Uranium in Surface Waters and Sediments Affected by Historical Mining in the Denver West 1:100,000 Quadrangle, Colorado

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INTRODUCTION

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Geochemical sampling of 82 stream waters and 87 stream sediments within mountainous areas of the Denver West quadrangle immediately west of Denver, Colorado, was conducted by the U.S. Geological Survey in October 1994. The primary purpose was to evaluate the effects of geology and past mining on the concentration and distribution of uranium. During the sampling period, local streams had low discharge and were more susceptible to U-bearing acid drainage originating from historical mines of base- and precious-metal sulfides within the Colorado Mineral Belt. The study area contains several inactive mines with documented minor production of U ore and one very large vein-type U deposit (Schwartzwalder mine) that produced 20,000,000 pounds of U_3O_8 from 1953-2000. The southeast and northwest portions of the quadrangle are generally devoid of mineralization and provided contrast with mineralized areas.

The Denver West quadrangle includes the entire drainage basin of Clear Creek which flows east towards Denver. Sample sites for collection of water and associated sediments included successive downstream locations within Clear Creek (12 samples), most tributaries to Clear Creek, and many other named creeks throughout the Denver West Quadrangle. Stream discharge was measured at the time of sampling. Other field measurements included temperature, specific conductance, and pH. Raw and 0.45 μm filtered water samples and two size fractions of sediments (<2 mm, and < 0.09 mm) were submitted for analysis of U and other elements, including heavy metals.

(1) Sample location 03, South Boulder Creek
(2) Sample location 23, Ralston Creek above Ralston Reservoir.

Goals of the Denver West Study

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1. Determine the concentration and distribution of U and other metals in surface waters and stream sediments and relate the observations to local geology and past mining practices.

2. Compare results with the results of a previous regional geochemical sampling of U completed in 1976.

3. Indicate important geochemical controls on the solubility of U and the sorptive uptake of U on stream sediments.

4. Compare the behavior of U with that of other heavy metals such as Fe, Mn, Cu, Pb, Zn, and Cd.

5. Describe a variety of analytical methods and data interpretation techniques that can be applied in other U-based studies.

6. Provide a description of the local geology and U mining history, and a bibliography of previous studies of U and other metals in the study area.

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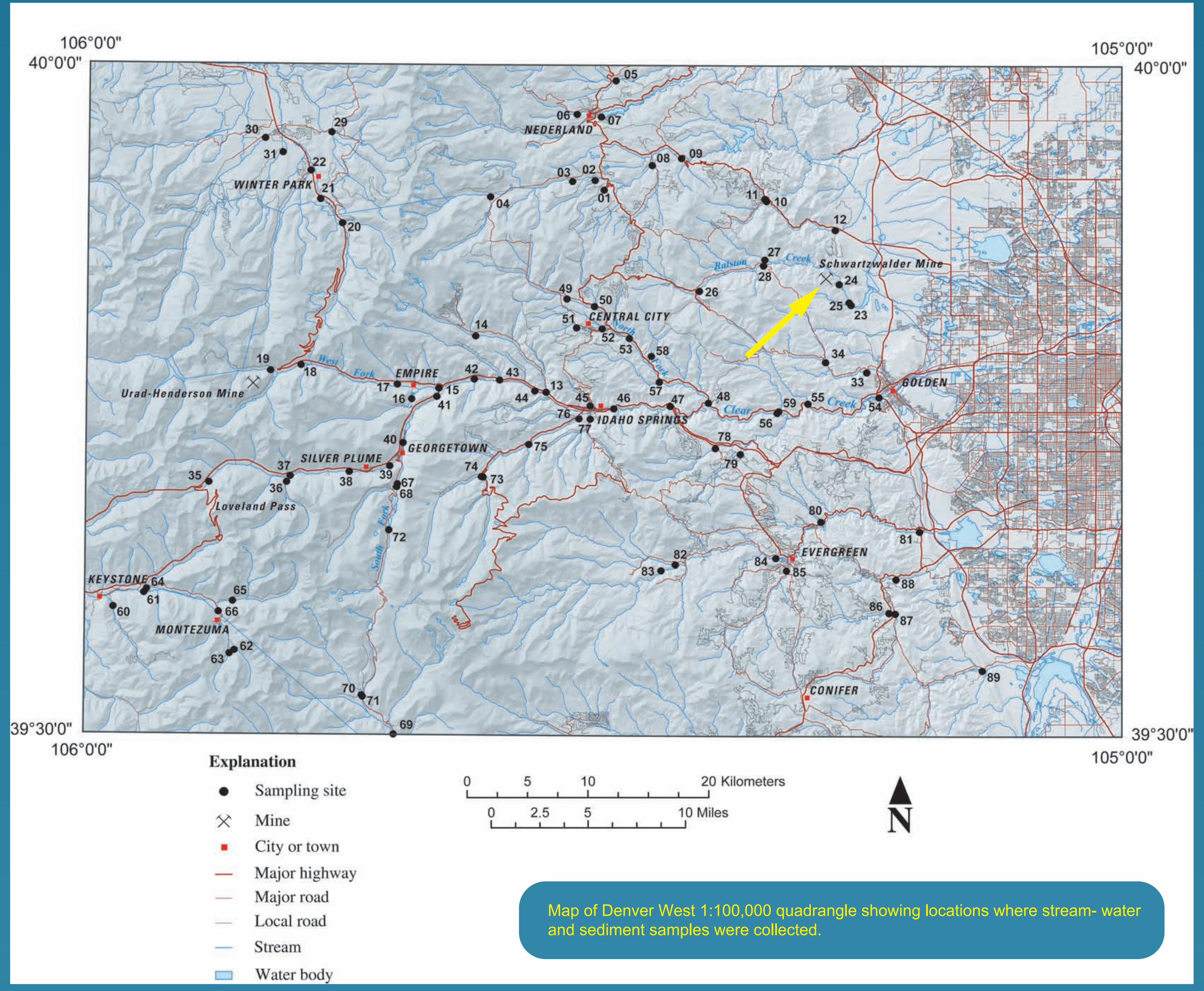

