

**NM WRRI Student Water Research Grant Final Report**  
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**Mineralogical and Kinetic Considerations for Uranium Leaching**

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**Research Problem and Objectives**

New Mexico holds world-class uranium deposits but scarce water resources. In the context of a possible revival of the uranium industry in New Mexico, we are conducting a study which investigates the geochemical suitability of New Mexican deposits for alkaline *in situ* recovery (ISR) of uranium, and the potential for groundwater quality degradation through metal loading (i.e., uranium, arsenic, selenium, and vanadium) associated with mining activity. Alkaline ISR is a widely-used form of ‘solution mining’, where an array of injection and extraction wells circulate chemical agents to complex and mobilize uranium from a water-saturated ore body.

**Methodology**

We are combining in-depth mineralogical and geochemical characterization with results from batch leaching tests to better understand the fundamental controls on metal leaching in Grants District deposits. Briefly, the mineralogical methods are thin section petrography (e.g., Figure 1 – see Appendix), and electron microprobe analysis. Bulk ore geochemistry is characterized by analyses for total metals, and total and organic carbon (Table 1). Periodically sampled leachate from batch leaching tests (milled ore exposed to a 1.98 g/L H<sub>2</sub>O<sub>2</sub> + 2g/L NaHCO<sub>3</sub><sup>-</sup> solution, and unaugmented groundwater from the Westwater Canyon Formation aquifer, host formation of many of the deposits) are analyzed via ICP-MS for metals to calculate metal solubility.

**Results**

We investigated the behavior of redistributed- and primary-type ores (~0.15% and 1% uranium, respectively) from the Grants District in northwestern New Mexico. The former, “Borrogo Pass” come from a deposit near Crownpoint, NM but were sampled from New Mexico Bureau of Geology & Mineral Resources core archives. The latter, “Saint Anthony” were sampled from the north pit of the abandoned Saint Anthony uranium mine near Bibo, NM.

Preliminary results from 48-hour batch leaching tests of samples show that samples leached with groundwater liberated approximately half the uranium that leaching using industry standard lixiviant did (Figures 2-5, Table 2). Ores from primary-type deposits associated with higher organic carbon appeared to liberate a smaller fraction of their bulk uranium than redistributed-type ores (Table 2).

Alkaline lixiviant leaching also released non-target metals arsenic, selenium and vanadium in greater amounts than by groundwater leaching alone (Table 2), which may have implications for groundwater quality and pregnant leach solution processing.

Much of the depositional porosity in the host sandstones of primary-type ores was reduced by deposition of organic matter (Figure 1) and/or calcite during diagenesis, which may render them physically unsuitable for ISR depending on the lixiviant used.

Results from electron microprobe analyses were unexpected: there is no definitive uranium mineralogy identified at present (i.e., point analyses of uraniferous material did not reflect the stoichiometry of any known uranium minerals). The precise paragenesis of uranium mineralization (or, perhaps more accurately, precipitation) in these deposits can be interpreted using electron microprobe element maps (e.g., Figures 6-8) and petrography. Uranium in primary-type deposits is amorphous and, generally, closely associated with carbon. It also has an element association with phosphorus, potassium, and vanadium (Figures 6 - 8).

Carbonaceous uranium ores may be more resistant to alkaline ISR, but the higher amounts of uranium in them imply a longer mine life. It is clear that an understanding of the ore's bulk geochemistry and uranium association is important in these systems, since the majority of uranium mineralization is within amorphous, carbonaceous or siliceous/ clayey material (Figures 6, 8), previously established kinetics for individual uranium minerals likely cannot be used to model these systems.

### **Recommendations**

This study highlights an unusual aspect of the sandstone-hosted uranium deposits of northwestern New Mexico: they are characterized by amorphous, uranium-rich carbonaceous or siliceous material, not recognizable minerals. It is imperative that a better understanding of them is developed before predictions on economic yield and the environmental effects of leaching can be made. The absence of known minerals and predominance of amorphous material means that there will not be a "one size fits all" modeling approach to mining and remediation in these systems.

