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Review of Samples of Tailings, Soils, and Stream Sediments Adjacent to and Downstream from the Ruth Mine, Inyo County, California

By James J. Rytuba, Christopher S. Kim, and Daniel N. Goldstein

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Abbreviations, definitions, and datum used

Vertical and horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27 CONUS).

As, generic shorthand for arsenic; does *not* denote speciation.

DOC, dissolved organic carbon

DOM, dissolved organic matter

EE/CA, Engineering evaluation/cost analysis for “non-time-critical removal actions,” as defined by the U.S. Environmental Protection Agency’s Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

EXAFS, Extended X-ray Absorption Fine Structure Spectroscopy

Hg, generic shorthand for mercury; does *not* denote speciation.

Hg_T, total mercury (inorganic plus organic).

Hg_F, total mercury (inorganic plus organic) in a filtered sample (either 0.1 μ m or 0.45 μ m, as specified in the text).

MMHg, monomethyl mercury, methylmercury, and monomethylmercury (CH₃Hg⁺)

ng/kg, nanogram per kilogram, equivalent to one (1) part per trillion.

ng/L, nanogram per liter, approximately equivalent to one (1) part per trillion.

ppm, parts per million, equivalent to mg/kg or μ g/g.

SC, specific (electrical) conductivity, reported in units of millisiemens per centimeter (mS/cm).

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By James J. Rytuba¹, Christopher S. Kim², and Daniel N. Goldstein¹

Introduction

Background and Objectives

The Ruth Mine and mill are located in the western Mojave Desert in Inyo County, California (fig. 1). The mill processed gold-silver (Au-Ag) ores mined from the Ruth Au-Ag deposit, which is adjacent to the mill site. The Ruth Au-Ag deposit is hosted in Mesozoic intrusive rocks and is similar to other Au-Ag deposits in the western Mojave Desert that are associated with Miocene volcanic centers that formed on a basement of Mesozoic granitic rocks (Bateman, 1907; Gardner, 1954; Rytuba, 1996). The volcanic rocks consist of silicic domes and associated flows, pyroclastic rocks, and subvolcanic intrusions (fig. 2) that were emplaced into Mesozoic silicic intrusive rocks (Troxel and Morton, 1962). The Ruth Mine is on Federal land managed by the U.S. Bureau of Land Management (BLM). Tailings from the mine have been eroded and transported downstream into Homewood Canyon and then into Searles Valley (figs. 3, 4, 5, and 6). The BLM provided recreational facilities at the mine site for day-use hikers and restored and maintained the original mine buildings in collaboration with local citizen groups for use by visitors (fig. 7). The BLM requested that the U.S. Geological Survey (USGS), in collaboration with Chapman University, measure arsenic (As) and other geochemical constituents in soils and tailings at the mine site and in stream sediments downstream from the mine in Homewood Canyon and in Searles Valley (fig. 3). The request was made because initial sampling of the site by BLM staff indicated high concentrations of As in tailings and soils adjacent to the Ruth Mine.

This report summarizes data obtained from field sampling of mine tailings and soils adjacent to the Ruth Mine and stream sediments downstream from the mine on June 7, 2009. Our results permit a preliminary assessment of the sources of As and associated chemical constituents that could potentially impact humans and biota.

¹U.S. Geological Survey, Menlo Park, Calif.

²Chapman University, Orange, Calif.

Mining History and Geology

The following history of the Ruth Mine is summarized from Julihn and Horton (1937) and Briggs (2007).

The Ruth Mine is in the Sherman Mining District, 12 miles north of Trona in Homewood Canyon, on the east side of the Argus Range (coordinates: 35°, 53', 26.24" N, 117°, 24', 32.18" W). Doug Graham and Smiley Jones discovered gold in the Canyon in 1899, and shortly after identifying the source, the Graham-Jones mine was formed. The mine operated under control of Jones and Graham until 1937 when they leased the mine to the Burton brothers. The Burton brothers renamed the mine the Ruth Mine in 1937 and upgraded the equipment to produce 70 tons of ore per day. Equipment included a 40-ton vat leaching cyanide mill. Nearby mines, including the Davenport Mine, also owned by the Burtons, transported ore to the Ruth Mill for processing. The mine operated until WWII when order L-208 shut down all gold mining in California. The camp became a ghost town nearly overnight.

The Ruth Mine is in an unnamed ephemeral drainage in the Argus Range. Tailings from the mine have migrated downstream toward Searles Valley, to the northeast, during episodes of heavy rainfall. The area, located in the Basin and Range province, consists of short mountain ranges generally trending north-south, separated by valleys filled with quaternary deposits (Stoffer, 2004). Ore at the Ruth Mine consists of free gold associated with pyrite in iron-stained quartz stringers in a fissure in quartz monzonite bedrock. Bedrock of the surrounding area mostly is Mesozoic granite, with some Paleozoic marine sedimentary rocks and Pliocene and Pleistocene basalts and pyroclastic rocks. Quaternary alluvium covers much of the area of Homewood Canyon.

Sample Locations and Methods

Sample Locations and Conditions

Samples were collected to assess the concentration of As and associated elements in tailings and soils at the Ruth Mine and in stream sediments downstream from the mine. Sample site locations and description are listed in table 1 and are shown in figures 3, 4, and 5.

Field Sampling Methods

Tailings, Soils and Sediments

Samples consisting of 100 to 500 g of mine tailings and soils were collected from the area of the Ruth Mine and stream sediments with the prefix S were collected from the unnamed drainage in Homewood Canyon (fig. 3). At each soil-sample site, a surface-soil sample, from the 0-2-inch depth interval labeled with suffix "0", and a subsurface-soil sample, from the depth interval 2-6 inches, labeled with suffix "1", was taken in order to assess the possible contamination of surface soils from wind- and water-transported tailings derived from the Ruth Mine (table 1, fig. 4). In Homewood Canyon, stream sediments downstream from the Ruth Mine were collected from the active channel at the surface, and at some sites, subsurface sediment was collected. Test pit samples within the

drainage in Homewood Canyon were dug to assess the depth of contaminated sediment within the active channel and have a TP prefix (table 1, figs. 4 and 5). Samples of tailings, soil, and sediments were stored and shipped in Ziploc[®] bags at ambient temperature.

One sample of tailings from the tailings pile was weighed and then sieved into 10 size fractions to evaluate the concentration of As as a function of grain size. The sample passed through a series of 10 stainless steel, 13-inch sieves featuring increasingly finer meshes, with the aid of a Ro-Tap Testing Sieve Shaker Model B from Tyler Industrial Products. The sample was agitated for a period of 30 minutes to insure effective size separation, resulting in 8 distinct size fractions (table 3); no significant amount of material was observed to pass through the 8th-10th sieves ($\leq 45 \mu\text{m}$). Splits of 5-10 g from the initial bulk sample and from each fraction size weighing >5 g were analyzed using inductively coupled plasma-mass spectrometry (ICP-MS).

Analytical Methods

Soils and Tailings

Multielement analyses for all dry soils and tailings were done in the laboratories of ALS Chemex. Bulk samples were ground in a zirconia ring mill and subjected to a near-total four-acid digestion. Elements, other than Hg, were determined by ICP-MS. Mercury was determined by cold vapor atomic absorption spectroscopy (CVAAS) following methods similar to those described by Crock (1996) and O'Leary and others (1996). Results of chemical analyses are listed in table 2.

Extended X-ray Absorption Fine-Structure (EXAFS) Spectroscopy

Bulk As K-edge EXAFS spectroscopic analysis was done at the Stanford Synchrotron Radiation Lightsource (SSRL) at room temperature, in fluorescence mode, with a Lytle detector (for high-concentration samples; $[\text{As}]_{\text{T}} > 1,000$ ppm) or a Ge 30-element detector (for low-concentration samples; $[\text{As}]_{\text{T}} < 1,000$ ppm). The speciation of As in the tailings sample was then determined by comparison of its EXAFS spectrum with those from an As model compound EXAFS library of 16 homogeneous As(III) and As(V) phases including crystalline, amorphous, and sorbed compounds collected in transmission mode. Each model EXAFS spectrum, reflecting the distinct structural arrangement of arsenic in that particular sample, is unique and can, therefore, be utilized as a component phase in combination with other model spectra to characterize a heterogeneous, natural, As-bearing sample. The EXAFS spectra of the mine-waste samples were analyzed using a linear least-squares fitting method that has been employed in a wide range of environmental systems (Foster and others, 1998; Paktunc and others, 2004) to deconvolute the composite spectrum of the natural sample into the sum of its individual As-bearing components.

EXAFS spectra were averaged, background-subtracted and fitted over a k-range of $2\text{-}10 \text{ \AA}^{-1}$ using the SixPack software program (Webb, 2005). Each model compound was first applied individually, with the compound yielding the best fit (that is, the lowest reduced χ^2 value, an indicator of the quality of fit) selected as the first component for subsequent fits. Additional model compound spectra were then individually combined

with the first component to generate two-component fits, repeating the process until no more significant contributors, that is, those representing ≥ 10 percent of the total fit, could be added that caused the reduced χ^2 value to decline by ≥ 10 percent. The final fit, providing both the identification of the relevant arsenic species and their percent contributions to the fit, represents the EXAFS-determined As speciation of that sample. This method, while providing a direct, nondestructive route to characterizing As speciation, is limited to the spectra in one's model compound database, has detection limits of ~ 100 ppm [As]_T and is considered to have errors of ± 10 percent in the final quantitative phase determinations (Wang and Mulligan, 2008; Kim and others, 2000).

Results

Tailings and Waste Rock at the Ruth Mine

Tailings present in the two piles at the Ruth Mine have high concentrations of As (1,300 to 3,880 ppm) based on samples collected by the BLM staff (U.S. Bureau of Land Management, 2008). The tailings, located on the banks of the drainage in Homewood Canyon, have been eroded and have migrated downstream (fig. 6). In addition, tailings were removed from the mine area to construct the dirt road in Homewood Canyon that provided access to the mine, as well as other dirt roads adjacent to the mine. The dirt road in Homewood Canyon subsequently was paved and then abandoned when a new paved road was constructed. Segments of the old road remain in the central and lower part of the canyon (fig. 5, road samples T3-8 and T10, T12, and T13). Locally, the pavement has disintegrated and exposed the tailings, which are being eroded and released into the drainage in Homewood Canyon (figs. 8 and 9). The As concentration of tailings in the road is variable, with the highest concentration recorded at 1,990 ppm (table 2, samples T3-T13). The dirt roads, which are adjacent to the mine area at the BLM recreation site, also are composed of tailings, with As concentrations up to 2,570 ppm (table 2, fig. 4, samples T1 and T2).

The results of the grain-size analysis of one tailings sample are listed in table 3 (sample RMS03C). No tailings were present in the size fractions smaller than 45 μm , and most of the mass of the tailings was present in the largest grain-size fraction, S1, that contains particles larger than 2,830 μm (fig. 13). The As concentration in the bulk sample was 2,230 ppm. The As concentration in the largest grain-size fraction was 2,280 ppm, and As concentration increased with decreasing grain size, reaching a maximum concentration of 3,270 ppm in the smallest size fraction, 45 μm - 75 μm (fig. 14).

Tailings from the Ruth Mine have been released into the drainage in Homewood Canyon, and then into Searles Valley, for a distance of about 6 km (fig. 3). Upstream from the mine area, the concentration of As in stream sediment is 10 ppm, comparable to the As concentrations in premining sediment (13 to 23 ppm) exposed in the stream bank (table 2, samples B1-B3). Sediment in the active channel of the drainage has the highest As concentration, more than 300 ppm, adjacent to the tailings piles (fig. 12, samples S2 and S3). The As concentration in sediment decreases downstream from the mine site and ranges from 40 to 65 ppm in the central part of Homewood Canyon (fig. 12, samples S8-12). In the lower part of Homewood Canyon, the As concentration decreases to background levels of 9 ppm (figs. 10 and 12, sample S15). The As concentration ranges

from 6 to 16 ppm in the drainages within the northern part of Searles Valley, and these values are similar to regional background levels (figs. 3 and 12, samples S16-22).

Sediment samples were collected from test pits dug within the active channel to assess the depth of contaminated sediment present. Test pits 1, 2, and 4 showed consistent, elevated As concentrations throughout the depth sampled, indicating that As-contaminated sediment is present to a minimum depth of 18 inches (table 2). In test pit 3, the As concentration decreased to background levels below a depth of 6 inches.

Samples of soils were taken along two parallel transects from the tailings piles to the BLM recreational picnic site located west of the mine (fig. 4). A surface sample and subsurface sample of soil was taken at each sample site to assess the level of contamination in surface soils from wind- and water-transported tailings. Both surface and subsurface soils have elevated As concentrations adjacent to the tailings piles (samples BK1, 2, and 3), indicating that tailings have contaminated the soils to a depth greater than 6 inches. Samples further from the tailings pile have background levels of As in the subsoil but are enriched in As in the surface soils, with enrichment ranging from 186 percent to 271 percent of As in the subsurface soil sample (table 4, fig. 11). Soil samples taken adjacent to dirt roads composed of tailings have high concentrations of As in both surface and subsurface samples (samples BK 5, 7, and 10; fig. 4). This indicates that tailings eroded from the roads in the picnic area have contaminated the soil to a depth greater than 6 inches.