Map of Denver West 1:100,000 quadrangle showing locations where stream- water and sediment samples were collected.

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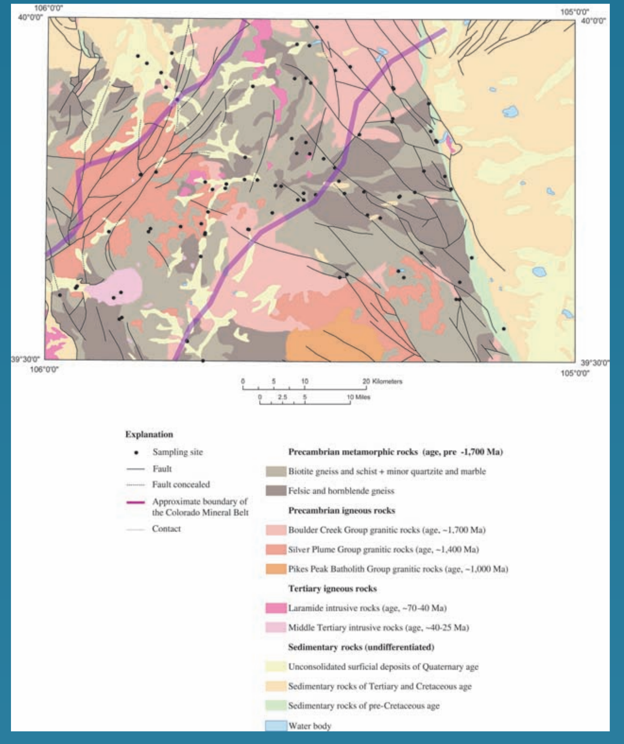

Generalized geologic map of Denver West 1:100,000 quadrangle showing sampling sites and approximate limits of the Colorado Mineral Belt.

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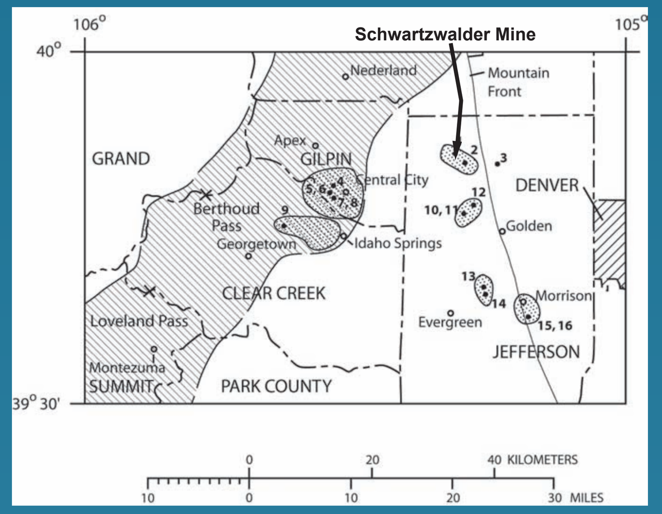

Map of Denver West 1:100,000 quadrangle showing approximate locations of uranium deposits with documented historical production. Stippled areas contain numerous uranium occurrences. Diagonal-lined area indicates approximate limits of the Colorado Mineral Belt.