Our study so far has implications for groundwater quality and mine water processing. This study, upon completion, will be of use to federal and state environmental protection agencies (US EPA, New Mexico Environment Department), the New Mexico Bureau of Geology and Mineral Resources, the United States Geological Survey, and the environmental departments of tribal lands which are near many of these deposits, particularly Laguna Pueblo and Navajo Nation.

### **Future Work**

The WRRRI research funds have assisted tremendously. In the coming year, we will:

1. Develop pseudo-first order rate constants for metals under groundwater and alkaline lixiviant leaching conditions.
2. Develop a paragenetic interpretation for uranium deposition in the studied primary-type and redistributed-type deposits, based on electron microprobe element maps and data.
3. Model uranium speciation and reactive transport in groundwater associated with these deposits.

### **Grant funds**

The remaining balance of funds is \$0.24 as of 15 May 2019.

#### Spending:

- \$5,490 for Electron Microprobe analyses at the University of New Mexico Institute of Meteoritics, carried out 18-22 March and 8-11 April 2019.
- \$509.76 for ICP-MS analyses (59 samples) at the New Mexico Bureau of Geology and Mineral Resources, carried out 27 March 2019.

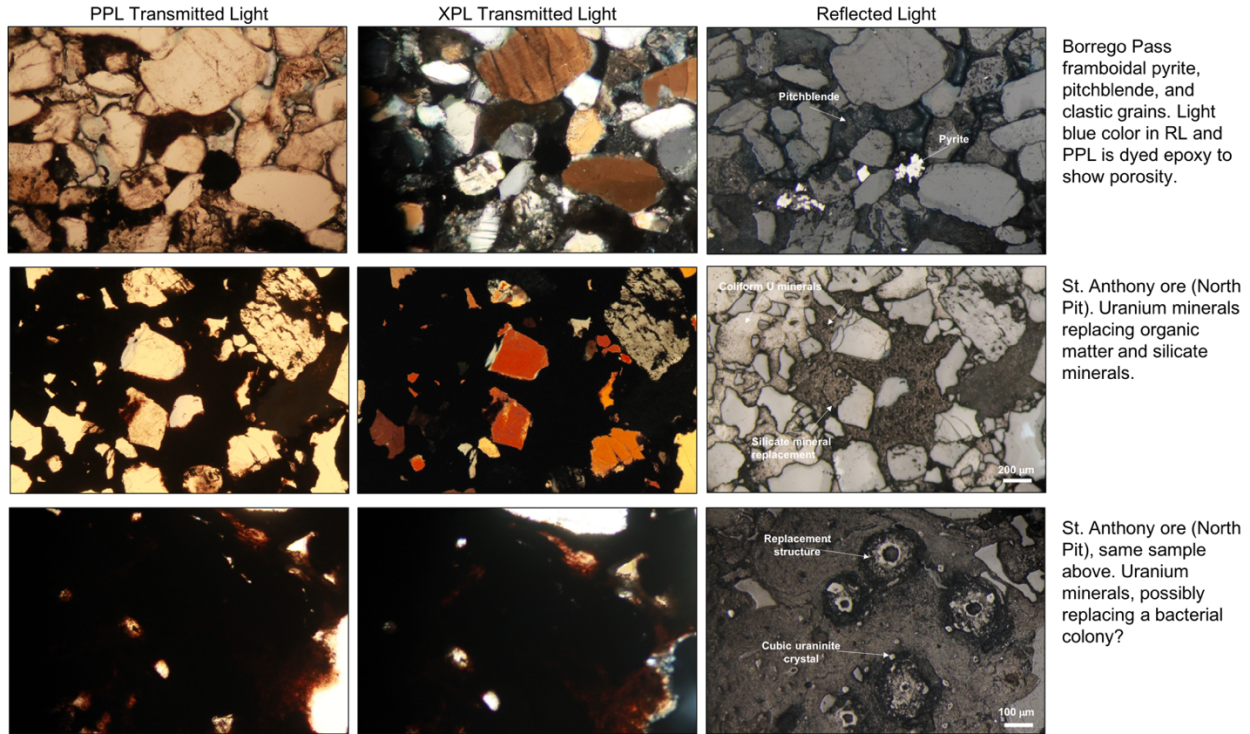
### **Acknowledgements**

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## Appendix



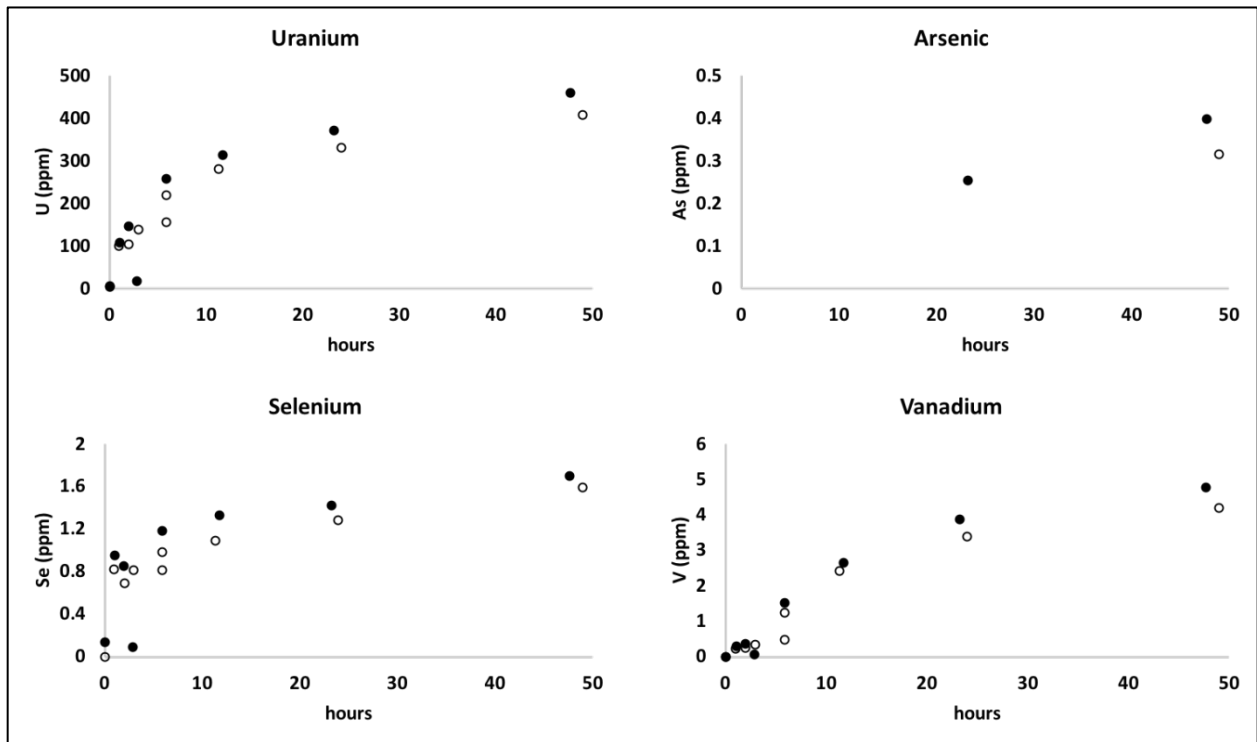
**Figure 1.** Photomicrographs of mineralized Grants Uranium District samples from Borrego Pass (redistributed-type) and the Saint Anthony Mine (primary-type). PPL = plane polarized transmitted light, XPL = cross-polarized transmitted light.