The concentration of As in tailings, sediment, and soil samples is summarized by box plots in figure 15. The concentration of As is highest in mine tailings (14–2,570 ppm), and lowest in pre-mining sediment (<20 ppm). The As concentrations are higher in surface soils compared to subsurface soils, indicating wind and fluvial transport of particulate As has resulted in significant As enrichment in surface-soils and stream sediment in the active stream channel in Homewood Canyon (table 4, figs. 11 and 12).

Speciation of Arsenic in Tailings

Fits of the As EXAFS spectra collected from different size fractions (S5, S7, and S9, the last of which yielded sufficient quantities of material for EXAFS but not ICP-MS analysis) of the size-separated tailings sample are shown in figure 16, with quantitative fits provided in table 4. Linear fitting of the EXAFS data indicates that Ca- (and Fe-) bearing As phases dominate, specifically the related minerals arseniosiderite, $\text{Ca}_2\text{Fe}^{3+}_3\text{O}_2(\text{AsO}_4)_3 \cdot 3(\text{H}_2\text{O})$ and yukonite, $\text{Ca}_3\text{Fe}^{3+}(\text{AsO}_4)_2(\text{OH})_3 \cdot 5\text{H}_2\text{O}$ in addition to Ca-arsenate, $\text{Ca}_3(\text{AsO}_4)_2$. Arsenic sorbed to goethite also is present in two of the three samples. The presence of As sorbed to goethite in Ruth mine wastes previously was reported by Paktunc and others (2004). These findings are consistent with the relatively high levels of Ca (>3.84 percent) and Fe (>3.15 percent) in the selected size fractions as shown in table 3 (notably, both As, Ca, and Fe concentrations increase with decreasing particle size). Based on EXAFS analyses of other mine sites, sorption of As on Fe phases is common; however arseniosiderite has only recently been reported in tailings from Au-Ag ore deposits in the Mojave Desert. In the Randsburg district, arseniosiderite is present as a primary As phase in the Au-Ag ores, and as a secondary As phase in the tailings (Rytuba and others, 2007).

Micro X-ray fluorescence maps of As and Fe in particles of the S7 (75-125 μm) tailings-size fraction indicates that Fe is associated with only some of the As phases, but

most of the observed As-enriched particles are not associated with high concentrations of Fe (fig. 17a-b). This suggests that there are multiple As phases present that contain variable amounts of Fe (fig. 17). A correlation plot, which plots the relative As and Fe fluorescence of every pixel in the map, reveals roughly three populations of pixels, two of which feature relatively high but separate As:Fe ratios, and one with a very low As:Fe ratio (fig. 18). Based on the EXAFS linear combination fitting results, the former populations likely correspond to As mineral phases, such as arseniosiderite and yukonite, while the latter likely represents iron oxides with low concentrations of sorbed As. Correlation plots showing the relative As and Fe fluorescence in four grain-size fractions, S5 (250–500 μm), S6 (125–250 μm), S7 (75–125 μm) and S8 (45–75 μm) indicate that distribution of As phases is somewhat dependent on grain size (fig. 19). For example, in grain size fractions S5 and S6, the phase characterized by a high As:Fe ratio is absent. This indicates that As speciation varies with grain size and that the finer grain-size fractions have more As phases.

Conclusions

Mine tailings present in two piles at the Ruth Mine have very high concentrations of As, compared to EPA guidelines. The As concentration in tailings is a function of grain size and increases with decreasing grain size, reaching a maximum concentration in the smallest measurable size fraction representing particles between 45–75 μm in diameter. The tailings piles are on the banks of an unnamed drainage in Homewood Canyon and have been eroded and released into the drainage and migrated downstream. Arsenic-contaminated sediment is present in the active channel of the drainage from the mine site to the central part of the canyon. At the mouth of the Homewood Canyon and in Searles Valley, As concentration in sediment within the drainage channel decreases to background levels. Tailings with high As concentration are present in the abandoned road in Homewood Canyon, which was constructed from tailings and subsequently paved. The road is disintegrating and releasing As-enriched tailings into the drainage within Homewood Canyon.

Two transects of soil samples collected in the mine area indicate that tailings eroded from the tailings piles and dirt roads have contaminated the surface soils, with the surface soil containing as much as 280 percent more As, compared to the subsurface soil. Concentrations of As in the surface-soil range from 13 to 5,396 ppm. Where surface soils are highly contaminated with As near the tailings piles and dirt roads, As concentrations are elevated in both surface and subsurface soils. The enrichment factor of 2,100 percent (site BK5) is anomalous. Other soil samples indicate a local enrichment factor closer to 200 percent (fig. 11). A consistent enrichment of surface soils of more than 200 percent occurs in the soil-sample transect nearest the mine site (table 4).

Three discrete As phases have been identified using EXAFS spectroscopy in the tailings: arseniosiderite, yukonite, and Ca-arsenate; these phases are likely to have a high As:Fe ratio in corresponding micro-X-ray fluorescence correlation plots and appear to be more dominant in the smallest grain-size fractions (45–125 μm). Arsenic also exists as a surface-sorbed phase to goethite, but if present at expectedly low concentrations it should yield a low As:Fe ratio in the same correlation plots.

Arsenic concentrations detected in sediments and soils from this study suggest the tailings and other mine wastes have the potential to be a significant source of As

contamination to the immediate surroundings. Enrichment factors ranging from 1 to 21 times higher As concentrations in surface soils relative to subsurface soils indicate that wind and local fluvial transport of As-enriched tailings has occurred. The fine-grained tailings are more amenable to transport and have higher As concentrations because As increases with decreasing grain size of the tailings.

The observed elevated concentrations of As present in tailings and soils adjacent to the Ruth Mine site are similar to observations at other mined areas in the western Mojave Desert where As-enriched tailings and soils are present. Hydrothermal systems associated with emplacement of Miocene volcanic centers have mobilized As, and subsequently concentrated it, in and adjacent to Au-Ag deposits. Erosion of As-enriched, altered material has resulted in large areas with anomalously high As in sediment and soils (fig. 20). The As concentration map shown in figure 20 is constructed from samples that originally were collected during the National Uranium Resource Evaluation (NURE) Hydrogeochemical and Stream Sediment Reconnaissance program in the 1970s; the samples were subsequently reanalyzed by the USGS (Smith, 1999). At mines and mine site areas in the western Mojave Desert, such as those near the Ruth Mine, processing of Au-Ag ores has contributed to exceptionally high As concentrations in tailings, sediments, and soils that have migrated from the mine site by means of both wind and fluvial processes. This has resulted in contamination of sediments and surface soils with As at levels that are of potential environmental concern to both humans and biota.

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References Cited

- Bateman, G.E.W., 1907, The Mojave mining district of California: Transactions of the American Institute of Mining Engineers, v. 37, p. 160-177.
- Briggs, J., 2007, Gold, ghosts and glory holes: The historic Ruth mine: Road Trip America, last accessed Apr. 2011 at <http://www.roadtripamerica.com/GettingOutThere/Ruth-Mine.htm>.
- Clark, W.B., 1970, Gold Districts of California: California Division of Mines and Geology, Bulletin 193, p. 160-161.
- Crock, J.G., 1996, Mercury—Chapter 29 in Sparks, D.L., ed., Methods of soil analysis, part 3, chemical methods: Soil Science Society of America Book Series, Number 5, p. 769-791.
- Foster, A.L., Brown, G.E., Jr., Tingle, T., and Parks, G.A., 1998, Quantitative arsenic speciation in mine tailings using X-ray absorption spectroscopy: American Mineralogist, v. 83, no. 5-6, p. 553-568.
- Gardner, D.L., 1954, Gold and silver mining districts in the Mojave Desert region of southern California: California Division of Mines Bulletin 118, p. 549-550.

- Julihn, C.E., and Horton, F.W., 1937, Mineral industries survey of the United States—California, Kern County, Mojave District—The Golden Queen and other mines of the Mojave district, California: U.S. Bureau of Mines Information Circular 6931, 42 p.
- Kim, C.S., Brown, G.E., Jr., and Rytuba, J.J., 2000, Characterization and speciation of mercury-bearing mine wastes using x-ray absorption spectroscopy (XAS): *Science of the Total Environment*, v. 261, no. 1-3, p. 157-168.
- O'Leary, R.M., Hageman, P.L., and Crock, J.G., 1996, Determination of mercury in water, geologic, and plant materials by continuous flow-cold vapor-atomic absorption spectrophotometry, *in* Arbogast, B.F., ed., *Quality assurance manual for the branch of geochemistry*: U.S. Geological Survey Open-File Report 96-525, p. 42-55.
- Paktunc, D., Foster, A., Heald, S., and Laflamme, G., 2004, Speciation and characterization of arsenic in gold ores and cyanidation tailings using x-ray absorption spectroscopy: *Geochimica et Cosmochimica Acta*, v. 68, no. 5, p. 969-983.
- Rytuba, J.J., 1996, Cenozoic metallogeny of California, *in* Coyner, A.R., and Fahey, P.L., eds., *Geology and ore deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings*, Reno/Sparks, Nevada, p. 803-822.
- Rytuba, J.J., Andrea Foster, A., Kim, C.S., Aaron Slowey, A., Forester, R., and David Lawler, D., 2007, Arsenic contamination from the Kelly silver and Yellow Aster gold mine tailings, north-central Mojave Desert, California: *Geological Society of America Abstracts with Programs*, v. 39, no. 6, p. 31, last accessed Feb. 2011 at http://gsa.confex.com/gsa/2007AM/finalprogram/abstract_132396.htm.
- Smith, S.M., 1999, National Geochemical Database: U.S. Geological Survey Open-File Report 97-492.
- Stoffer, Philip, 2004, Desert landforms and surface processes in the Mojave National Preserve and vicinity: U.S. Geological Survey Open-File Report 2004-1007, last accessed Feb. 2011 at <http://pubs.usgs.gov/of/2004/1007/>.
- Troxel, B.W., and Morton, P.K., 1962, Mines and mineral resources of Kern County, California: California Division of Mines and Geology, County Report 1, p. 120-124.
- Tucker, W.B., 1923, Kern County, Mojave mining district: California Division of Mines and Geology. County Report 1, p. 43-45.
- Tucker, W.B., and Sampson, R.J., 1933, Kern County, Mojave mining district: California Division of Mines and Geology. County Report 31, p. 465-485.
- U.S. Bureau of Land Management, 2008. Draft Removal Site Inspection—Ruth Mine: Denver, Colo., National Operations Center.
- Wang, S.L.; Mulligan, C.N., 2008, Speciation and surface structure of inorganic arsenic in solid phases—A review: *Environment International*, v. 34, no. 6, p. 867-87.
- Webb, S.M., 2005, SIXpack—a graphical user interface for XAS analysis using IFEFFIT. *Physica Scripta*, T115, p. 1011-1014.

Table 1. Sample locations and notes from Ruth Mine, Inyo County, California.

Field number	Latitude	Longitude	Sampling date	Notes
Background				
09RU-BK1-0	35.89071	117.40958		This background sampling is closest to the tailings
09RU-BK1-1	35.89071	117.40958		Mostly tailings, still very reddish in color
09-RU-BK2-0	35.89056	117.40946		
09-RU-BK2-1	35.89056	117.40946		
09RU-BK3-0	35.89071	117.40958		Soil not as red
09RU-BK3-1	35.89071	117.40958		
09-RU-BK4-0	35.89044	117.40993		
09-RU-BK4-1	35.89044	117.40993		
09RU-BK5-0	35.8905	117.41062		Sample taken near the parking lot
09RU-BK5-1	35.8905	117.41062		
09-RU-BK6-0	35.89023	117.41035		
09-RU-BK6-1	35.89023	117.41035		
09RU-BK7-0	35.89024	117.41108		Near road - Very red & rocky
09RU-BK7-1	35.89024	117.41108		
09-RU-BK8-0	35.89009	117.41077		Located about 10 ft from clear tailing contaminated soil
09-RU-BK8-1	35.89009	117.41077		Run-off from the road. About 20 ft from campsite
09RU-BK9-0	35.89	117.41152		Between road and campground
09RU-BK9-1	35.89	117.41152		
09-RU-BK10-0	35.89001	117.4122		At foot of hiking trail
09-RU-BK10-1	35.89001	117.4122		
Sediment				
09RUS1	35.89105	117.41061		
09RU-S2	35.8913	117.40928		Taken from right under the main tailings pile
09RUS3	35.89205	117.41061		
09RU-S4	35.89309	117.40726		Downstream from tailings
09RUS5	35.89426	117.407		
09RU-S6	35.89548	117.40619		Downstream from tailings
09RUS7	35.89635	117.40514		
09RU-S8	35.89934	117.38968		
09RU-S9	35.90007	117.39098		
09RUS10	35.89984	117.39238		

Table 1. Sample locations and notes from Ruth Mine, Inyo County, California—Continued.