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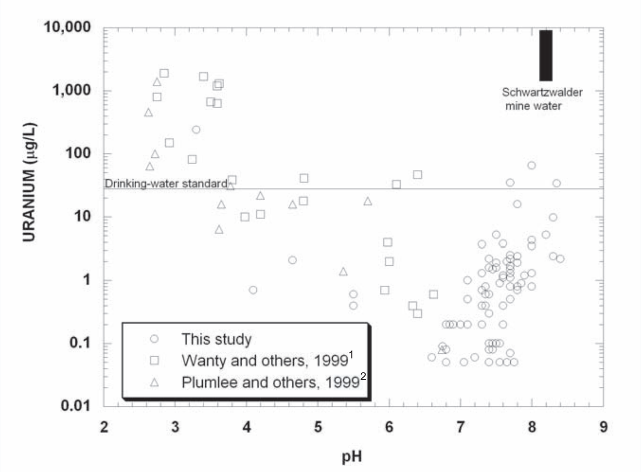

Plot showing dissolved uranium concentration relative to pH for surface waters and mine drainages of the Denver West quadrangle. The U.S. Environmental Protection Agency (USEPA) drinking-water standard of 30 micrograms per liter is indicated for reference.

1. Reviews in Economic Geology, v.6A, Society of Economic Geologists Inc., p. 201-213.
2. Reviews in Economic Geology, v.6B, Society of Economic Geologists Inc., p. 373-432.

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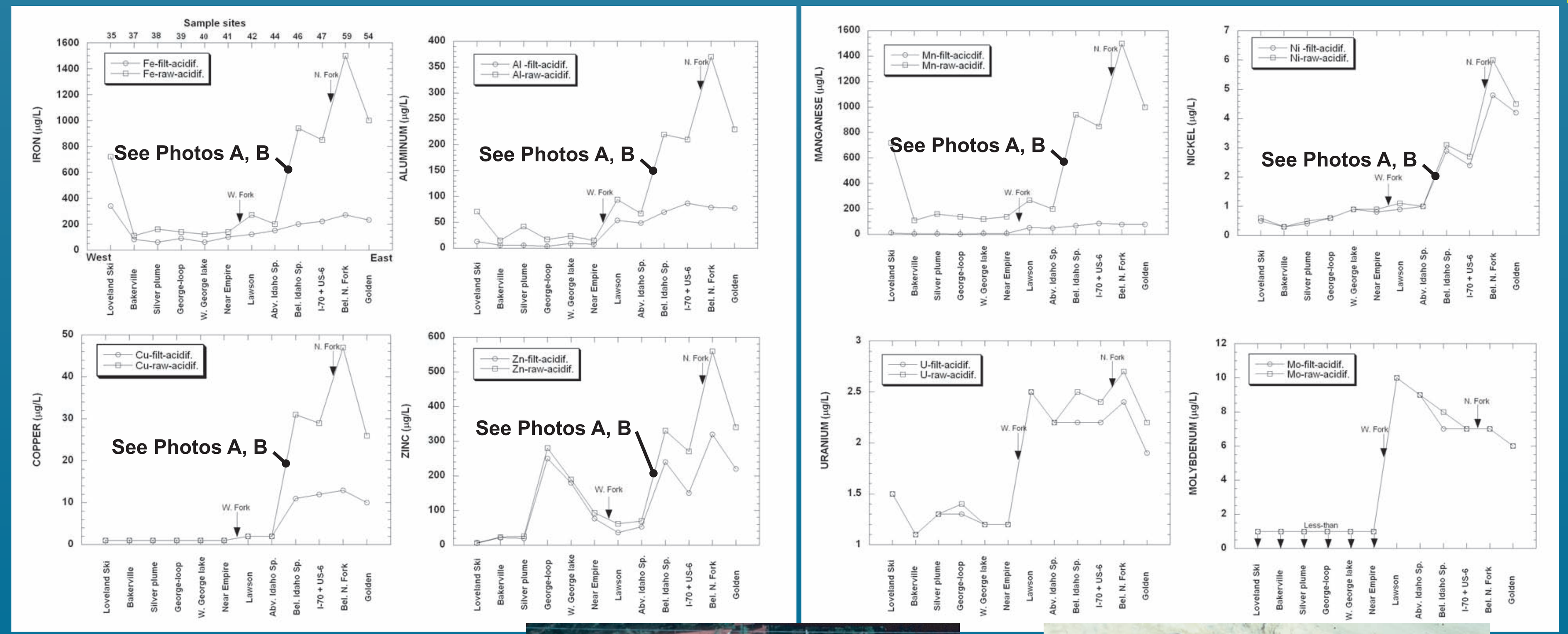

Plots showing abundance of various dissolved elements as a function of sampling site location along the main stem of Clear Creek. The two curves in each plot illustrate concentration differences between raw-acidified and 0.45 μm filtered-acidified samples.

