Low Uranium Extraction Rates and Possible Causes in the Powder River Basin.

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Abstract:

Uranium is an important element that occurs naturally in the ground. Its uses range from energy to medicine to military. These many uses make it an attractive target for mining. Though once mined in pits and underground, as other ores are, recent advances in understanding have made it possible to mine by in-situ methods. However, In-Situ Recovery (ISR) raises unique challenges. One such challenge is to understand differences in extraction rates without physical access to the ore body.

The study area is the southern Powder River Basin (PRB) in north-eastern Wyoming. This area is notable for the most productive ISR mines in the United States. However, the PRB also contains ISR mines that, though they appear identical, produce very little uranium. In the PRB, uranium is found in roll-front uranium deposits, which form when the groundwater changes from reduced to oxidized, causing uranium minerals to precipitate in an advancing front.

The researchers propose four possible explanations for under-producing wells in the Powder River Basin (PRB), and describe the methods by which each will be evaluated. By understanding roll-fronts as systems incorporating radioactive decay, diverse mineralogy, groundwater movement, and oxidation-reduction reactions the researchers plan to contribute to both the academic institution and industry.

Introduction:

Uranium has historically been mined in open pits and underground, but growing environmental and economic concerns have discouraged large, high visibility operations. The industry has responded to these forces by adopting “in-situ recovery,” which necessitates a fraction of the workforce and has the same environmental impact as placing a few 50-gallon drums in an open field. In-Situ Recovery (ISR) is only possible because of uranium's solubility under oxidizing conditions, and insolubility in reducing conditions. However, with this new technique has come complications. The uranium ore body is not exposed requiring that all evaluation and interaction with the ore body is mediated by drill-holes and sensing equipment. This has caused problems which used to be solved by a simple walk through the mining area to become much more difficult to solve, as physical access to the ore body is now severely limited.