Field Number	Latitude	Longitude	Sampling Date	Notes
09RUS11	35.89886	117.39309		
09RUS12	35.89837	117.39427		
09RUS15	35.89333	117.35651		
09RUS16	35.90593	117.33018		
09RUS17	35.87787	117.31702		
09RUS18	35.88579	117.34871		
09RUS19	35.87909	117.34594		
09RUS20	35.8711	117.33955		
09RUS21	35.85772	117.32724		
09RUS22	35.828	117.31705		
Sediment Depth Profile				
09RU-TP1-0	35.90012	117.39125		Very rocky consistency - looked slightly damp as we got deeper
09RU-TP1-6	35.90012	117.39125		Large rocks kept us from going any farther. (Light breeze)
09RU-TP1-12	35.90012	117.39125		
09RU-TP2-00	35.89963	117.3904		
09RU-TP2-06	35.89963	117.3904		Mixed sediment. Could only dig to about 14 inches
09RU-TP2-12	35.89963	117.3904		
09RU-TP3-0	35.90031	117.39174		
09RU-TP3-6	35.90031	117.39174		
09RU-TP3-12	35.90031	117.39174		Samples were taken from an embankment on an incline
09RU-TP3-18	35.90031	117.39174		
09RU-TP4-00	35.8931	117.40721		
09RU-TP4-06	35.8931	117.40721		
09RU-TP4-12	35.8931	117.40721		
Tailings				
09-RU-T1	35.89006	117.41087		Tailings used for road material. Adjacent to table. Sloping downward
09-RU-T2	35.89027	117.41104		Base of side road that leads to picnic area. Intersection with main road
09RU-T3	35.90042	117.39143		Base of bank at where erosion is bringing road metal/tailings into wash
09RU-T4	35.90051	117.39156		Top of bank cut near side road, below boulder. Largely tailings
09RU-T5	35.90055	117.39155		On side road where erosion is exposing tailings used for base of trail
09RU-T6	35.8997	117.3933		Samples collected near old road
09RU-T7	35.89932	117.39389		Had to break up some of the asphalt to get to the samples

Table 1. Sample locations and notes from Ruth Mine, Inyo County, California—Continued.

Field Number	Latitude	Longitude	Sampling Date	Notes
09RU-T8	35.89909	117.39469		
09RU-T9	35.9002	117.39257		
09RUT10	35.89415	117.37652		
09RUT11	35.8936	117.37616		
09RUT12	35.89431	117.37773		
09RUT13	35.89443	117.37848		
09RUB3	35.89296	117.40733		

Table 2. CHEMEX data for background soils, tailings, and sediment from the Ruth Mine site.

[ppm: parts per million; %: percent]

Sample	Ag ppm	Al %	As ppm	Ba ppm	Ca %	Co ppm	Cr ppm	Cu ppm	Fe %	K %	Mg %	Mn ppm	Na %
Background													
09RU-BK1-0	0.3	0.69	1,230	230	2.17	9	23	31	2.51	0.29	0.38	578	0.03
09RU-BK1-1	0.2	1.11	1,140	260	1.81	11	12	36	3.01	0.42	0.58	652	0.04
09RU-BK2-0	0.3	0.68	1,325	290	2.95	11	10	27	2.82	0.3	0.38	675	0.03
09RU-BK2-1	0.3	1.1	507	230	1.58	10	27	32	2.76	0.3	0.66	514	0.06
09RU-BK3-0	0.2	1.39	289	230	1.25	10	13	31	2.81	0.4	0.73	526	0.07
09RU-BK3-1	0.2	1.49	197	220	1.03	11	13	35	2.9	0.4	0.8	524	0.07
09RU-BK4-0	0.2	1.41	18	190	1.13	10	19	36	3.51	0.3	0.73	439	0.08
09RU-BK4-1	0.2	1.55	9	220	1.32	11	15	38	3.76	0.25	0.8	478	0.09
09RU-BK5-0	0.2	1.17	536	210	1.32	11	19	31	2.84	0.28	0.68	553	0.05
09RU-BK5-1	0.2	1.44	246	170	1.04	11	26	33	2.88	0.31	0.86	571	0.05
09RU-BK6-0	0.2	1.95	25	200	0.94	13	29	47	3.32	0.46	1.17	600	0.08
09RU-BK6-1	0.2	1.88	11	210	1.09	12	20	43	3.22	0.48	1.11	597	0.07
09RU-BK7-0	0.2	0.72	2,160	270	2.2	11	17	31	2.77	0.32	0.28	732	0.02
09RU-BK7-1	0.4	0.59	2,900	300	2.69	12	11	33	2.97	0.31	0.21	879	0.02
09RU-BK8-0	0.2	1.83	76	170	1.15	13	22	40	3.09	0.39	1.11	651	0.04
09RU-BK8-1	0.2	1.9	28	170	1.13	12	25	39	3.08	0.39	1.09	640	0.05
09RU-BK9-0	0.2	1.44	13	140	0.52	9	18	21	2.04	0.4	0.65	577	0.05
09RU-BK9-1	0.2	1.5	7	140	0.53	9	18	22	2.07	0.4	0.68	571	0.05
09RU-BK10-0	0.4	0.62	1,485	330	2.82	11	19	61	2.37	0.29	0.28	678	0.02
09RU-BK10-1	0.2	1.14	683	220	1.52	10	13	38	2.23	0.35	0.5	606	0.04
Tailings													
09RU-T1	0.4	0.47	2,570	430	2.96	14	5	50	2.89	0.31	0.18	885	0.01
09RU-T2	0.3	0.6	2,570	320	2.85	13	12	31	2.93	0.32	0.22	913	0.02
09RU- T3	0.2	0.65	1,990	360	3.3	12	10	38	2.78	0.33	0.3	813	0.03
09RU- T4	0.2	0.63	2,170	340	3.61	12	13	30	2.71	0.35	0.21	851	0.03
09RU- T5	0.2	0.66	1,500	290	2.49	9	10	18	2.36	0.3	0.22	712	0.03
09RU- T6	0.2	1.43	109	200	1.09	8	12	24	2.55	0.38	0.65	486	0.06
09RU- T7	0.2	1.07	372	170	1.02	7	11	17	2.5	0.35	0.43	472	0.05
09RU- T8	0.2	1.23	577	250	1.23	10	13	23	3.45	0.4	0.55	588	0.05
09RU- T9	0.2	0.86	683	250	1.97	8	10	17	2.34	0.31	0.35	573	0.03
09RU- T10	0.2	0.92	1,490	260	2.39	12	7	36	3.37	0.39	0.34	681	0.05
09RU- T11	0.2	1.15	14	130	0.5	6	12	16	2.37	0.21	0.38	313	0.05
09RU- T12	0.2	1.12	939	300	2.13	10	11	26	2.7	0.45	0.54	678	0.05
09RU- T13	0.2	0.72	1,760	320	2.63	10	11	33	2.67	0.34	0.28	715	0.03
09RU-B1	0.2	1.84	16	280	1.17	9	20	25	2.36	0.73	0.89	784	0.08
09RU-B2	0.2	1.24	13	210	0.87	6	15	14	1.85	0.4	0.51	520	0.05
09RU-B3	0.2	0.7	23	130	0.55	5	11	16	2.17	0.18	0.33	411	0.04

Not detected (detection limit): B (10 ppm), Be (0.5 ppm) , Bi (2 ppm), Cd (0.5 ppm), Ga (10 ppm), Hg (1 ppm), La (20 ppm), Mo (1 ppm), Th (20 ppm), Tl (10 ppm), U (10 ppm), W (10 ppm)

Table 2. CHEMEX data for background soils, tailings, and sediment from the Ruth Mine site—Continued.

Sample	Ni ppm	P ppm	Pb ppm	S %	Sb ppm	Sc ppm	Sr ppm	Ti %	V ppm	Zn ppm
Background										
09RU-BK1-0	7	1,410	57	0.03	14	4	89	0.03	42	316
09RU-BK1-1	8	1,150	8	0.01	12	5	76	0.07	63	142
09RU-BK2-0	8	1,050	32	0.03	11	4	69	0.03	43	126
09RU-BK2-1	9	1,120	29	0.02	5	4	62	0.08	62	110
09RU-BK3-0	8	1,080	12	0.01	4	4	56	0.11	68	74
09RU-BK3-1	8	1,190	22	0.01	2	4	56	0.13	77	72
09RU-BK4-0	6	1,110	2	0.01	2	4	60	0.13	100	48
09RU-BK4-1	7	1,060	3	0.01	2	4	73	0.13	108	47
09RU-BK5-0	10	1,100	12	0.01	8	4	53	0.07	63	73
09RU-BK5-1	11	1,200	8	0.01	3	4	52	0.1	68	64
09RU-BK6-0	14	1,270	10	0.01	2	6	62	0.17	93	69
09RU-BK6-1	11	1,250	5	0.01	2	5	59	0.16	89	59
09RU-BK7-0	7	870	17	0.01	21	5	53	0.02	34	131
09RU-BK7-1	7	820	11	0.01	25	5	61	0.01	32	121
09RU-BK8-0	14	1,210	11	0.01	2	5	52	0.14	78	82
09RU-BK8-1	12	1,160	4	0.01	2	5	50	0.13	77	61
09RU-BK9-0	11	780	6	0.01	2	3	43	0.12	42	48
09RU-BK9-1	11	780	6	0.01	2	3	46	0.13	43	48
09RU-BK10-0	9	580	20	0.01	31	4	57	0.01	36	151
09RU-BK10-1	10	660	10	0.01	15	4	51	0.06	39	97
Tailings										
09RU-T1	7	730	11	0.02	37	5	69	0.01	31	101
09RU-T2	8	820	13	0.01	24	5	59	0.01	32	103
09RU- T3	12	780	11	0.03	27	5	70	0.01	38	200
09RU- T4	14	680	12	0.03	27	5	66	0.01	41	258
09RU- T5	11	650	10	0.02	17	4	52	0.01	32	217
09RU- T6	7	930	5	0.01	2	4	51	0.1	58	47
09RU- T7	7	770	9	0.01	5	3	48	0.07	52	56
09RU- T8	9	970	11	0.02	7	4	51	0.08	78	95
09RU- T9	8	660	51	0.01	9	3	52	0.04	39	77
09RU- T10	7	880	9	0.02	19	5	63	0.04	63	127
09RU- T11	5	520	4	0.01	2	3	39	0.07	59	28
09RU- T12	10	940	7	0.02	11	4	58	0.07	54	156
09RU- T13	11	760	10	0.03	24	4	55	0.01	40	202
09RU-B1	15	810	9	0.01	2	4	56	0.1	40	62
09RU-B2	10	550	6	0.01	2	2	39	0.07	30	38
09RU-B3	3	480	3	0.01	2	2	32	0.07	51	27

Table 2. CHEMEX data for background soils, tailings, and sediment from the Ruth Mine site—Continued.

	Ag ppm	Al %	As ppm	Ba ppm	Ca %	Co ppm	Cr ppm	Cu ppm	Fe %	K %	Mg %	Mn ppm	Na %
Sediment													
09RU-S1	0.2	0.55	10	90	0.26	4	9	8	3.09	0.19	0.16	481	0.07
09RU-S2	0.2	0.54	310	120	0.82	6	8	12	1.8	0.19	0.2	328	0.04
09RU-S3	0.2	0.92	333	210	1.45	10	16	21	4.12	0.3	0.44	565	0.05
09RU-S4	0.2	1.09	12	140	0.62	6	9	14	1.98	0.35	0.44	376	0.1
09RU-S5	0.2	0.69	284	170	1.19	7	6	14	1.7	0.25	0.31	461	0.04
09RU-S6	0.2	1.06	19	140	0.7	8	11	17	2.54	0.32	0.51	429	0.06
09RU-S7	0.2	0.88	200	170	1.04	6	7	14	1.7	0.31	0.35	437	0.06
09RU-S8	0.2	0.52	40	80	0.43	4	7	8	1.24	0.15	0.2	194	0.05
09RU-S9	0.2	0.84	52	150	0.66	10	22	18	5.17	0.26	0.41	406	0.05
09RU-S10	0.2	0.77	41	100	0.59	7	18	15	4.16	0.18	0.26	262	0.08
09RU-S11	0.2	0.54	39	90	0.45	4	5	9	1.42	0.17	0.23	225	0.04
09RU-S12	0.2	1.01	66	150	0.75	8	10	17	2.38	0.31	0.47	431	0.06
09RU-S15	0.2	0.57	9	80	0.37	3	6	9	1.27	0.17	0.17	195	0.05
09RU-S16	0.2	0.73	13	110	0.5	5	9	13	1.93	0.22	0.35	297	0.05
09RU-S17	0.2	0.62	9	100	0.6	5	7	11	1.6	0.19	0.32	280	0.04
09RU-S18	0.2	0.84	6	110	0.44	6	11	15	2.45	0.23	0.36	313	0.07
09RU-S19	0.2	0.63	10	90	0.41	6	13	13	2.62	0.16	0.32	274	0.04
09RU-S20	0.2	0.69	7	100	0.42	4	6	12	1.34	0.2	0.31	236	0.06
09RU-S21	0.2	1.03	11	110	0.91	5	10	16	1.94	0.26	0.53	376	0.06
09RU-S22	0.2	0.72	16	100	0.85	4	9	12	1.65	0.2	0.41	280	0.05

Sample	Ni ppm	P ppm	Pb ppm	S %	Sb ppm	Sc ppm	Sr ppm	Ti %	V ppm	Zn ppm
09RU-S1	3	310	5	0.01	2	1	25	0.07	65	18
09RU-S2	4	370	5	0.01	4	2	31	0.04	36	35
09RU-S3	8	800	7	0.01	3	3	46	0.10	102	60
09RU-S4	6	520	5	0.01	2	3	45	0.11	41	35
09RU-S5	5	460	5	0.01	4	2	36	0.06	30	46
09RU-S6	7	620	6	0.01	2	3	42	0.12	59	39
09RU-S7	5	460	5	0.01	3	3	42	0.07	31	44
09RU-S8	2	370	3	0.01	2	1	27	0.04	26	17
09RU-S9	8	630	5	0.01	2	3	37	0.11	153	36
09RU-S10	6	460	7	0.01	2	2	46	0.09	137	20
09RU-S11	3	350	3	0.01	2	1	26	0.05	30	20
09RU-S12	7	590	6	0.01	2	3	43	0.11	54	41
09RU-S15	3	320	7	0.01	2	1	30	0.04	24	17
09RU-S16	5	530	4	0.01	2	2	31	0.07	43	29
09RU-S17	4	490	3	0.01	2	2	40	0.07	36	24
09RU-S18	5	550	9	0.01	2	2	37	0.08	60	27
09RU-S19	5	530	2	0.01	2	2	29	0.07	71	21
09RU-S20	3	460	3	0.01	2	2	35	0.06	29	20
09RU-S21	5	480	5	0.01	2	2	66	0.08	41	31
09RU-S22	4	600	5	0.01	2	2	76	0.07	38	27

Table 3. Concentration of elements in sieved size fractions of tailings sample from Ruth Mine.

