Enumeration of Microorganisms Capable of Mediating Anaerobic Oxidation of Uranium in Subsurface Sediments

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Abstract

Naturally occurring uranium (U) minerals are subject to oxidation via oxidants e.g. nitrate, thus forming soluble U(VI) which is a recognized contaminant in public water supplies throughout the Great Plains. In order to determine the potential impact of microbially-mediated U dissolution, this study focused on evaluating the abundance of anaerobic microorganisms within subsurface sediment cores capable of mediating five major metabolisms which impact uranium oxidation: heterotrophic nitrate reduction, heterotrophic U(VI) reduction, nitrate-dependent U(IV) oxidation, iron (Fe(III)) reduction, and nitrate-dependent Fe(II) oxidation. The cores used were obtained from two sites in Hastings, NE (5A and 5D) where subsurface sediment and groundwater (15-180 ft) were collected. At site A, nitrate concentrations in groundwater remained constant with increasing depth and increasing U(VI) while at site 5D, both concentrations increased with depth. Additionally, Most Probable Number enumeration at both sites showed that nitrate-dependent U(IV) oxidizing microorganisms had the highest abundance of all metabolisms tested. Oxidation of U(IV) by microorganisms could contribute to more U mobilization in groundwater, increasing risk to human health when consumed.

Background

Uranium (U) is a toxic radioactive mineral that occurs naturally within some types of rocks and soils throughout the United States, including the Great Plains. In Nebraska, U occurs predominantly in its reduced form, U(IV), which is generally insoluble. However, reduced U is subject to oxidation via oxidants such as oxygen and nitrate, thus forming a main end product of U(VI) which is soluble and thus mobile. This soluble U is recognized contaminant found in groundwater supplies, a common source of drinking water for public consumption and use.

Anthropogenic activity can affect the mobilization of U. For example, the application of fertilizer onto agricultural fields is a known source of nitrate contamination within soil and groundwater. This increased nitrate contamination can act as an oxidant, oxidizing the reduced U(IV) to form soluble U(VI) which can easily be carried by groundwater. This can occur abiotically, but it can also be microbially mediated. Additionally, microorganisms can further mediate U dissolution by oxidizing Fe(II) in soil into Fe(III) oxides. This is another potential pathway as Fe(III) oxides are known to oxidize U(IV). Both these reactions can contributed to further mobilization of U into water, affecting both urban and rural communities, as consuming elevated levels of U may be associated with human health concerns such as kidney damage.

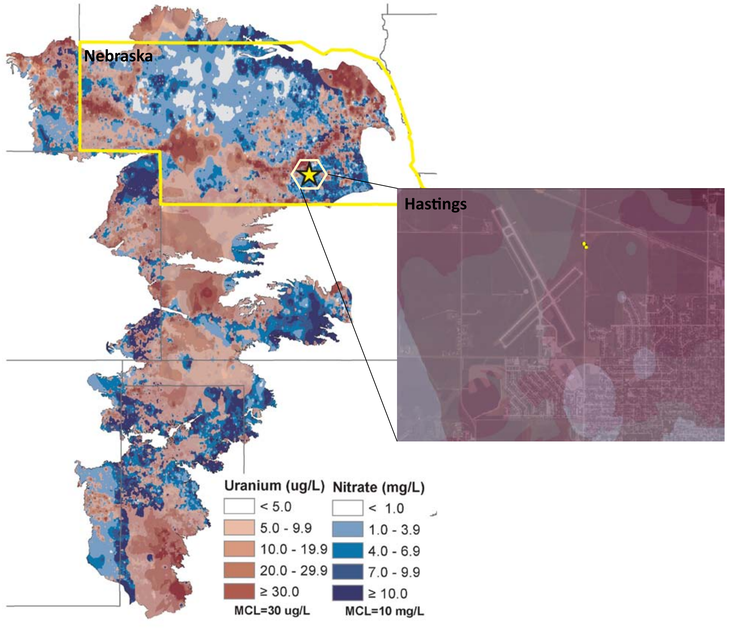


Figure 1. Predicted concentrations of soluble U and nitrate in groundwater within the High Plains Aquifer. The yellow circles on the enlarged image indicates the two locations where core samples were taken in Hastings, NE.

Objective

To obtain an accurate quantitative measure of the abundance of microorganisms in sediment capable of contributing to U(IV) oxidation and subsequent mobility.

Method

Collection of sediment core
Images were taken at one of the two sites in Hastings, NE.

Clockwise left to right: Set-up of drilling rig to collect core, makeshift laboratory to process samples *in situ*, two core segments.

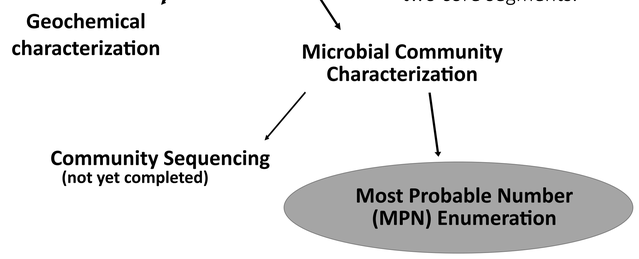
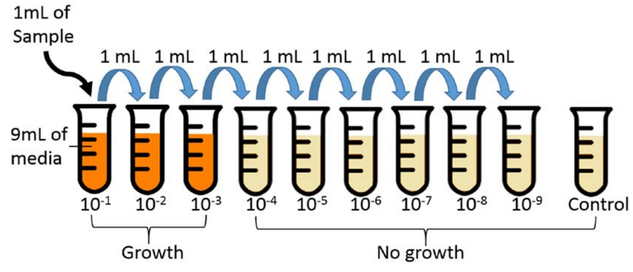


Figure 2. The MPN method is done in a serial dilution as depicted. For each of the five major metabolisms tested in this experiment, a nine-fold dilution series was prepared in replicates of three. Each set included controls.