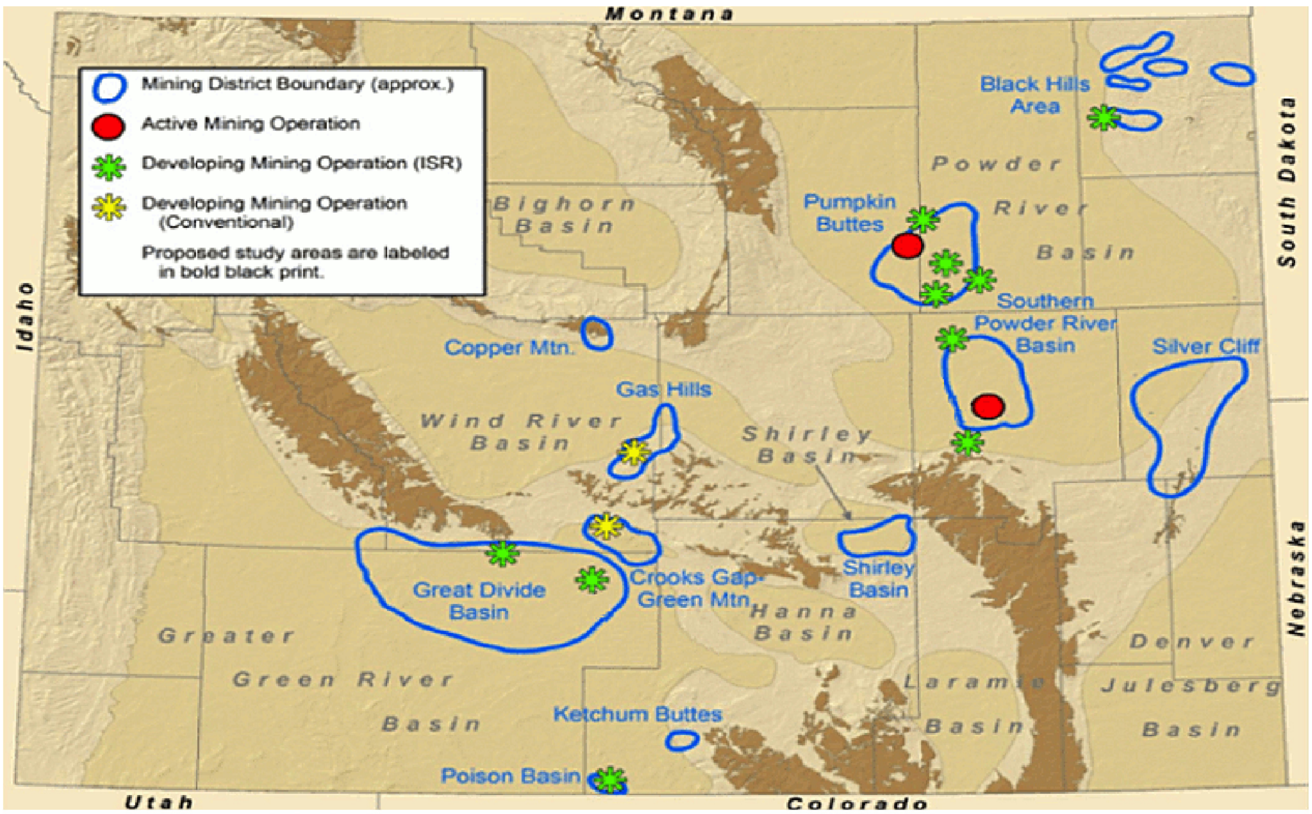

Illustration 1: Uranium mining in the southern PRB and greater Wyoming. The study area is marked by the red dot at Pumpkin Buttes. Adapted from Gregory et al. (2010).

The proposed research addresses such a problem in the Powder River Basin (PRB) of north-eastern Wyoming (Illustration 1). UraniumOne is a licensed in-situ recovery company operating wells in the southern PRB and experiencing disappointingly low returns in some wells, but very good returns in others. The only existing data on these wells comes from well-logs and drill tailings. The proposed research will investigate the reason for this extreme difference in production between wells that, based on well-logs and drill tailings, appear very similar.

The study area requires some hydrologic characterization to understand the challenges accompanying ISR development in Campbell and Johnson counties (Warren, 1972). The division between wells with good or poor recovery rates divides approximately down the Campbell-Johnson county line. As arbitrary geo-political boundaries have no effect on the geology of an area, this distinction is intended only to provided names to the two areas of differing recovery rates. The Campbell County well fields are generally experiencing low returns, but with notable exceptions of highly productive wells. On the other side of the county line, the Johnson County wells are mostly returning normal or above normal returns, but again with notable exceptions of under-producing wells. The direction of groundwater flow is generally from east to west and slightly south (UraniumOne, personal communication, September 2012; Sharp 1964). This means Johnson County receives water from Campbell County. Most of the wells in Campbell County are currently being used for production. In contrast, there are a small number of wells in Johnson County which have yet to begin production and therefore provide samples of unaltered source rock.

Proposed work:

At this time the researchers have identified four possible explanations for this problem, summarized in Table 1. The researchers plan to investigate these four possible explanations, as well as additional explanations raised in the course of their work. The researchers will need to use or construct mineral separation equipment that can operate at the five micron scale, to answer some questions.

Hypothesis	Method(s) of Testing
1) Super-abundance of Reductant	- Sample core, identify and quantify the volume of organics or other reductancts.
2) “Disequilibrium”	- “Bottle-tests” would show lower recovery than suggested by gamma-logs. - Separation of uranium minerals would show fewer uranium minerals than suggested by gamma-logs.
3) Variable Permeability	- Uranium minerals contained within impermeable portions of core, as indicated by thin section examination.
4) Insoluble Uranium Minerals	- Uranium minerals are identified by SEM and XRD and found to be insoluble in oxidizer.

Table 1: Summary of four possible causes for different return rates in apparently identical wells.

1) A super-abundance of reductant may cause the uranium minerals in the arkosic Fort Union Formation (Love, 1952; Boberg, 1981; Davis, J.F., 1969; Webb, 1969) sandstone to remain insoluble despite the large quantities of oxidizing-agent added by UraniumOne's engineers. This explanation is supported by the presence of large quantities of organics in the PRB and associated well fields. These organics may be low-grade coal, oil, natural gas, biogenic methane, and buried plant matter. Although the composition of these organics varies greatly, they are easily identified by the industry as grimy black lines in core or outcrop. These organics are powerful reducing-agents. Consequently they may maintain a reducing environment despite large volumes of oxidizing agent. To determine the validity of this explanation the researchers will need to quantify the reducing potential of the organics in the ground as well as the amount of oxidizer required to neutralize it.