**Table 1.** Bulk geochemistry for ores mentioned in this report.

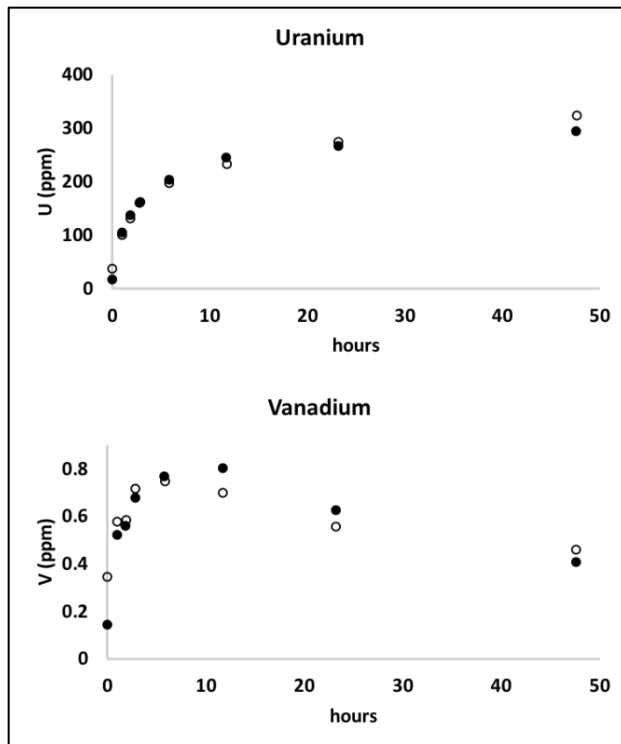
	C (%)	Organic C (%)	As (%)	Se (ppm)	U (ppm)	V (ppm)
<i>Borrego Pass</i>	0.04	0.03	14.1	54	1500	90
<i>Saint Anthony</i>	6.95	3.5	74	1	10200	1960

**Table 2.** Proportion of metals released (expressed as percent) during groundwater and alkaline lixiviant 48-hour batch leaching tests.

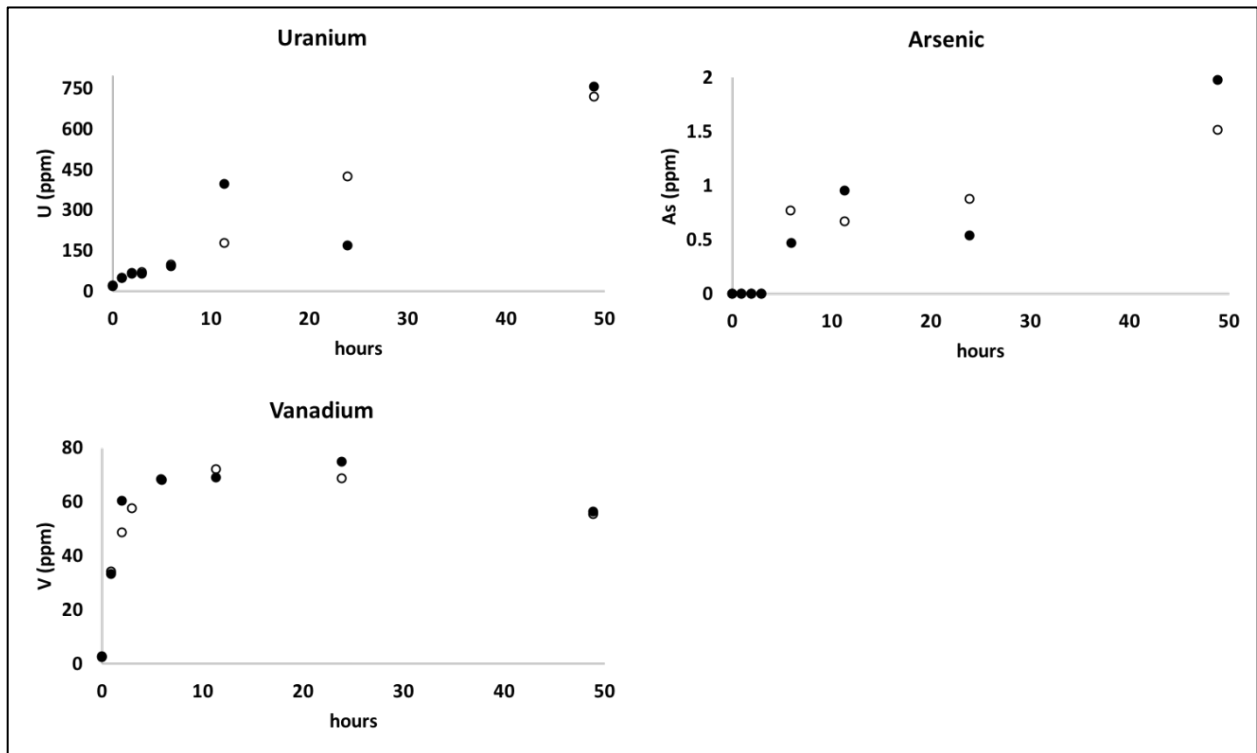
<i>Groundwater</i>	As	Se	U	V
<i>Borrego Pass</i>	3	3	31	5
<i>Saint Anthony</i>	0	0	3	0.04
<i>Alkaline lixiviant</i>				
<i>Borrego Pass</i>	11	8	50	17
<i>Saint Anthony</i>	14	0	7.4	4