[ppm: parts per million; %: percent]

Sample	Size	Hg ppm	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %
Sample RMS03C																
RMS03C-S1	> 2,830 µm	0.56	0.23	5.55	2,280	500	0.84	0.06	2.35	0.12	35.7	9.4	26	2.64	16.5	2.66
RMS03C-S2	2,830 µm -1,700 µm	0.65	0.24	5.42	2,200	520	0.94	0.1	2.42	0.13	33.9	9.8	23	2.98	16.4	2.75
RMS03C-S3	1,700 µm -1,000 µm	0.69	0.24	5.71	2,340	460	0.84	0.05	2.51	0.15	35.4	10.1	22	3.01	19.2	2.77
RMS03C-S4	1,000 µm -500 µm	0.03	0.23	5.77	2,290	550	0.95	0.07	2.79	0.16	31.9	11	22	3.3	17.1	2.84
RMS03C-S5	500 µm -250 µm	0.9	0.22	6.73	2,720	680	1.01	0.06	3.84	0.19	35.6	14.5	22	4.2	20.8	3.15
RMS03C-S6	250 µm - 125 µm	1.29	0.23	6.7	2,860	810	1.15	0.08	4.38	0.22	36.8	16.9	23	4.48	24.9	3.24
RMS03C-S7	125 µm - 75 µm	1.08	0.22	6.82	3,050	890	1.15	0.08	4.91	0.23	43.7	18.9	26	4.91	29.3	3.62
RMS03C-S8	75 µm -45 µm	1.25	0.22	6.64	3,270	910	1.15	0.1	5.2	0.26	44.6	19.5	28	5.11	32.4	3.73
RMS03C-Bulk		0.79	0.24	6.09	2,230	530	0.99	0.07	3.17	0.18	36.8	12.7	25	3.51	17.1	2.74
Sample	Size	Ga ppm	Ge ppm	Hf ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm
Sample RMS03C																
RMS03C-S1	> 2,830 µm	12.15	0.1	0.6	0.036	2.45	18.8	16.1	0.33	492	4.08	0.06	4.9	12.5	510	8.8
RMS03C-S2	2,830 µm -1,700 µm	13	0.08	0.7	0.038	2.49	16.8	15	0.27	495	2.04	0.05	5.4	11.5	470	8.8
RMS03C-S3	1,700 µm -1,000 µm	13	0.08	0.6	0.039	2.59	18.3	13.8	0.28	527	1.86	0.05	5.9	11.1	490	9.1
RMS03C-S4	1,000 µm -500 µm	13.7	0.09	0.6	0.039	2.74	15.8	13	0.28	605	2.01	0.06	6	10.9	440	9.2
RMS03C-S5	500 µm -250 µm	15.95	0.09	0.7	0.046	3.25	18.1	13.2	0.31	841	2.23	0.07	6.8	13.1	480	11
RMS03C-S6	250 µm - 125 µm	16.55	0.09	0.7	0.043	3.32	18.1	12.7	0.31	985	2.53	0.07	7	14.1	510	12.5
RMS03C-S7	125 µm - 75 µm	17	0.11	0.7	0.046	3.29	22.1	13.1	0.32	1130	2.9	0.07	7.4	16.6	590	14.3
RMS03C-S8	75 µm -45 µm	16.6	0.11	0.7	0.049	3.2	22.7	12.6	0.32	1170	3.18	0.07	7.3	17.4	630	15.5
RMS03C-Bulk		14.15	0.08	0.6	0.037	2.76	19.3	14.5	0.3	630	2.05	0.06	5.8	12.6	500	10.2
Sample	Size	Rb ppm	S %	Sb ppm	Sc ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm
Sample RMS03C																
RMS03C-S1	> 2,830 µm	84.7	0.07	48.2	8.3	2	0.7	88.9	0.28	0.08	2.9	0.205	0.4	6.4	88	3.5
RMS03C-S2	2,830 µm -1,700 µm	84.3	0.03	44.6	8.2	1	0.9	80.2	0.31	0.09	3.3	0.198	0.44	5	85	3.6
RMS03C-S3	1,700 µm -1,000 µm	85.9	0.03	47.2	8.2	1	0.8	82.8	0.33	0.1	3.2	0.217	0.42	5	86	3.9
RMS03C-S4	1,000 µm -500 µm	82.6	0.03	44.6	7.6	2	0.9	83.7	0.37	0.1	3	0.209	0.44	4.9	87	4.1
RMS03C-S5	500 µm -250 µm	96.2	0.03	47.6	8.7	2	0.9	101.5	0.4	0.09	3.4	0.233	0.54	5.9	101	4.5
RMS03C-S6	250 µm - 125 µm	94.8	0.04	48.9	9	2	1	113.5	0.41	0.11	3.5	0.23	0.53	6.3	104	4.7
RMS03C-S7	125 µm - 75 µm	100.5	0.04	50.4	9.6	2	1.2	119.5	0.41	0.11	4.1	0.237	0.55	7	106	4.9
RMS03C-S8	75 µm -45 µm	98	0.03	51.4	9.9	2	1.2	135.5	0.4	0.13	4.3	0.24	0.57	7.7	106	5.4
RMS03C-Bulk		93	0.04	45.5	8.6	2	0.9	92.5	0.32	0.1	3.3	0.207	0.47	5.5	89	3.9

Table 3. Concentration of elements in sieved size fractions of tailings sample from Ruth Mine—Continued.

Sample	Size	Y ppm	Zn ppm	Zr ppm
Sample RMS03C				
RMS03C-S1	> 2,830 µm	6.1	127	17.4
RMS03C-S2	2,830 µm -1,700 µm	6.2	142	16.9
RMS03C-S3	1,700 µm -1,000 µm	6.1	154	15.9
RMS03C-S4	1,000 µm -500 µm	5.6	176	16
RMS03C-S5	500 µm -250 µm	6.3	251	16.2
RMS03C-S6	250 µm - 125 µm	6.7	290	16.3
RMS03C-S7	125 µm - 75 µm	7.7	326	19.1
RMS03C-S8	75 µm -45 µm	8.4	365	19.4
RMS03C-Bulk		6.1	179	15.8

Table 4. Enrichment of As and Zn in surface-soil samples compared to subsurface concentrations at Ruth Mine, Inyo County, California.

Field Number	As ppm Surface Soil 0-2 inches	As ppm Subsurface Soil 2-4 inches	Percent As in surface soil compared to subsurface soil	Zn ppm Surface Soil 0-2 inches	Zn ppm Subsurface Soil 2-4 inches	Percent Zn in surface soil compared to subsurface soil
09RU-BK1	1,230	1,140	108	316	142	223
09RU-BK2	1,325	507	261	126	110	115
09RU-BK3	289	197	147	74	72	103
09RU-BK4	18	9	200	48	47	102
09RU-BK5	5396	246	2193	73	64	114
09RU-BK6	25	11	227	69	59	117
09RU-BK7	2,160	2,190	99	131	121	108
09RU-BK8	76	28	271	82	61	134
09RU-BK9	13	7	186	48	48	100
09RU-BK10	1,485	683	217	151	97	156

Table 5. Arsenic speciation determined by EXAFS spectroscopy for selected grain size fractions of Ruth Mine tailings.

Sample name	Size Range	[As] (ppm)	As Speciation				Red. χ^2
			Arseniosiderite	Yukonite	As(V)-goethite	Ca-arsenate	
RMS03C_S5	250-500 μm	2,720	65 %		53 %		1.092
RMS03C_S7	75-125 μm	3,050	39 %	46 %		39 %	0.888
RMS03C_S9	32-45 μm	N/A		56 %	55 %		0.943

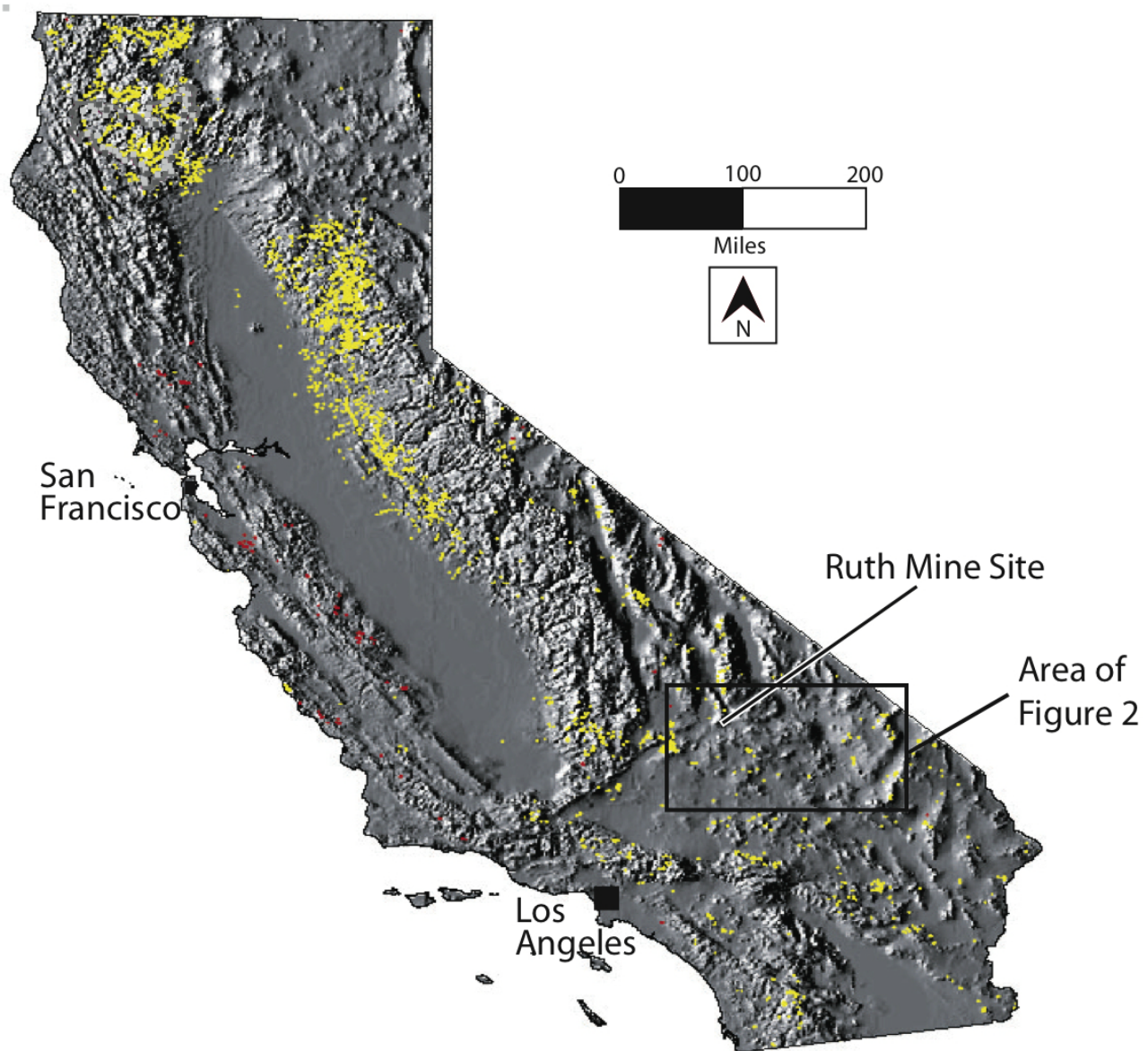


Figure 1. Location map of the Ruth gold mine in the western Mojave Desert. Gold mines are shown by yellow squares and mercury (Hg) mines are shown by red squares.