Results

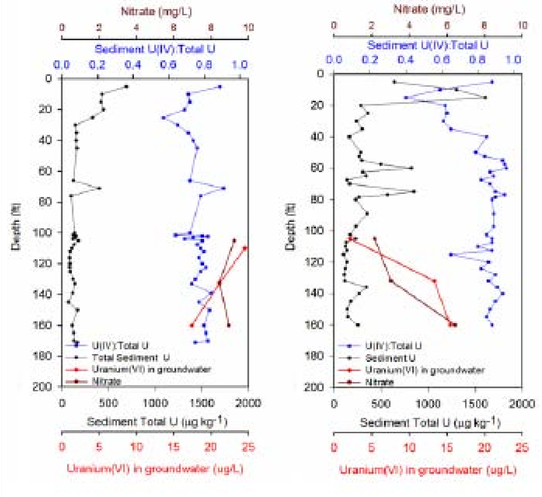


Figure 3A & 3B. The geochemical data from both sites at 5A and 5D in Hastings, NE. Nitrate and U(VI) levels were obtained from groundwater, whereas the ratio for U(IV):Total U and Sediment U were obtained from sediment.

At site 5A, groundwater nitrate concentrations in remained constant with increasing depth and decreasing soluble U(VI), while in site 5D both nitrate and U(VI) increased with depth.

Results (continued)

Most Probable Number (MPN) Enumeration

Figure 4A: Site 5A

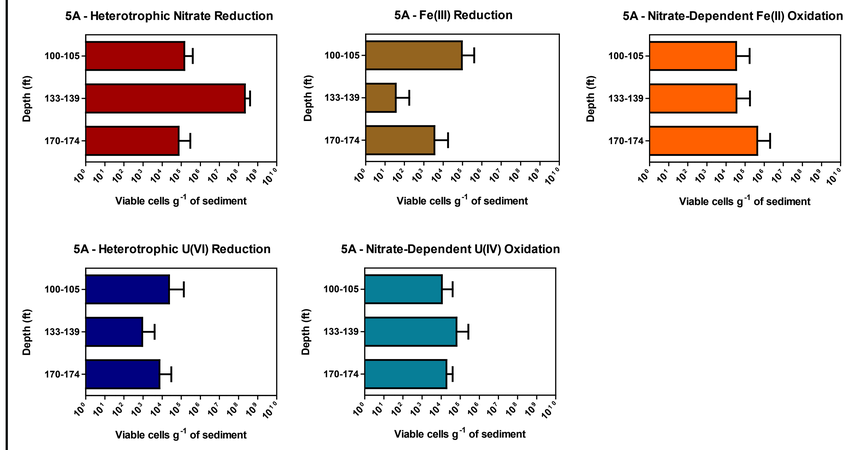


Figure 4B: Site 5D

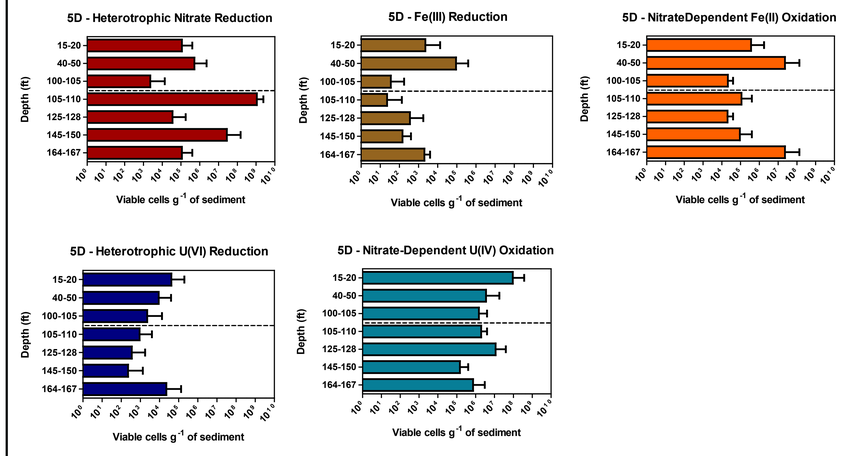


Figure 4A & 4B. The MPN enumerations of the microorganisms capable of affecting U(IV) oxidation through the five major metabolisms tested at different depths from sites 5A **(Figure 4A)** and 5D **(Figure 4B).**

MPN enumeration revealed abundant communities of microorganisms capable of all five metabolisms. At both sites, heterotrophic nitrate reducing microorganisms were the most abundant of the metabolisms: 5A with 2.15 x 108 viable cells g^{-1} at 133 – 139ft and 5D with 2.44 x 109 viable cells g^{-1} at 100 – 105ft.

Conclusion

At both sites, Most Probably Number (MPN) enumeration showed the highest abundance for nitrate-dependent U(IV) oxidizing microorganisms, suggesting significant abiotic mediation of U(IV) oxidation by indigenous microorganisms, *in situ*. In addition, there was an abundance of nitrate-dependant Fe(II) oxidizing microoganisms, which can further contribute towards the conversion of U(IV) into mobile U(VI). These microbially mediated processes could have a significant impact on the oxidation and subsequent mobility of naturally occurring uranium in subsurface environments. The increased mobilization of U(VI) could contribute to increased U contamination groundwater which is a common source for public use.

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*Images used in Figure 1 & 4 credited to Jason Nolan