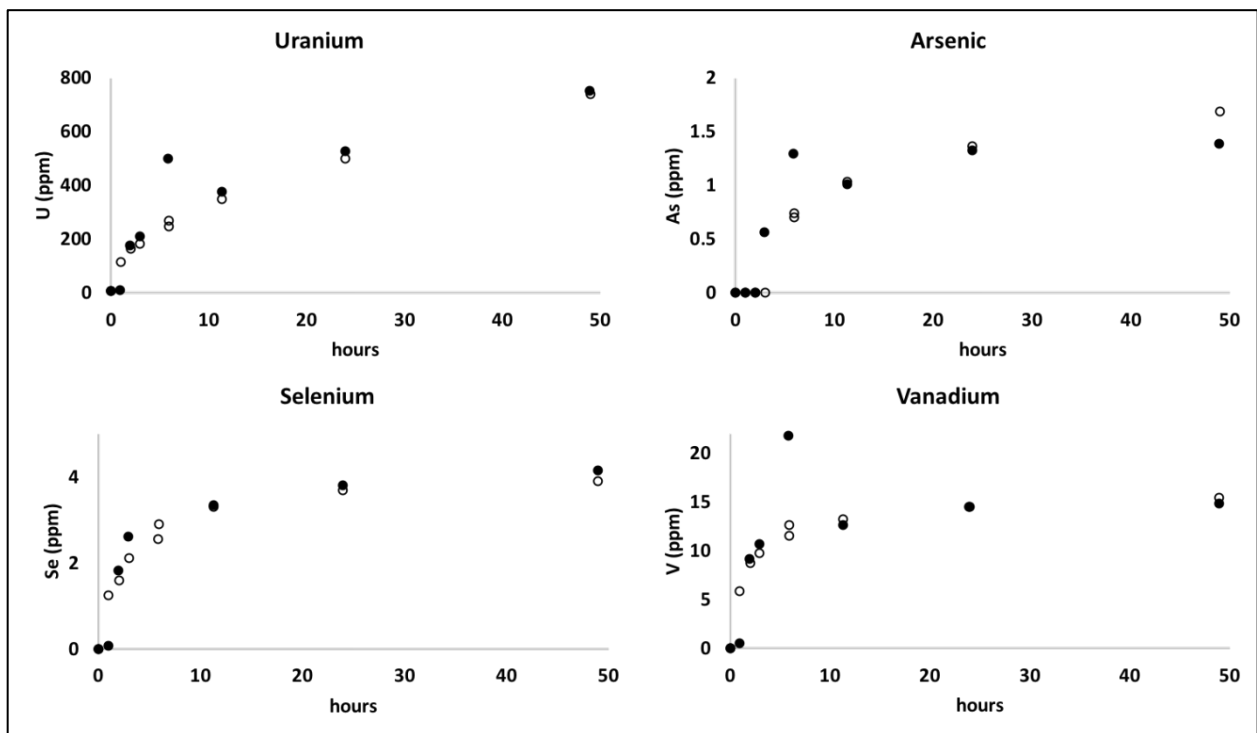
**Figure 2.** Plots of metals (uranium, arsenic, selenium, vanadium) liberated from Borrego Pass ores, during groundwater batch leaching tests, expressed as milligrams of metal released per kilogram of material (ppm). Samples were leached in duplicate (represented by black and white circles). For all batch leaching figures, the magnitude of error is not visible at this scale.



