari, 2007), where is defined as follows:

$$\text{delta}\,^{13}\text{C}=[(^{13}\text{C}/^{12}\text{C})_{sa}/(^{13}\text{C}/^{12}\text{C})_{st}-1]\times 10^{3}[^{0}/_{00}, \text{PDB}]$$

The value of delta ^{13}C is close to zero when the sample coincides with the PeeDee belemnite standard (PDB) in which (^{13}C/^{12}C) = 88.99 and delta ^{13}C is defined as equaling 0.00 $^{0}/_{00}$. This parameter can be used as a good biosignature. On the Earth biota, for instance, there is ample evidence that photosynthetic bacteria, algae and plants have typical significant deviations that yield values of up to - 30 and beyond, due to biological processes (Schidlowski et al., 1983).

But the main point that we have emphasized in the past is that negative values of the delta ^{13}C parameter do not arise exclusively from biogenic sources. For this reason we have mentioned in the present paper that sulfur is a better biomarker for the study of possible biosignatures.

THE ROLE OF SULFUR IN THE EXTINCTION OF LIFE

This could be related with global oceanic anoxia near the Precambrian/Cambrian boundary. This was also the period when soft-bodied Ediacaran metazoans declined (extinction?) on earth and another biological diversification of Cambrian life took place. It is interesting that small shelly fauna (protoconodonts and conodonts, phosphatised oncolites and stromatolites having pyritic and phosphatic microlaminae and algae) were restricted to the reducing (non photosynthetic) environment (Tewari, 1984, 1989, 1994, 1996, 2004, 2007, Tewari and Qureshy, 1985).

The global sulfur isotopic trends suggest a major increase in the importance of sulfate reducing bacteria with rising sulfate levels (Lambert and Donnelly, 1992). The decreasing delta ^{34}S values for sedimentary pyrite and increasing D34S for sea water sulfate may be the result of widespread reduction under conditions similar to those of modern oceans (Lambert and Donnelly, 1992).

DISCUSSION AND CONCLUSION

We would like to restate the main conclusion of the previous paper (Seckbach and Chela Flores, 2007). S isotope analysis is the most valuable for planetary exploration. In situ analysis of the Europan surficial patches of sulfur, together with carbon signatures could yield a clearer interpretation of biosignatures. In the present paper we have indicated that geological and biogeochemical data from many sources of the Precambrian demonstrate that pyrites and evaporates were formed biologically by dissimilatory sulfate reduction (Schidloswski et al, 1983, Konhauser, 2007). Rocks of Archean age [older than 2.5 Gyr BP] provide the best evidence of early metabolic processes. Their study allows reconstruction of the biogeochemical cycle for sulfur since the origin of life on Earth. The remarkable sulfur icy patches on the Europan surface will inevitably be targets for future space missions that are expected to return to Europa in the next decade.

With landers, or low-cost penetrators that could first of all be tried out on the Lunar surface (Smith and Gao, 2007), we would be in a position to test the redox state of the Europan ocean. Alternatively, the imprint of the possibly biogenic signature of the surficial sulfur would be retained in the dust cloud that surrounds this singular jovian satellite (Kruger *et al.*, 2003).

The arguments in the present paper continue to point towards mass spectrometry as the principal instrumentation for future probing of the Europan patches, either in orbit, or with penetrators of the Moon type.

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