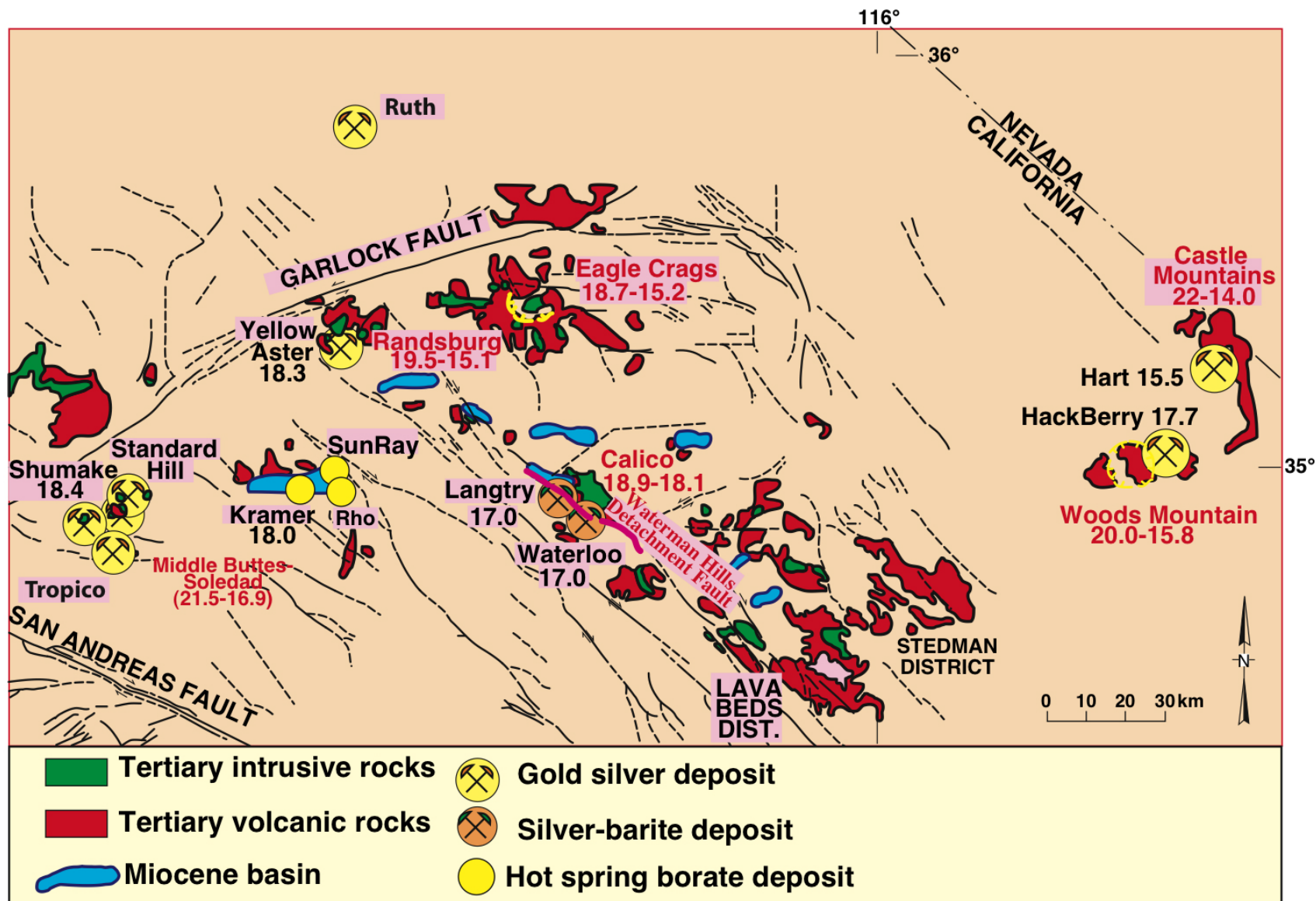


Figure 2. Generalized geologic map showing location of volcanic fields and associated Au-Ag deposits, including the Ruth Mine Au deposit in the western part of the Mojave desert, Inyo County, California.

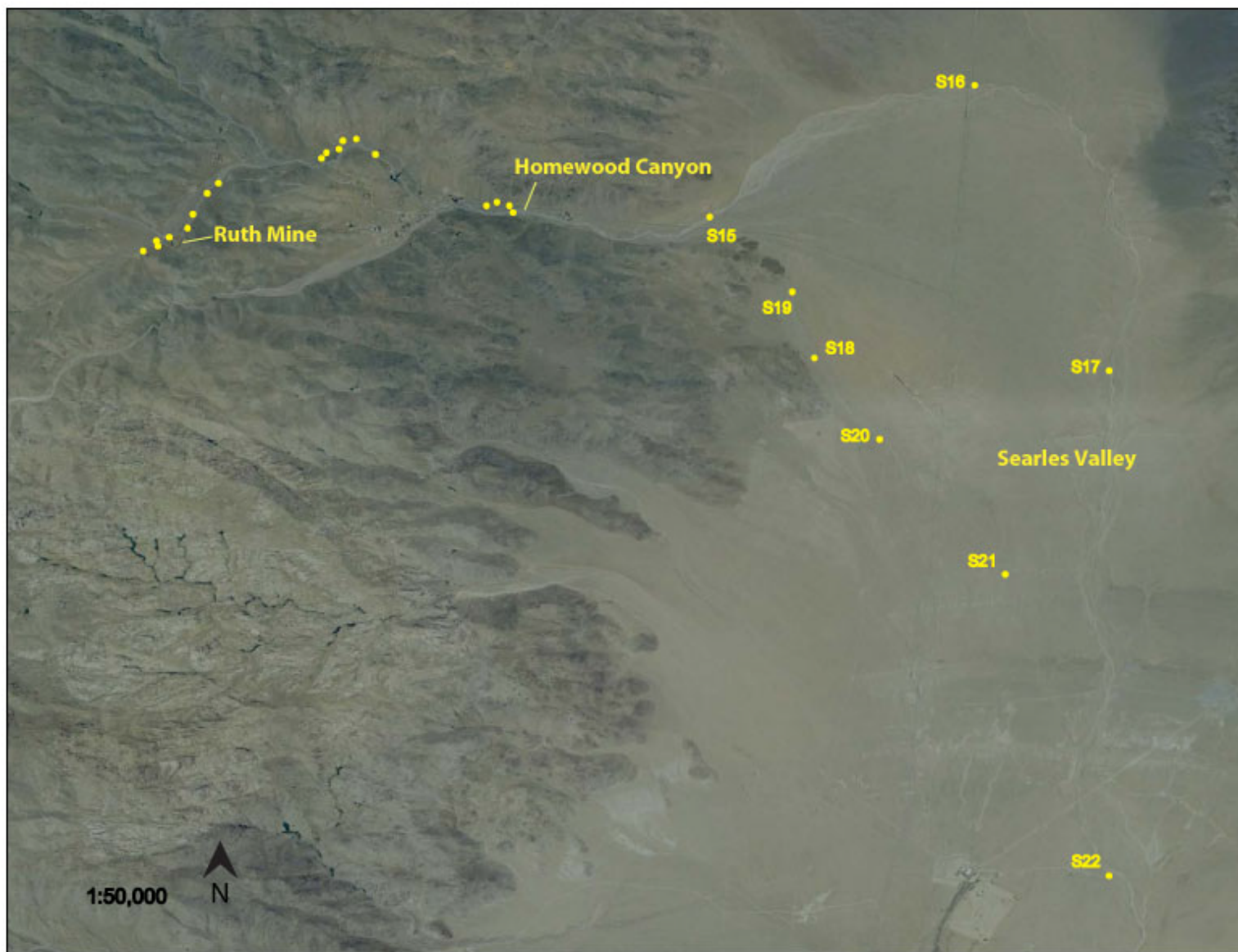


Figure 3. Overview of the Ruth Gold Mine and mill site, Inyo County, California. Sediment samples were taken at sites (yellow dots) in the dry wash in Homewood Canyon and the northern part Searles Valley to assess the migration of tailings downstream from the mine site. Sample IDs for the sample locations on the left-hand side of the image are provided in figures 4 and 5.

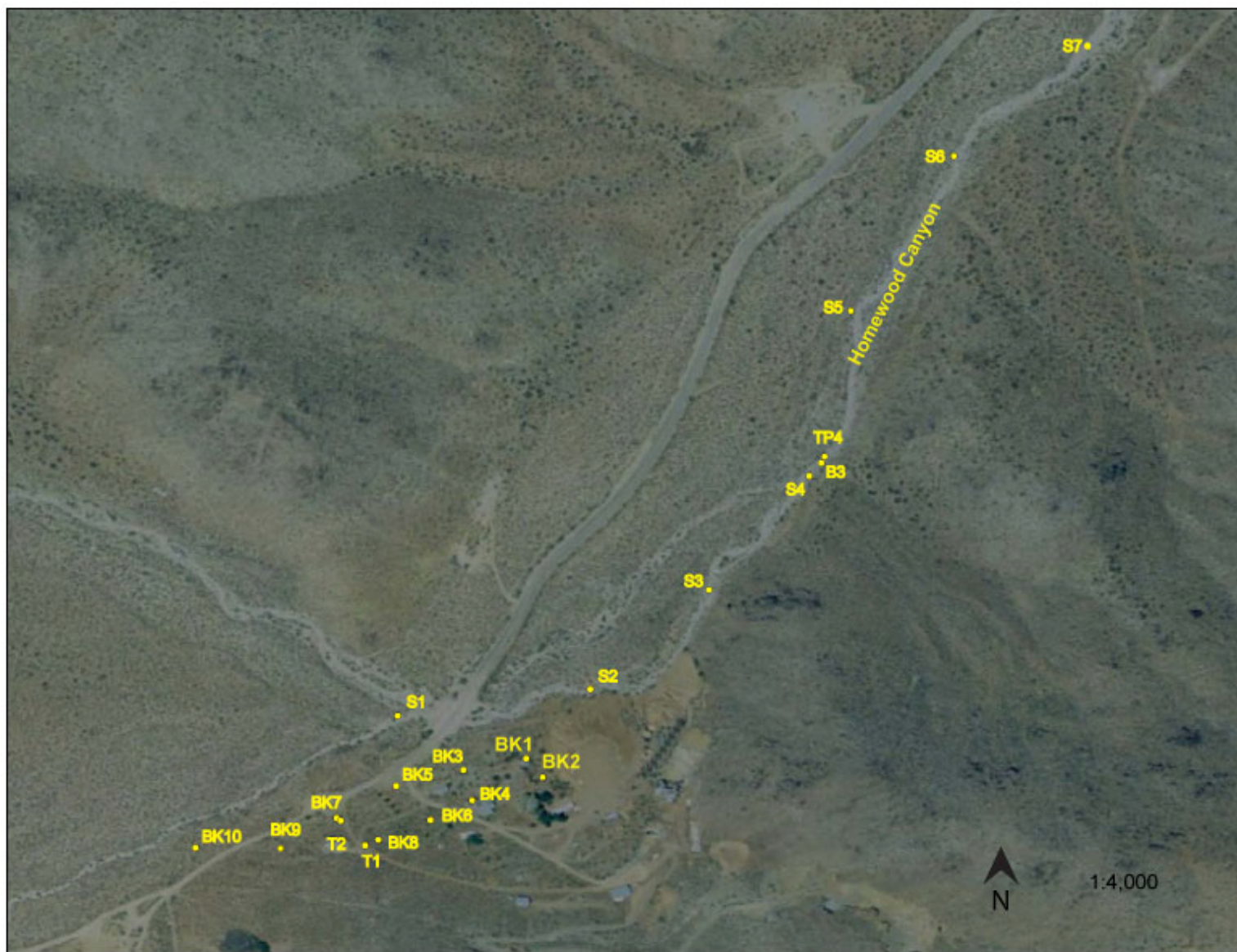


Figure 4. Soil sample sites noted by a BK prefix were collected adjacent to the Ruth Mine to assess contamination of soils by the Ruth tailings. Tailings were used for road constructions and samples noted by a T prefix are of tailings present in the roads. Samples of stream sediment, noted by an S prefix, were collected to assess migration of tailings downstream from the mine site.