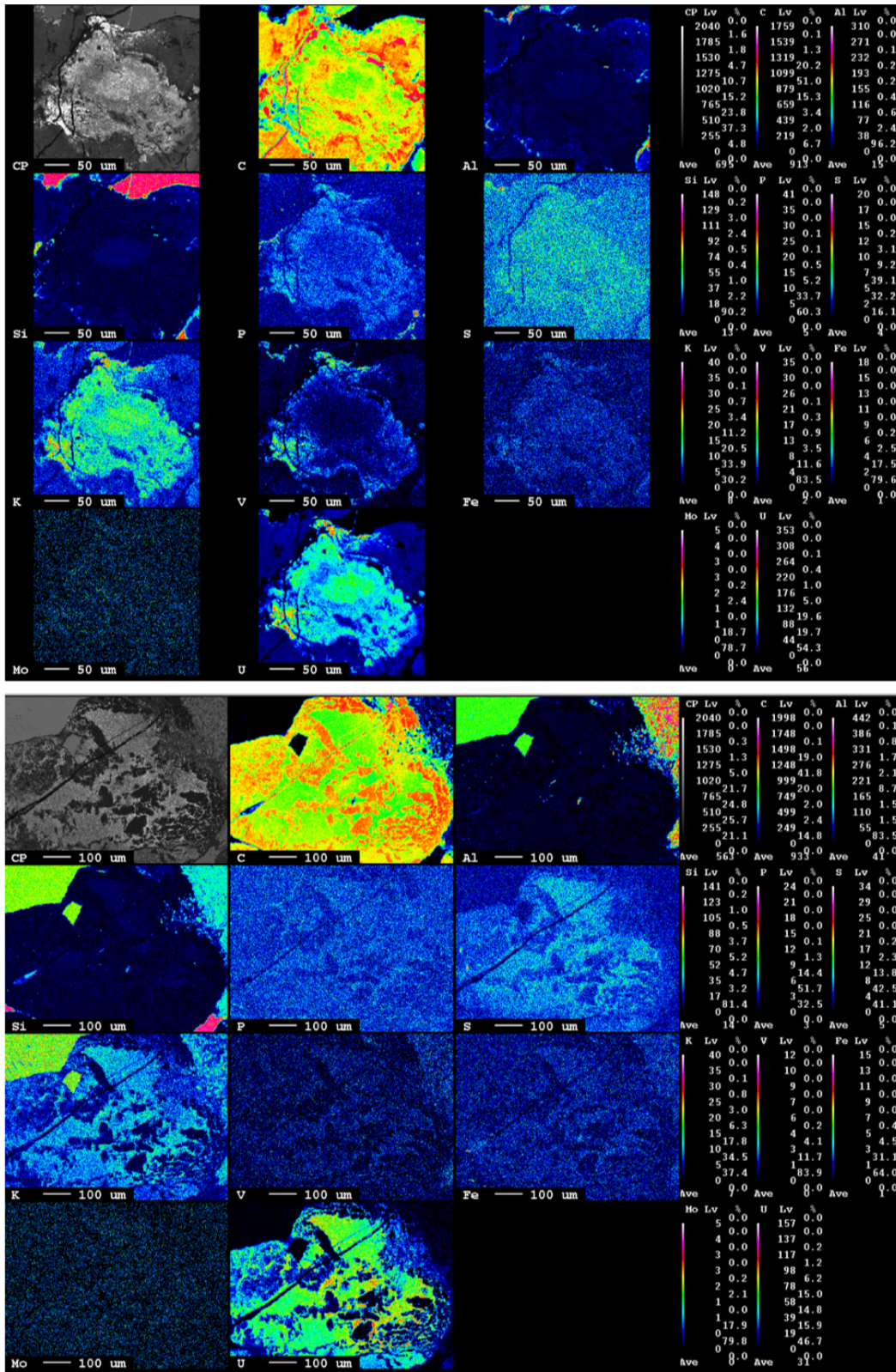
**Figure 3.** Plots of uranium and vanadium liberated from Saint Anthony ores during groundwater batch leaching tests.



