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Homework 2
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ARSENIC

The element Arsenic(As) is a metalloid that is highly toxic to humans and most other organisms. As is abundant in rock minerals and can be released through natural weathering, microbial activity, and anthropogenic pressures such as mining. Upon release into the environment, dissolution may occur, modifying the oxidation state of As (As(V) to As (III)). The state of As, as well as it's toxicity level, is driven by the biogeochemical processes of reduction, oxidation, and methylation(Lloyd et al, 2011). In order for these biogeochemical processes to occur, specific prokaryotes that have genetically adapted to withstand the toxic As chemical structure can utilize minerals that contain As for energy yields. These unique microbes allow As to undergo various biogeochemical conversions through metabolic pathways (Saltikov, 2011). These biogeochemical reactions play a critical role in the mobility of As in groundwater, and ongoing research on these reactions is pivotal to addressing greater public health implications.

Aforementioned, specific microbes have the ability to utilize minerals that contain As for energy yield through biogeochemical reactions. At the foundational level, the binding of metalloids to bacteria cell walls is dependent upon ion exchange, nucleation, and complexation reactions (Monachese et al, 2012). Although As is highly toxic to organisms, these specified prokaryotes have adapted over time and carry genetic traits that are resistant to As toxicity (RuiLun et al., 2013). Prokaryotes with gram-positive cell walls have the potential to absorb greater amounts of metalloids; however, both gram-negative and gram-positive bacteria are able to carry the resistant gene. In an effort to identify these specified prokaryotes, PCR sequencing tests were performed in groundwaters contaminated with high As levels in Southeast Asia. The results of these tests confirmed that microbial communities present in the contaminated groundwater were oxidizing bacteria, sulfate-reducing bacteria and methanogens; these prokaryotes are identified as chemolithoautotrophic and heterotrophic; however, further identification remains unknown (Li et al, 2017).

Microbial responses to As are dependent upon the species of microbes, the environmental conditions, and the type of As form that may result in chelation, sectionalization, omission, and immobilization of As. As is predominantly available in a mineral form with various chemical elements attached, such as Arsenopyrite (FeAsS), and is made available through weathering of rock or microbial activity. In redox conditions, low-oxygen and alkaline pH levels reduce the mineral into a soluble form of oxides (As(V) into As(III)), allowing for As mobilization from water dissolution or microbial reduction. The reduction of As(III) is highly toxic and difficult to bioremediate. Chemolithoautotrophs utilize specialized metabolic pathways to further reduce minerals, such as Fe or S, for ATP and releasing the As into the environment (Drewniak, 2012).

Below is an example of the chemolithoautotroph reduction of Arsenopyrite:

$$2FeAsS + 5{:}5O2 + 3H2O \Longrightarrow 2H3AsO3 + 2FeSO4\ .$$

On the contrary, with O_2 available and lower pH levels, oxidation of As(III) is able to occur and has the potential for converting As(III) into the solid, less toxic form of As(V). In environments consistently conducive to oxidation, minerals such as Fe, are oxidized to a solid-state and can absorb As and other toxins. In a 2010 study conducted by Jeong et al. on aerobic oxidation of mackinawite(FeS) and arsenic mobilization, it was found that pH levels hold a substantial role in arsenic mobilization. These findings played upon aerobic environments to which pH levels at 4, 6, and 9 were clear determinates on whether As would be mobilized, wherein acidic levels were conducive and basic levels inhibited (Jeong et al., 2010). Basic understanding of these environmental conditions affecting As mobility has allowed for greater regulatory standards specifically regarding groundwater potability.

Under the guidance of the World Health Organization (WHO), the current standard for safe drinking water should not exceed 10 ppb of As. Although the WHO holds strict guidance standards regarding toxic concentrations in drinking water, various regions across the globe have long-endured toxic levels of As in their water resources (Omoregie et al., 2013). In particular, Southeast Asia has experienced a long-term public health crisis due to groundwater contaminated with high As levels, which if consumed, can lead to arseniasis. Arseniasis is a condition that may result in cancer, kidney failure, and even death (Li et al, 2017). These toxic levels can be attributed to the excessive depth of water wells dug to surpass microbial pathogens that reside in surface-level soils.

Current bioremediation of high levels of As is limited; however, there are mitigation strategies that have been executed in certain regions. The most pertinent dynamics that remove As are pH and the availability of Fe and S. In addition to pH and specified elements, factors such as temperature, Carbon availability, and dissolved Oxygen support microbial growth (Lizama et al., 2011). Through exploitation of these factors, experts can remove As from the contaminated site effectively. One method of exploitation is to construct natural systems, such as wetlands, to exploit these conditions to naturally remove As (Fendorf et al., 2010).

In summary, the dissolution of As into the environment through weathering of rock or anthropogenic activity has led to the contamination of groundwater. This contamination has led to a global health crisis across the globe. Research findings suggest there are microbes with genes that can carry out biochemical reactions without being affected by As toxicity. The process of reduction of As by these microbes, allow for the uptake of minerals while mobilizing As into the environment. However, through the process of oxidation, As will be oxidized to solid form and bioremediation may be accomplished. Through an understanding of these biogeochemical processes of As mobility, scientists can exploit conditions that are conducive to As microbial removal from contaminated sites.

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