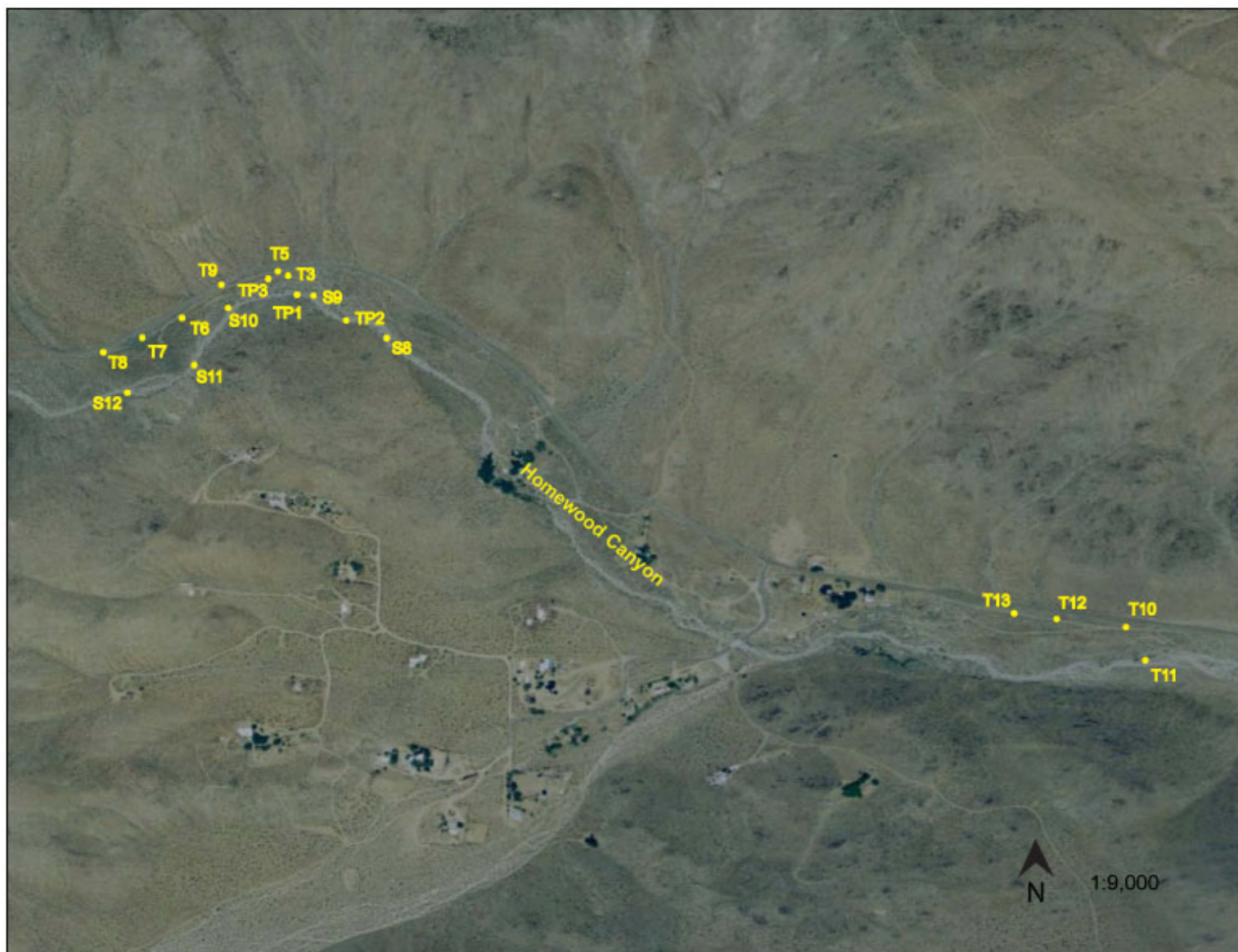


Figure 5. Central part of Homewood Canyon downstream from the Ruth Mine. Sediment sample sites in the dry wash have a prefix S and test pit samples within the wash to assess the depth of contaminated sediment have a TP prefix. Tailings used in the construction of the old Homewood Canyon road were sampled where they are being eroded from the road at sites noted with a T prefix.



Figure 6. Mine and mill workings at the Ruth Mine and tailings piles that are being eroded into the unnamed wash in Homewood Canyon.



Figure 7. Mine building maintained and used by visitors to the Ruth Mine and recreation area with picnic tables (area to right of buildings).



Figure 8. Central part of dry wash in Homewood Canyon with tailings exposed in bank eroded from old road and deposited on the north (left) side of the wash (brown sediment).



Figure 9. Tailings used in construction of the old road in the central part of Homewood Canyon. Sample sites T5 –T9 shown in figure 5.



Figure 10. Tailings in bank deposits in the wash located in the lower part of Homewood Canyon, sample site T11 shown in figure 3.

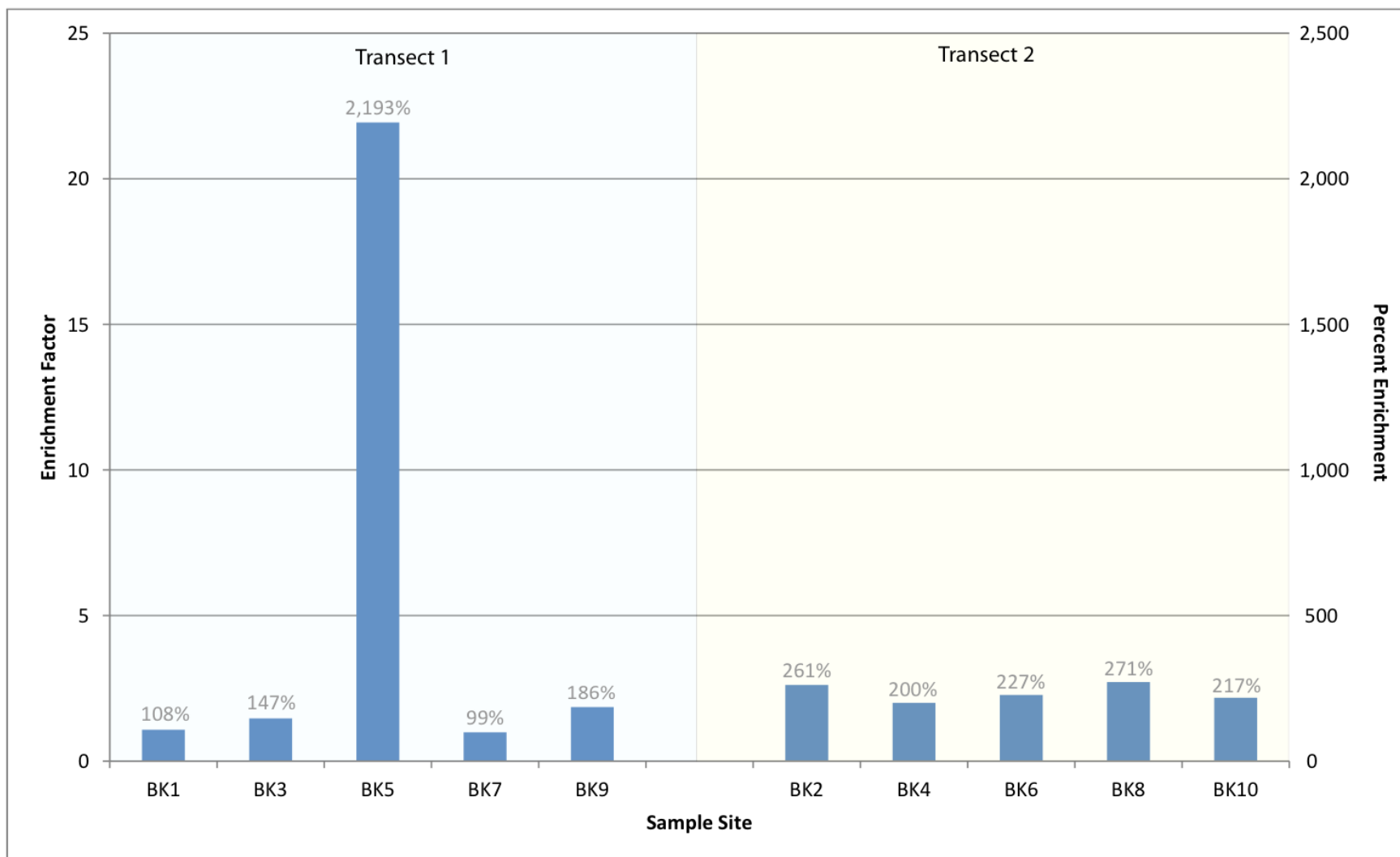


Figure 11. Enrichment of As in surface background soil sample as compared to subsurface soil at the same sample sites in the Ruth mine area.

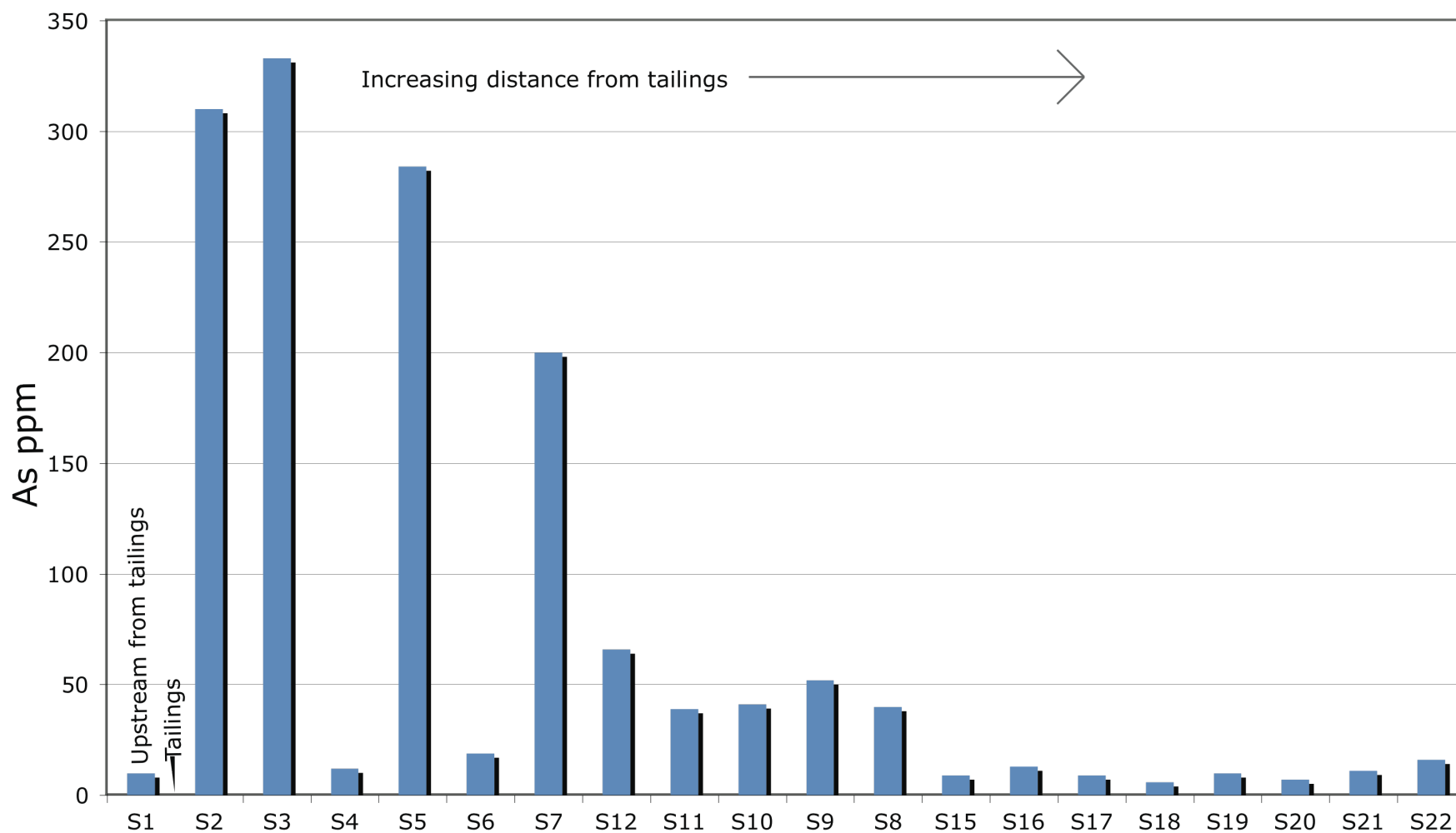


Figure 12. Arsenic concentrations from stream sediment collected in the center of the active channel of the dry wash passing through Homewood Canyon in the Ruth Mine area. See figures 3-5 for sample locations. Sample are arranged in order of increasing distance from the tailings pile, but the distance between sample locations is not to scale.

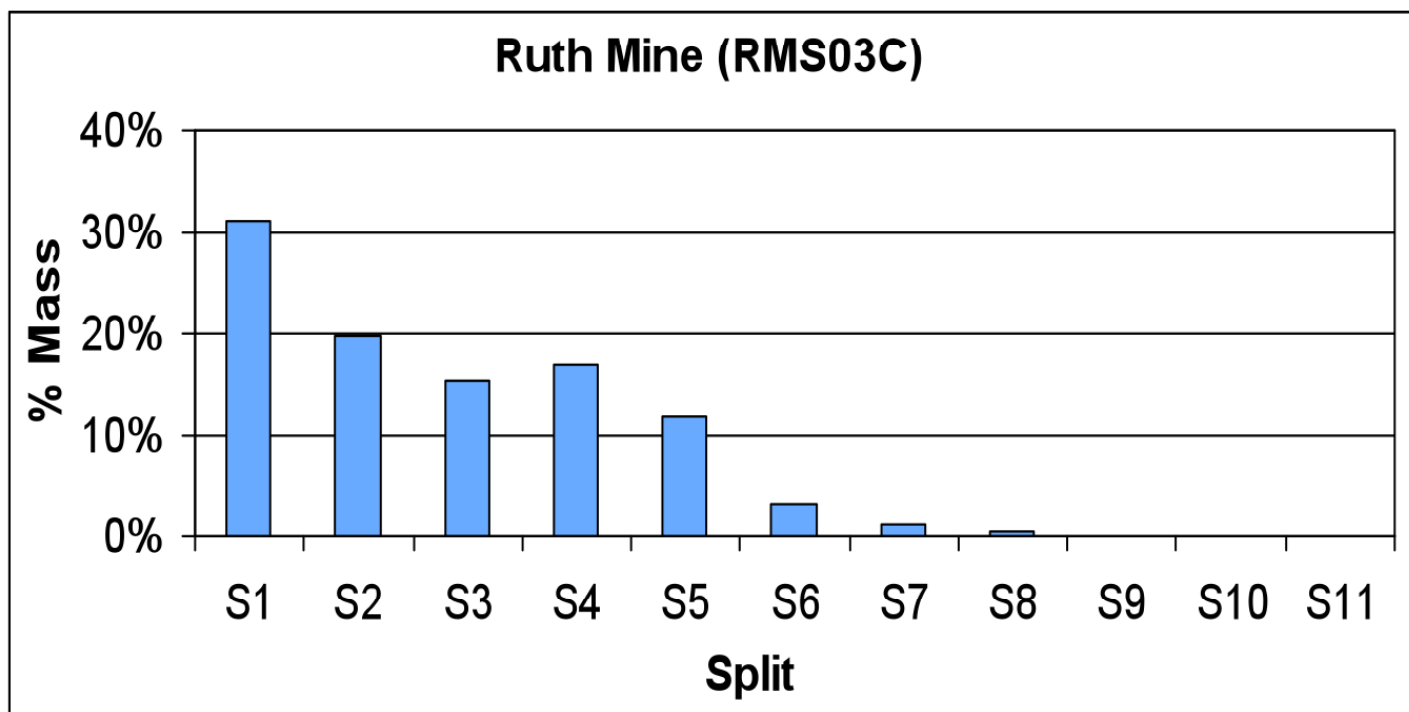


Figure 13. Distribution of mass in 8 size fractions of tailings produced by dry sieving, Ruth Mine area. No appreciable quantities of tailings were present in the size fractions less than 45 μm (size fractions S9-S11).