(A) Acid mine drainage from the Argo tunnel entering Clear Creek at Idaho Springs, August 1995. This point source of acidity, metals, and (B) associated chemical precipitates of iron oxyhydroxides was remediated in 1998 by construction of a water treatment plant.

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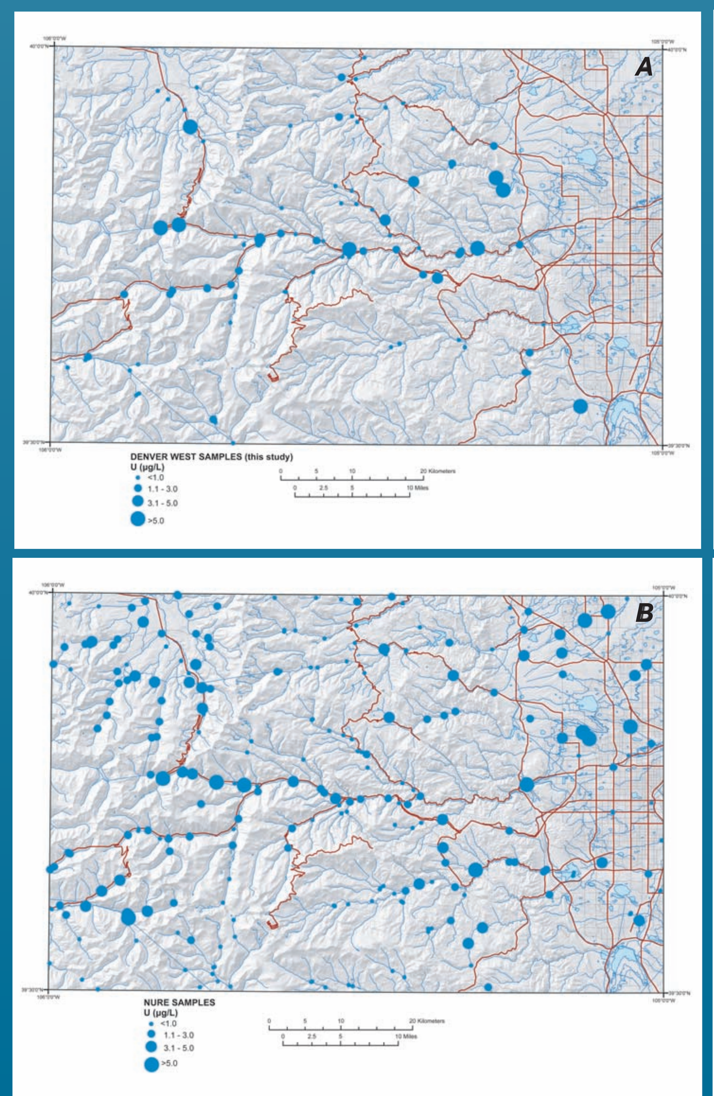
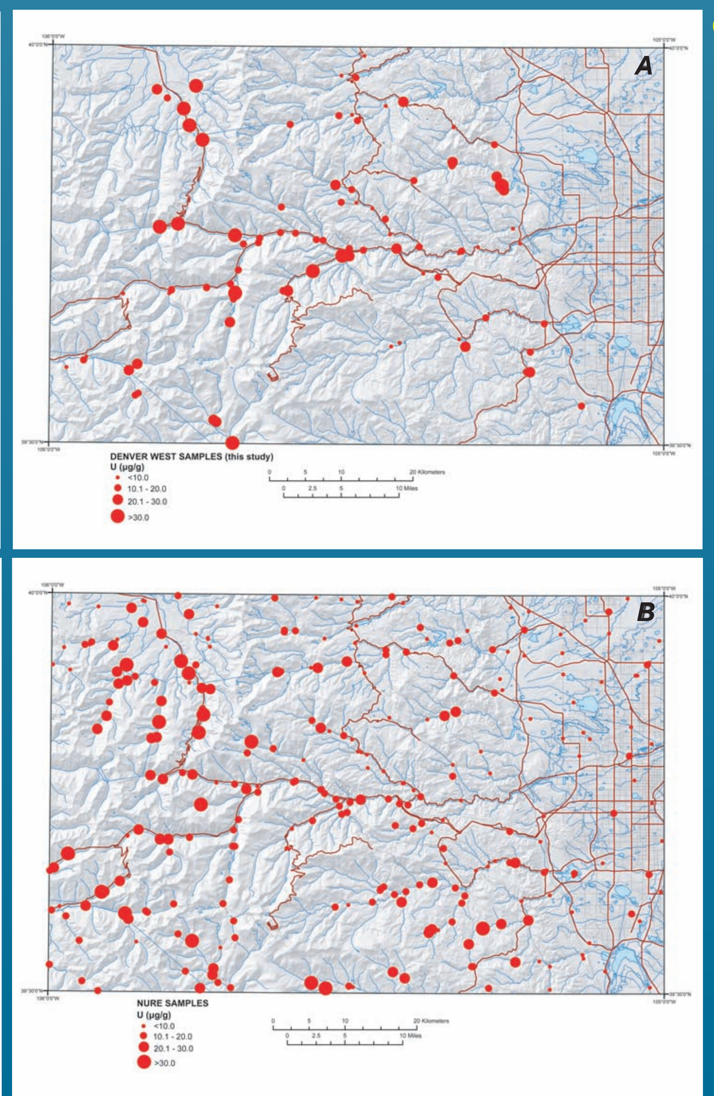


