Hydrothermal sulfate reduction as a posssible sink of sulfate in Europa

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Europa's subsurface ocean is one of the promising habitable environments beyond Earth, yet little is known about its ocean chemistry. Recent observations of Europa's surface by groundbased telescopes suggest that a large quantity of exogenic sulfate accumulates on the trailing side [1, 2]. Given recycling of the icy shell, these sulfate should have been suppiled to the ocean. On the other hand, geologically-active chaotic terrains on Europa show the presence of chlorides and a lack of sulfates [1, 2], implying chlorine would be a major anion in Europa's ocean despite a supply of large quantities of exogenic sulfate.

Here, we investigate the fate of exogenic sulfate in Europa's ocean by laboratory experiments and thermochemical equilibirium calculations. We evaluate a possibility that hydrothermal sulfate reduction could remove exogenic sulfate from the ocean. Using a newly-developed hydrothermal experimental system, we obtain the reaction rates of sulfate reduction at various pressures and pH.

Comparing with the results at pressures of 10 and 100 MPa, we find that the pressure dependence of the reaction rate is small. We also find a strong pH dependence of the reaction. Sulfate reduction proceeds effectively at pH < 6, whereas it is highly inhibited at pH > 6. This is because reactive HSO_4^- is converted into non-reactive SO_4^{2-} at pH > 6. Our experimental results show that in order to remove exogenic sulfate effecitively through hydrothermal reaction on Europa, hydrothermal fluid pH needs to be lower than 6.

Through thermochemical calculations, we suggest that such low pH conditions can be achieved if basaltic rocks host hydrothermal systems within Europa. Sulfate reduction would not proceed hydrothermal systems with chondritic rocks due to high pH. This happends because basaltic rocks are less mafic than chondritic rocks. In basalt-hosted hydrothermal systems, the fluids composition would be dominated by Na^+, Mg^{2+}, and Cl^-, which is consistent with the findings of chlorides on Europa's chaotic terrains [1, 2]. Our results suggest that the sulfur cycles in Europa would be largely affected by the rock compositions of the seafloor.

[1] Fischer *et al.* (2015) *AJ* **150**, 164. [2] Ligier et al. (2016), *AJ* **151**, 163.