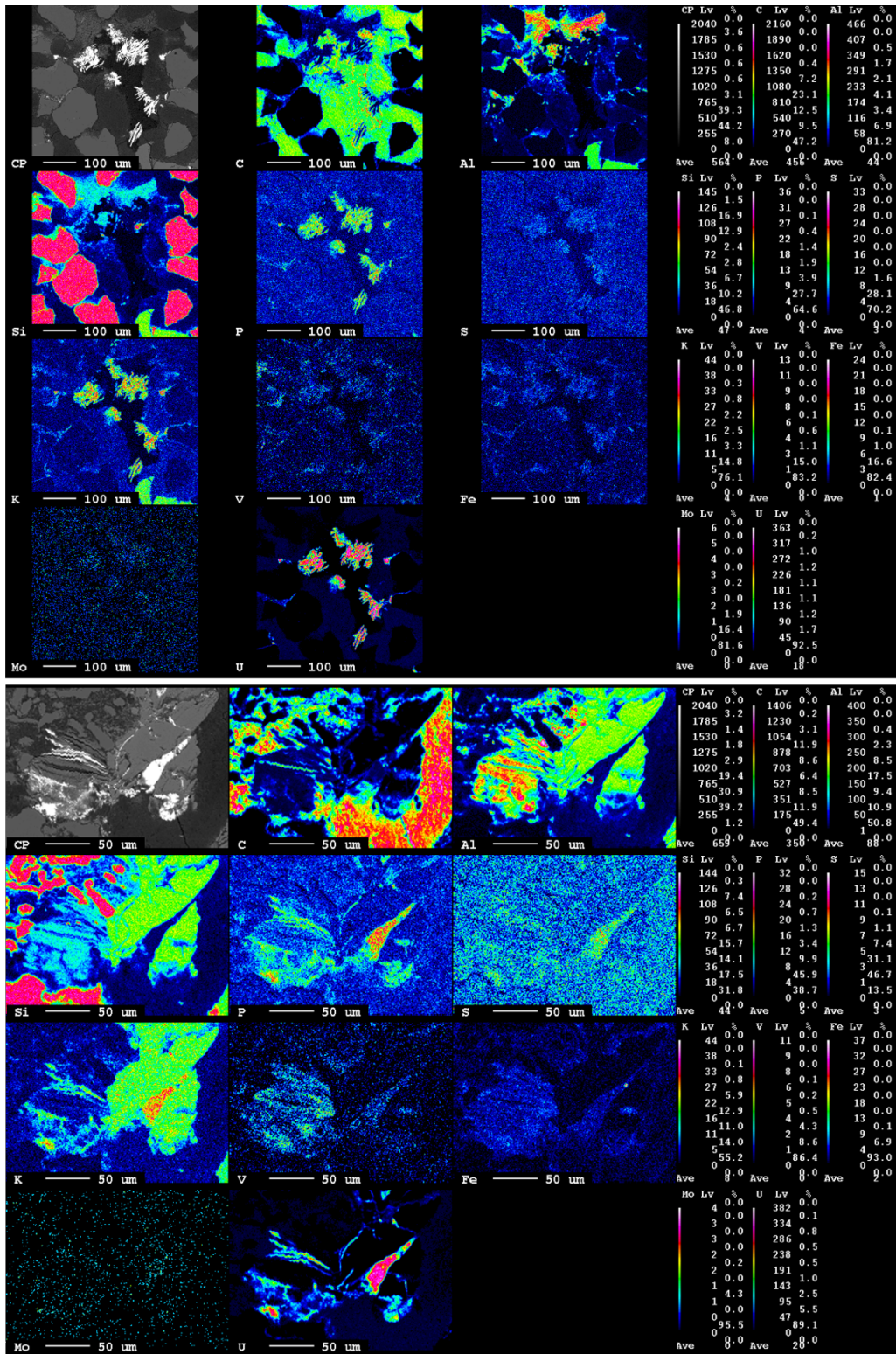
**Figure 4.** Plots of metals (uranium, arsenic, and vanadium) liberated from Saint Anthony ores during alkaline lixiviant batch leaching tests.



**Figure 5.** Plots of metals (uranium, arsenic, selenium and vanadium) liberated from Borrego Pass ores during alkaline lixiviant batch leaching tests.