2) The problematic nature of gamma-logs from the wells may have caused UraniumOne to over-estimate the amount of uranium in the ground. Uranium is not a good source of gamma radiation because it has a very long half-life (Faure, 1986). However, the daughter products of uranium have a very large gamma signature because of their much shorter half-lives. This opens the possibility of what the industry calls a "disequilibrium" or a difference between the amount of uranium that a gamma-log would lead them to expect and the amount of uranium actually in the ground (UraniumOne, personal communication, September 2012). A "disequilibrium" has nothing to do with entropy or chemical equilibria and therefore is something of a misnomer.

In this explanation the uranium would have decayed to daughter products which formed insoluble minerals; the still soluble uranium then would have left the area with the advancing roll-front. The result is a situation where the uranium is no longer present, but the daughter products are. If this is the case, the gamma-logs are no longer reliable. This hypothesis is discounted by industry because "bottle-tests" of the well tailings, which, though not conclusive, indicate that the uranium exists in the expected concentrations. This test involves adding oxidizer to powdered ore until all uranium has been dissolved. The bottle-test represents ideal conditions for ISR because all ore is in contact with the oxidizer facilitating complete dissolution. In non-ideal conditions trace uranium is always left behind, as seen in Illustration 2.

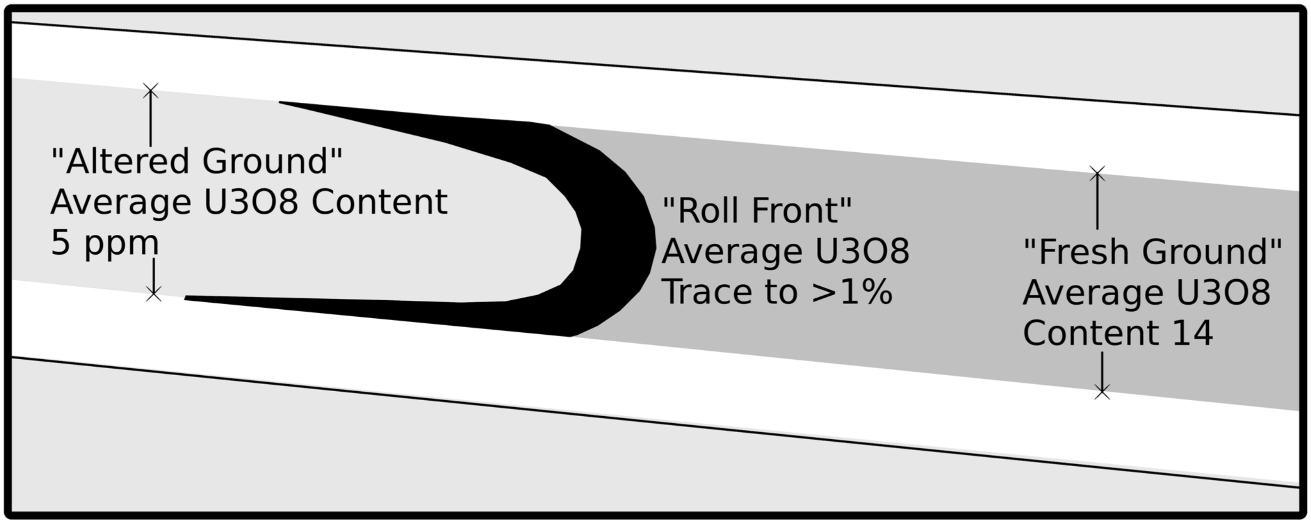

Illustration 2: Diagrammatic cross section through a typical roll front showing differences in U_3O_8 concentration between "Fresh" (oxidized) and "Altered" (reduced) Ground. In a non-ideal situation some uranium remains undissolved as the trace U_3O_8 behind the roll front. Adapted from Renfro (1969).