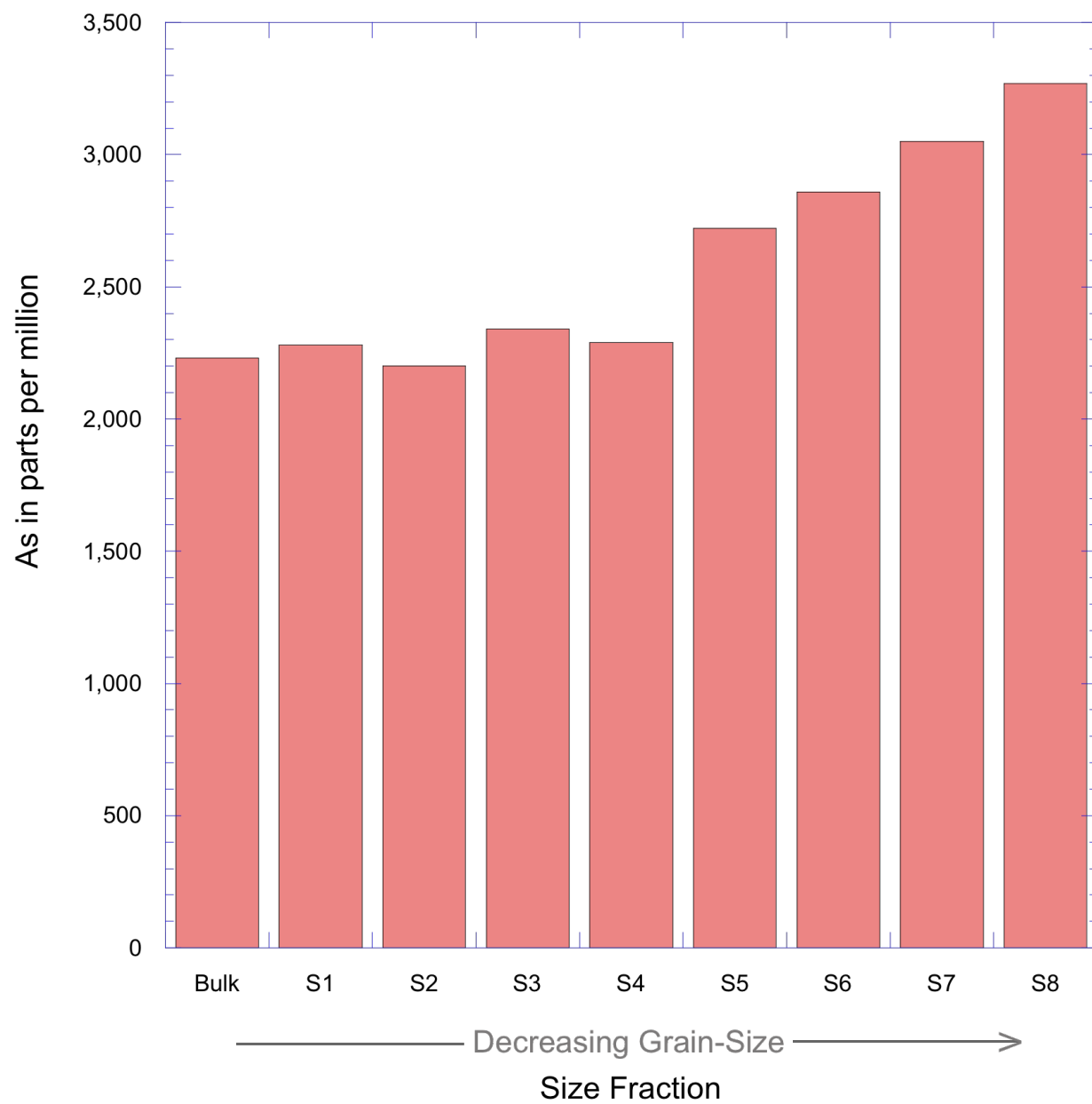


Figure 14. Concentration of As in tailings increases with decreasing grain size to the S8 size fraction, Ruth Mine, Inyo County, California.

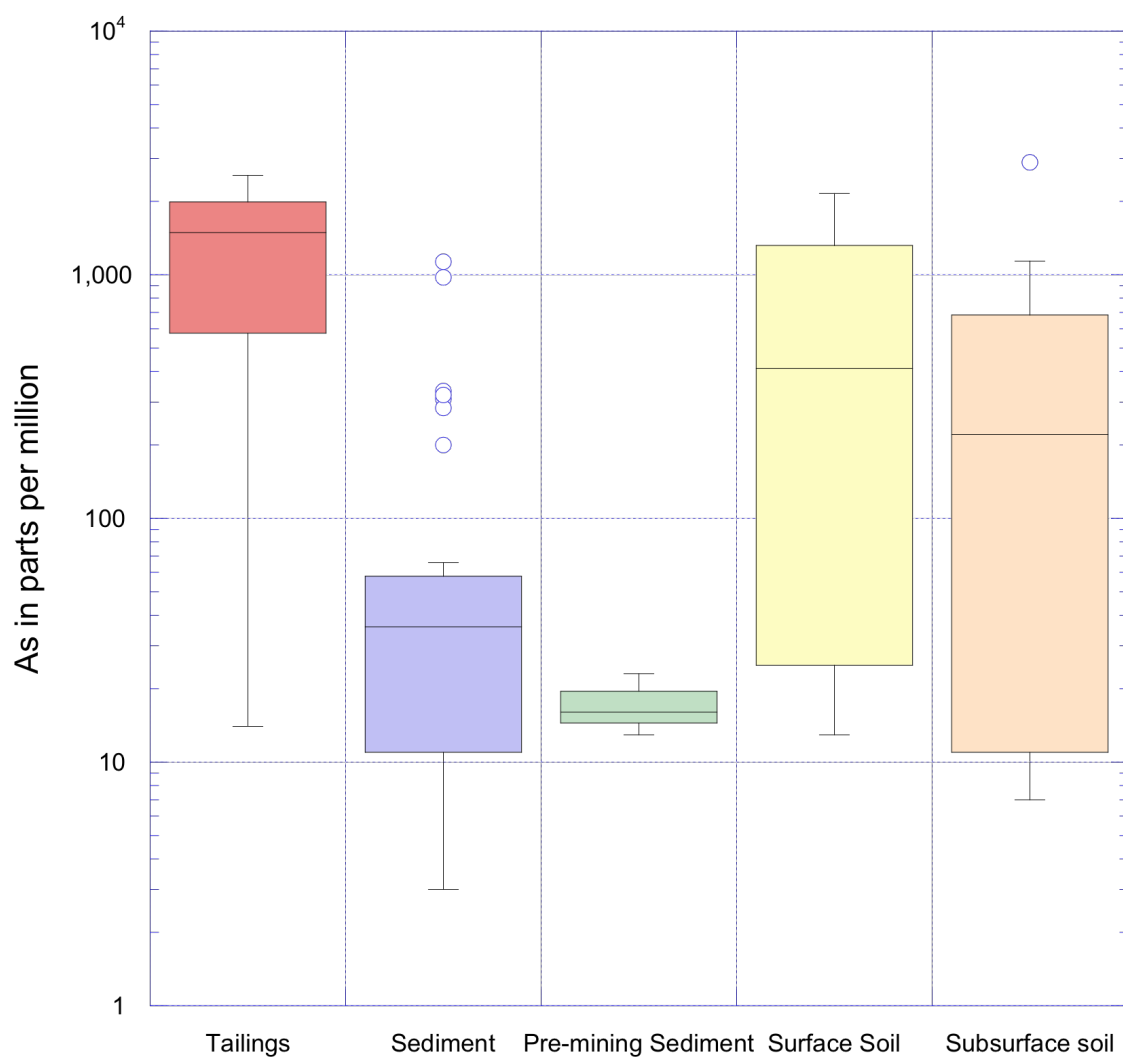


Figure 15. Box plot of As concentration in tailings at the Ruth Mine, sediment and pre-mining sediment downstream from the mine, and surface soil, 0-2 inch depth, and subsurface soil, 2-6 inch depth in the area of the Ruth Mine.

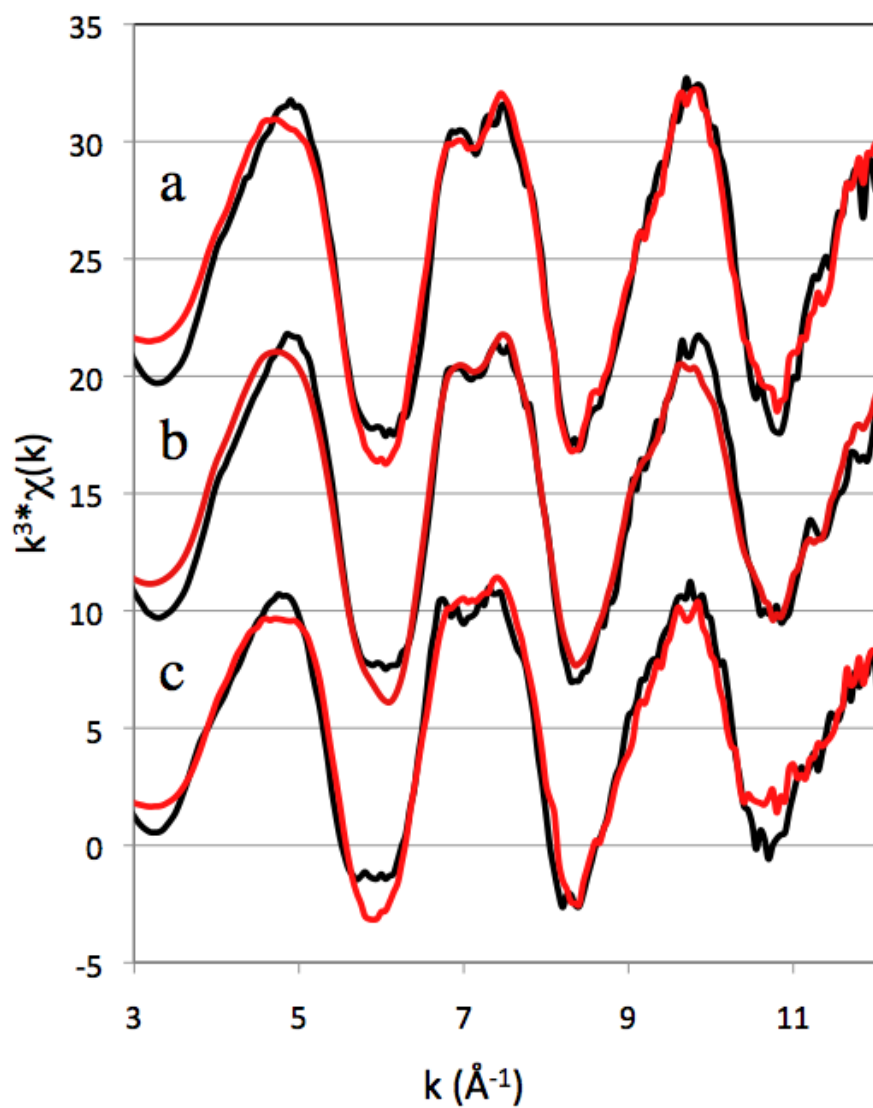


Figure 16. EXAFS raw spectra (black) and linear combination fits (red) for size fractions of the RMS03C sample, specifically the A, S5, B, S7, and C, S9 size fractions. See table 4 for quantitative fitting results.