Geochemical "dot maps" indicating distribution of dissolved uranium in stream waters of the Denver West quadrangle. Dot size increases with increasing ranges of uranium concentration. Samples collected in 1994 during this study (**A**) are compared with a 1976 sampling under the National Uranium Resource Evaluation (NURE) program (**B**).



Geochemical "dot maps" indicating the distribution of uranium in fine-grained (less than 0.09 millimeter) stream sediments of the Denver West quadrangle. Dot size increases with increasing ranges of uranium concentration. Samples collected in 1994 during this study (**A**) are compared with a 1976 sampling under the NURE program (**B**).

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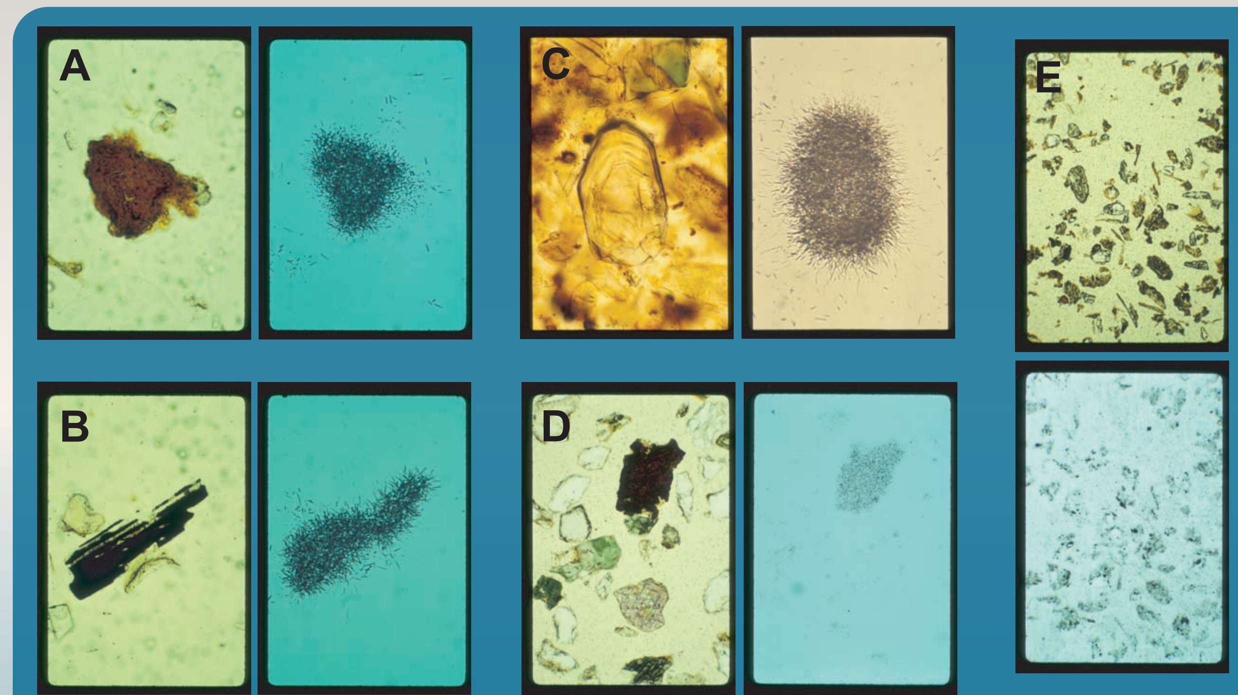