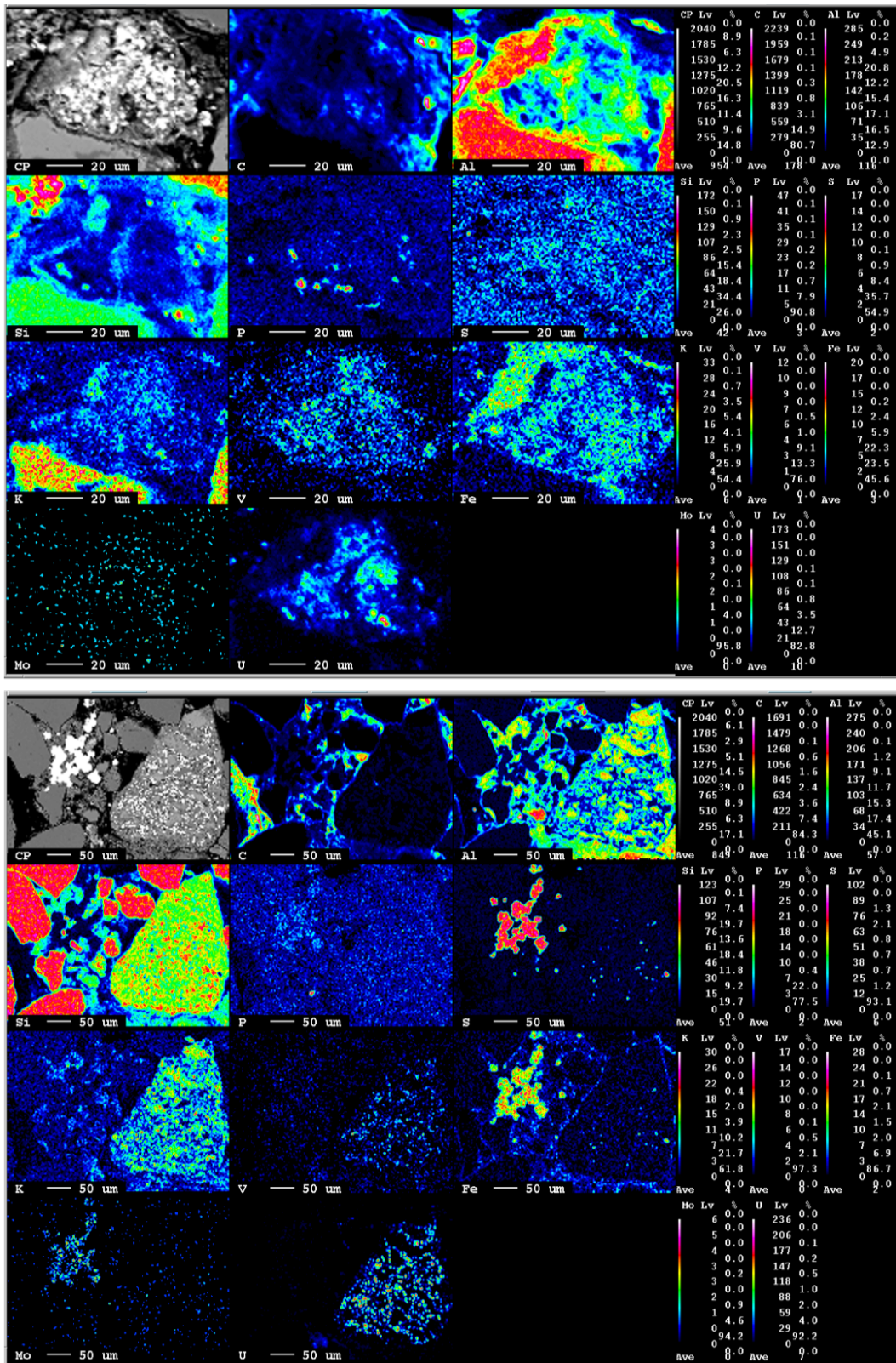


**Figure 6.** Electron microprobe element maps of primary-type Saint Anthony ore. Though microprobe spot analyses were inconclusive regarding precise mineral identification of these samples, there is distinct association between uranium, carbon, vanadium, potassium, and phosphorus.



**Figure 7.** Electron microprobe element maps of primary-type Saint Anthony ore. Here, uranium is associated with phosphorus and potassium. Based on the element distribution, it was expected that these bladed assemblages would be part of the carnotite or autunite groups of uranium minerals (uranyl potassium/calcium vanadates, and uranyl calcium phosphates, respectively). However, they were not positively identified as such after microprobe point analyses.





**Figure 8.** Electron microprobe element maps of redistributed-type Borrego Pass ore. Uranium is associated with possible clay minerals (top, see associations with aluminum, potassium, iron) and filling space within silicate grains (bottom).