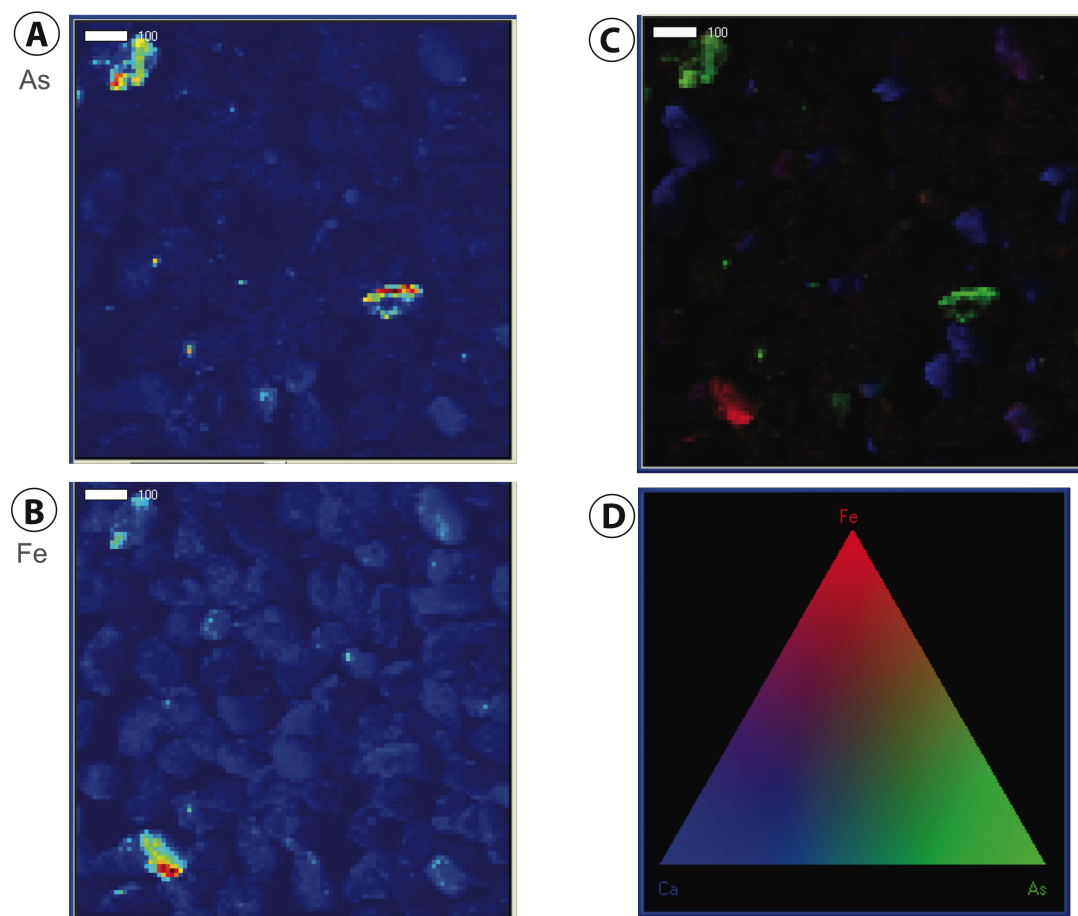


Figure 17. Micro x-ray fluorescence intensity maps of As (A) and Fe (B) in tailings from the Ruth Mine, and a tri-color fluorescence map (C) showing relative concentrations of As, Ca, and Fe. Fe is shown in red, Ca in blue, and As in green, according to the legend (D). Scale bar in all maps is 100 μm .

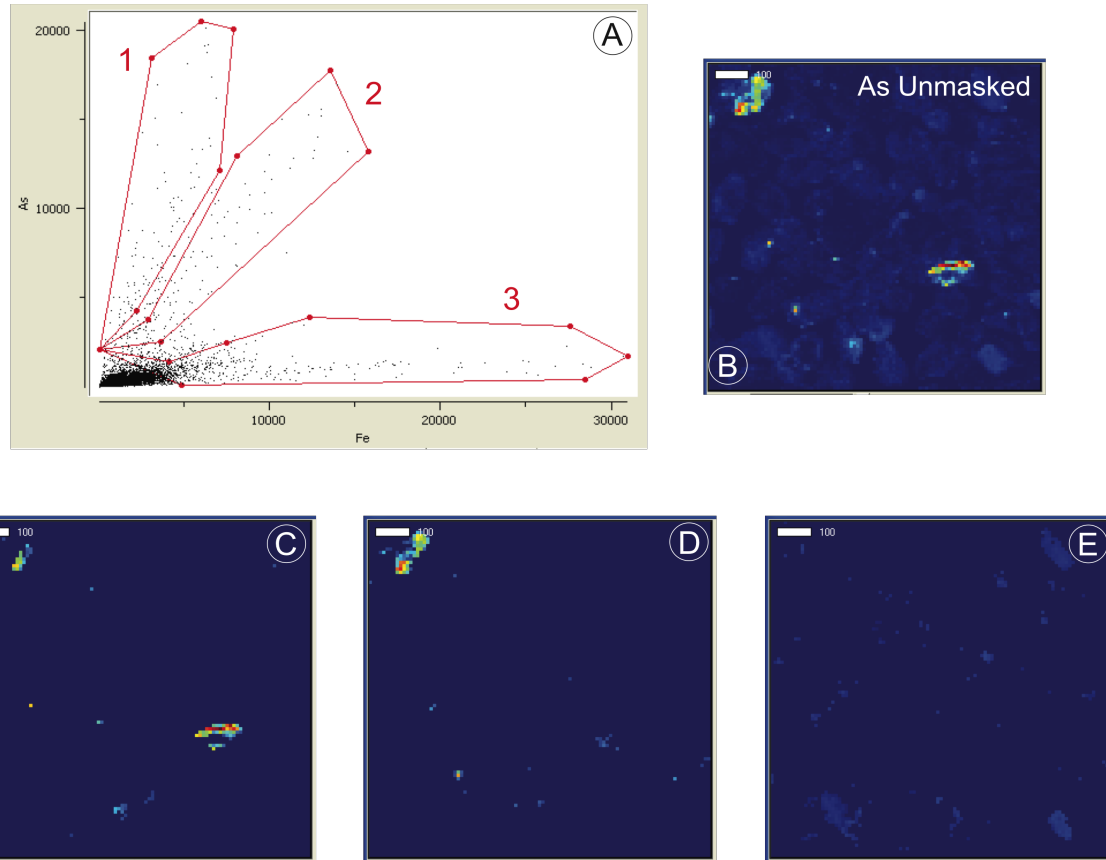


Figure 18. Correlation plot of As and Fe shows three distinct populations (A) numbered 1-3 based on X-ray fluorescence analysis of the S7 size fraction of the Ruth Mine tailings (B). Each of the three populations map to different As-enriched locations with variable As:Fe ratios (C, D, and E, representing populations 1, 2, and 3, respectively).

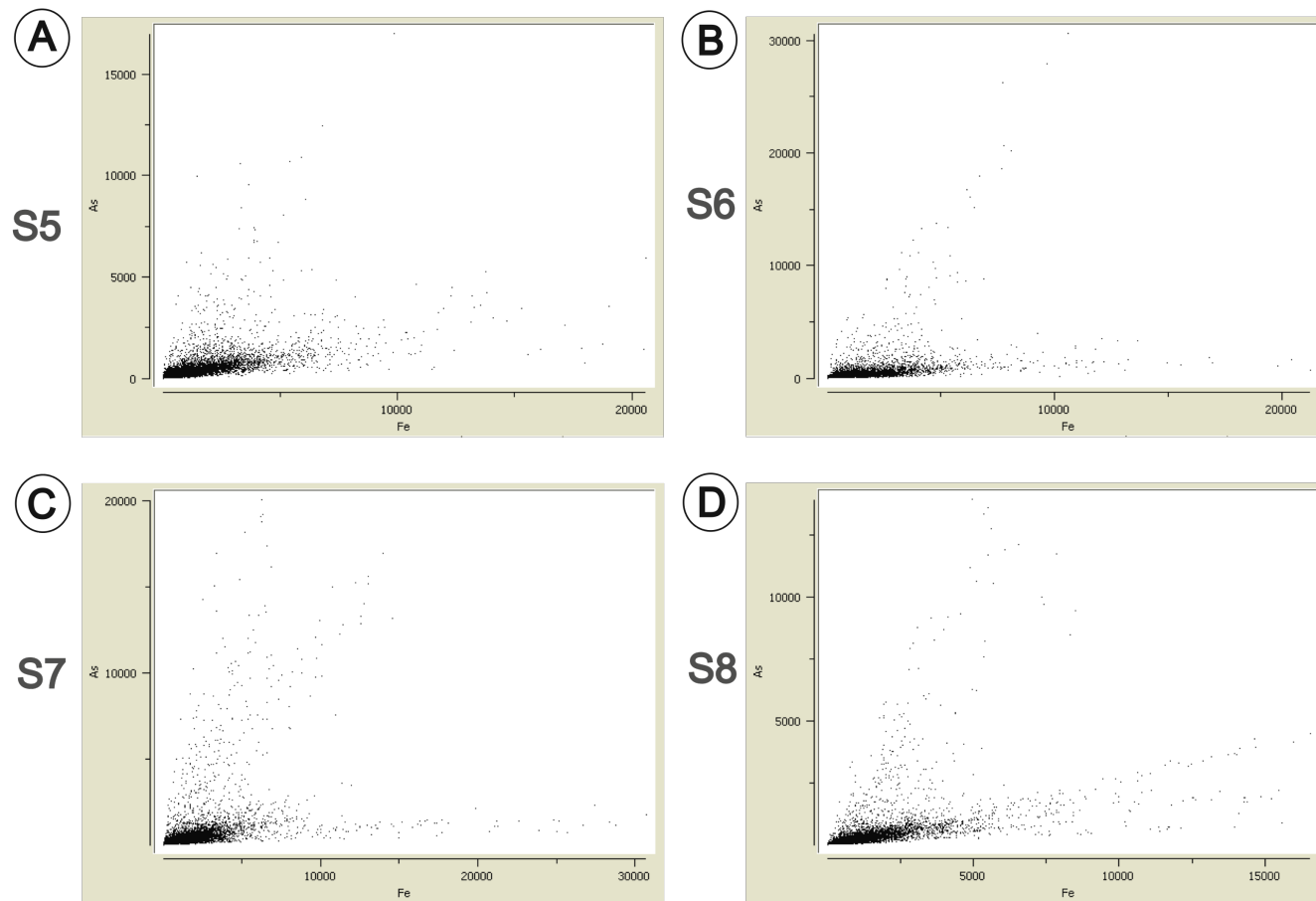


Figure 19. Arsenic-Iron correlations for four different size fractions of Ruth Mine tailings. A, S5 (250 μm –500 μm), B, S6 (125 μm –250 μm), C, S7 (75 μm –125 μm), and D, S8 (45 μm –75 μm).

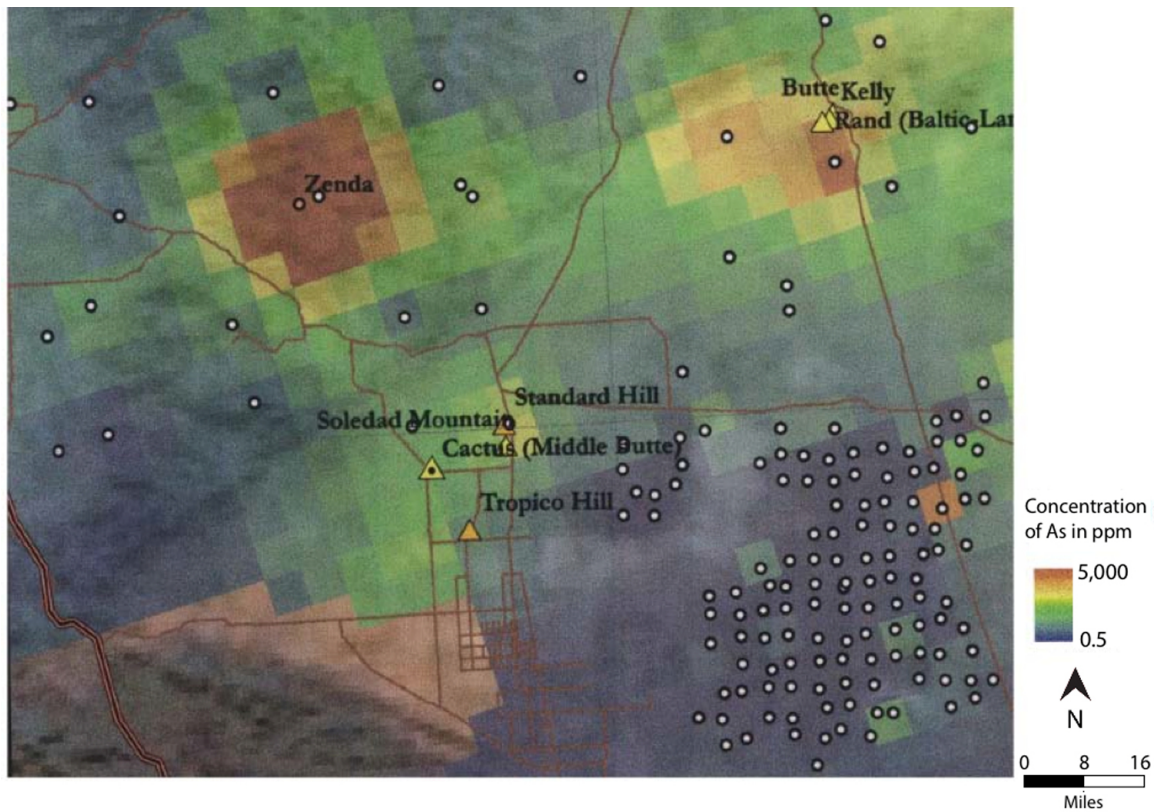


Figure 20. Color contour map of As concentration in stream sediment and soil samples from the NURE sample set. The Ruth Mine, located to the north of the pictured area in fig. 20, is linked, both in historic mining activity and fundamental geology, to the mines shown in this study area.