Photomicrographs (left) and corresponding fission track radiographs (right) showing representative uranium hosts in fine-grained sediments (less than 0.09 millimeter) of the Denver West quadrangle. Higher densities of fission tracks indicate higher uranium concentrations and produce darker areas on the radiographs. (**A**) grain coating of uranium-rich, reddish-brown secondary iron oxide (short axis of view, 0.15 millimeter); (**B**) carbonized wood fragment of high uranium concentration (short axis of view, 0.15 millimeter); (**C**) zircon grain (short axis of view, 0.15 millimeter); (**D**) unidentified mafic mineral grain coated with uranium-rich secondary iron oxide (short axis of view, 0.15 millimeter). Uranium is much less concentrated in other mineral grains including fluorite, unaltered hornblende, and clear quartz grains (short axis of view is 0.6 millimeter); (**E**) low-power view of assorted mineral grains coated by uranium-bearing secondary iron oxides. Some uranium detected in the epoxy matrix was redistributed from the grain coatings during preparation of the thin section (short axis of view is 1.5 millimeters). Photomicrographs A-E are from sampling sites 2, 21, 23, 24, and 48, respectively.

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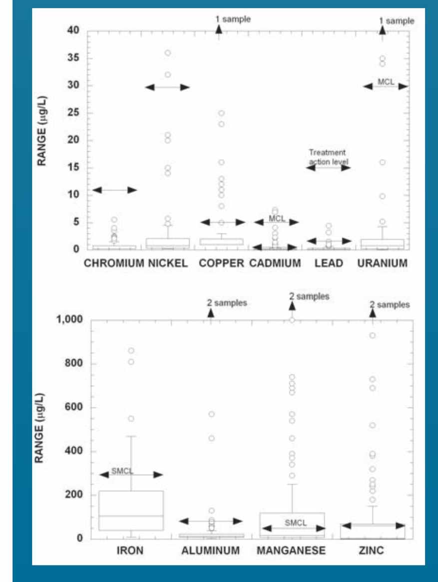

Box and whisker plots showing concentration distributions of selected elements in stream waters of this study. Unlabeled double-arrows indicate USEPA aquatic-life toxicity standards that are appropriate for conditions of average carbonate hardness in these waters (~50 milligrams per liter) and an assumed chronic exposure level. Labeled double-arrows are included for reference and are USEPA drinking-water standards that fall within the plotted concentration ranges. Values shown as circles are outliers from the normal population distribution for each element. MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; µg/L, micrograms per liter.

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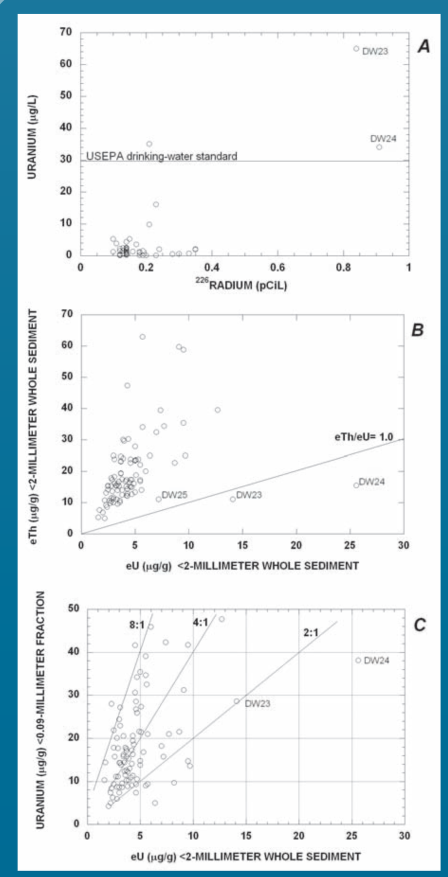

Plots indicating distinctive chemical characteristics of water and sediment from locations 23 and 24 along Ralston Creek below the Schwartzwalder uranium mine. (**A**) concentrations of dissolved uranium and radium are both high compared to other stream waters; (**B**) the Th/U ratio in fine-grained stream sediments is low (less than 1.0) compared to other locations in the Denver West quadrangle; (**C**) the relative degree of enrichment of uranium in fine-grained compared to coarse-grained sediment fractions is low (less than 2:1) compared to most other locations.