3) The permeability of the source rock may vary encouraging the formation of channels, and causing the reducing agent to not reach the majority of the source rock. For insoluble uranium to become mobilized it must be oxidized. The oxidation reaction, as all chemical reactions, can only occur during physical contact of the reactants. In this case the reactants are the oxidizer and the uranium minerals. This explanation considers that the massive excess of oxidizer will not affect the reaction if it never contacts the uranium, but rather flows in channels around the ore. At present, the heterogeneous permeability of the source rock is the most likely hypothesis for explaining why adding large quantities of oxidizing agent have had no effect on the recovery rates.

4) Insoluble uranium minerals may contain the majority of the uranium in Campbell County. There are over 200 common uranium minerals, some of which are insoluble even in moderately oxidizing conditions. If these insoluble minerals make up a significant proportion of the uranium in the southern PRB it could lead to reduced recovery.

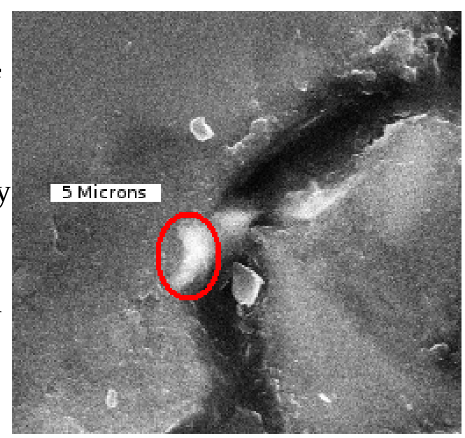

Illustration 3: The circled grain from a sample of the study site's core, is uranium-rich. Its small size makes separation from the surrounding rock difficult.

Methods:

To search for these minerals the researchers will need to separate the uranium minerals from the core provided by UraniumOne. This separation is challenging because the minerals must not be chemically altered during separation, and most of the minerals are very small -- less than 5 microns (Illustration 3). Traditional methods for non-chemical separation are designed for particles of larger size, where most use Stokes' law in one form or another. However, at sizes of less than 5 microns, Stokes' law no longer adequately describes the behavior of particles in solution (Stokes, 1851). This complicates separation and requires the design of specialized equipment, most likely an elutriation column (Illustration 4).

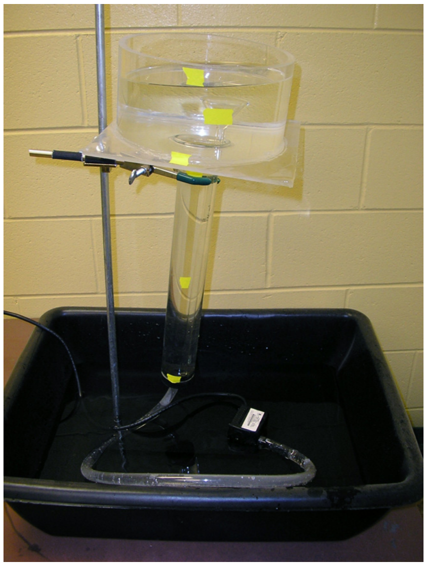

Illustration 4: A small-scale prototype of our elutriation column. It separates one order of magnitude larger particles than desired. A full scale version will perform better.

Once separation is achieved, the minerals may be analyzed in a Scanning Electron Microscope (SEM), and their structure discovered from element-ratios. These results may then be compared against a table of known solubilities for uranium minerals to decide if the mineral in question is insoluble even in oxidizing conditions.

Impacts:

By investigating the four possible explanations listed above the researchers will make various contributions, both to the ISR industry and to the academy. Among these contributions will be an increased understanding of the amount, types, and strength of organic reductants in the southern PRB. This will assist the industry in evaluating future ISR sites with organic content, and better constrain the academy's list of proposed components in the organic reductancts. Also, the research will provide the industry with methods for corroborating gamma-ray well-logs. At the same time, the academy will gain a better understanding of the role that radioactive decay plays in the roll-front system. In addition to these benefits, both the industry and the academy will gain an understanding of the hydrologic channels that constitute a roll-front. Yet, perhaps most importantly, the study will add new data on the occurrence of less common uranium minerals and their solubility to the common literature of the academy and industry. Still other contributions await the researchers if one of the four hypothesized explanations yields a new and different explanation to explore.

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