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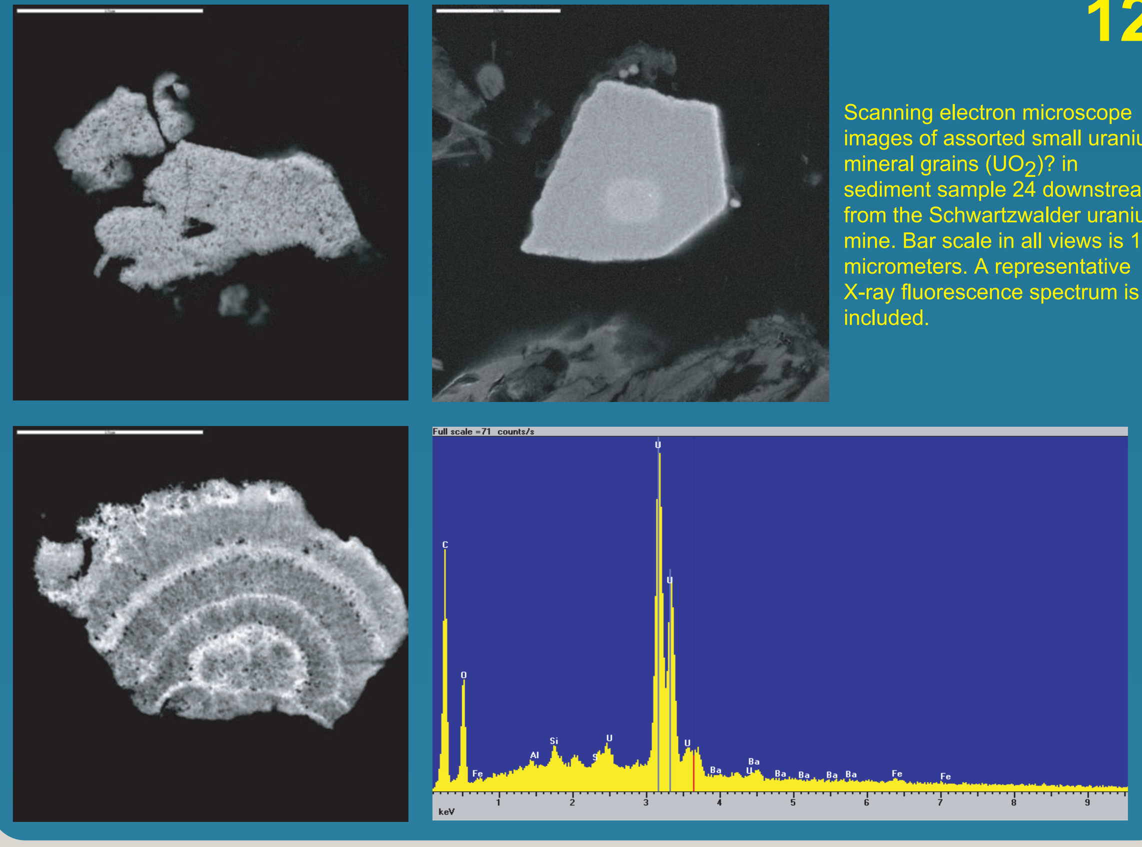

Scanning electron microscope images of assorted small uranium mineral grains (UO_2)? in sediment sample 24 downstream from the Schwartzwalder uranium mine. Bar scale in all views is 10 micrometers. A representative X-ray fluorescence spectrum is included.

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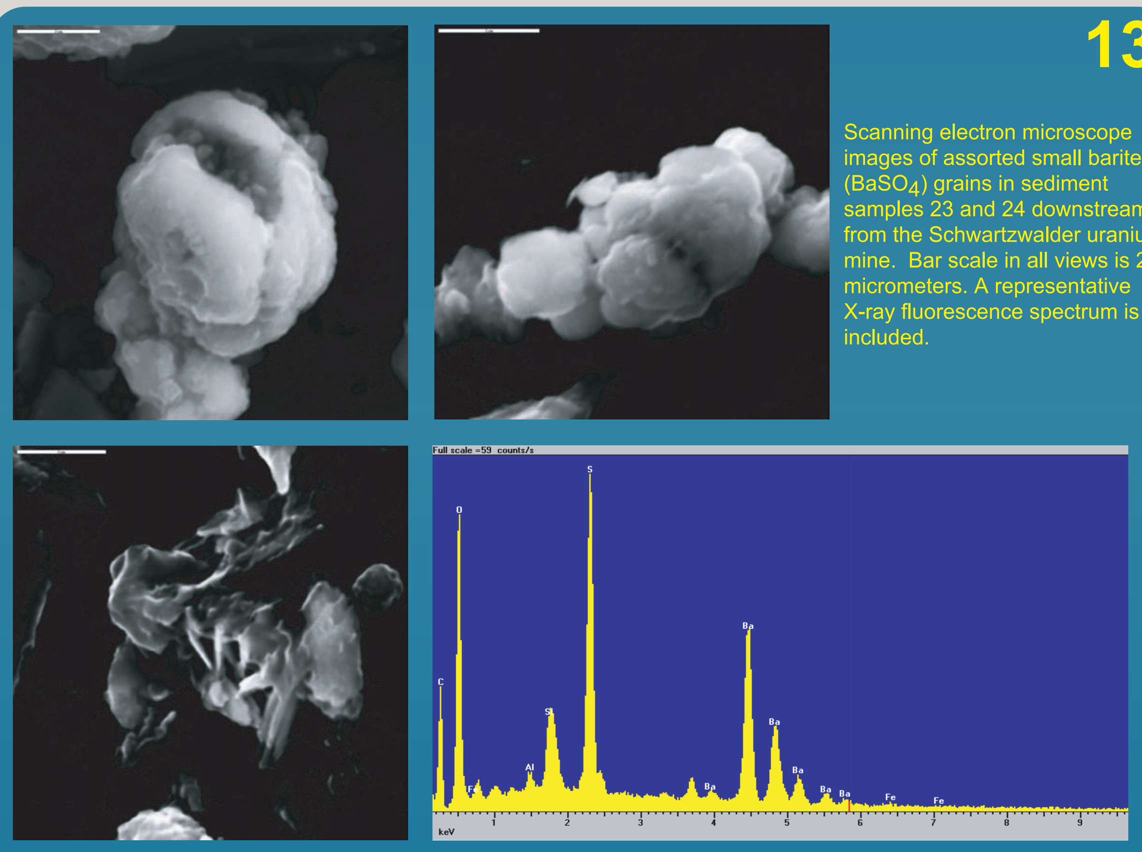

Scanning electron microscope images of assorted small barite ($BaSO_4$) grains in sediment samples 23 and 24 downstream from the Schwartzwalder uranium mine. Bar scale in all views is 2 micrometers. A representative X-ray fluorescence spectrum is included.

CONCLUSIONS

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1. With three exceptions, dissolved U concentrations in stream waters are below the USEPA drinking water standard of 30 ppb. All dissolved U concentrations are well below locally applied aquatic-life toxicity standards. Concentrations of U in stream sediments are below a proposed aquatic life toxicity standard of 100 ppm.

2. Fission-track radiography indicated that U in sediments is contained within insoluble detrital minerals or is sorbed onto iron oxyhydroxides or organic matter. Granitic detritus in stream sediments is generally more U-rich than detritus derived from metamorphic rocks of the study area.

3. U in stream sediments can be transported far downstream by re-suspension of minerals and/or iron oxyhydroxides, most likely during high flows associated with spring runoff or storm events.

4. High concentrations of dissolved U (ppm levels) are observed in both acid mine drainage and alkaline mine drainage. Much lower concentrations of dissolved U in the measured streams (ppb levels) are the result of both dilution and neutralization followed by sorption onto stream sediments and chemical precipitates of iron oxyhydroxides. The dominant form of dissolved U in the streams is U(VI) complexed with carbonate species.

5. Waters collected downstream from the Schwartzwalder U mine contained relatively high concentrations of dissolved U (30-65 ppb) and Ra (0.8-1.0 picocuries/L). Sediments from the same sites have unusually low Th/U ratios (<1.0) and unusually high proportions of total U in coarser size fractions. SEM observations indicated that the sediments contain detrital uraninite and also very fine-grained barite. The latter was produced during early attempts to remove radium from mine waters using coprecipitation with barite.

6. The methodologies applied in this regional-scale study are readily transferable to other sites and scales of investigation. They can be used to determine pre-mining baselines, and to evaluate the environmental effects of past or present U mining activities. To read more about this 2007 study go to http://pubs.usgs.gov/sir/2007/5246.