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Review of Samples of Sediments, Tailings, and Waters Adjacent to the Cactus Queen Gold Mine, Kern 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).

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 µm or 0.45 µm, as specified in the text).

mg/L, milligram per liter, approximately equivalent to one (1) part per million.

µg/L, microgram per liter, approximately equivalent to one (1) part per billion.

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

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

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

Review of Samples of Sediments, Tailings, and Waters Adjacent to the Cactus Queen Gold Mine, Kern County, California

By James J. Rytuba[1], Christopher S. Kim[2], and Daniel N. Goldstein[1]

Introduction

Background and Objectives

The Cactus Queen Mine is located in the western Mojave Desert in Kern County, California (fig. 1). The Cactus Queen gold-silver (Au-Ag) deposit is similar to other Au-Ag deposits hosted in Miocene volcanic rocks that consist of silicic domes and associated flows, pyroclastic rocks, and subvolcanic intrusions (fig. 2). The volcanic rocks were emplaced onto a basement of Mesozoic silicic intrusive rocks. A part of the Cactus Queen Mine is located on Federal land managed by the U.S. Bureau of Land Management (BLM) (fig. 3). Staff from the BLM initially sampled the mine area (figs. 3 and 4) and documented elevated concentrations of arsenic (As) in tailings and sediment (table 1). BLM then requested that the U.S. Geological Survey (USGS), in collaboration with Chapman University, measure and characterize As and other geochemical constituents in sediment, tailings, and waters on the part of the mine on Federal lands (fig. 4). This report is made in response to the request by the BLM, the lead agency mandated to conduct a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) - Removal Site Investigation (RSI). The RSI applies to the potential removal of As-contaminated mine waste from the Cactus Queen Mine as a means of reducing As release and exposure to humans and biota.

This report summarizes data obtained from field sampling of sediments, mine tailings, and surface waters at the Cactus Queen Mine on January 27, 2008. Our results provide a preliminary assessment of the sources of As and associated chemical constituents that could potentially impact humans and biota.

Mining History and Geology

Cactus Queen Mine

The Cactus Queen Mine is located on the southwest slope of Middle Buttes, 10 miles southwest of Mojave in the southern half of Sec. 17, T. 10 N., R. 13 W. (fig. 4). Gold was discovered at the Cactus Queen Mine site in 1934, and shortly after, Clifford

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Burton purchased the property and sold it to Cactus Mines Co. Ore was initially mined in a quartz vein occurring in dacite that strikes N. 45° E. and dips 35° SE with a width of about 16 ft (Julihn and Horton, 1937). Very fine free gold occurs in the quartz vein, along with finely disseminated cerargyrite. The vein lies along a major fault separating Mesozoic quartz monzonite bedrock from Tertiary quartz latite porphyry, and the main ore minerals include proustite, argentite, electrum, and finely divided free gold (Julihn and Horton, 1937). The mine operated from 1935 until WWII when underground mine operations were shut down by the War Production Board. During this period 230,000 tons of ore with an average 0.35 ounces per ton of gold and 10 ounces per ton of silver were mined, resulting in a total production of 92,000 ounces of Au and 2,300,700 ounces of Ag (Terra-Gen Power, 2009). Some of the ore extracted at the Cactus Queen mine was hauled to the Tropico Mill for processing (Julihn and Horton, 1937).

In 1986, Cactus Gold Mines Co. began open-pit mining combined with heap leaching in the Middle Buttes area. Open-pit mining ceased in 1992, but heap leaching of stockpiled ore continued through 1996. Total production during this period was about 400,000 ounces of gold and 3,000,000 ounces of silver (Terra-Gen Power, 2009). The ores contained a significant amount of mercury (Hg) in the mineral corderoite and Hg was recovered as a byproduct (Blaske and others, 1991). Subsequent exploratory drilling in 1997 by Summo Minerals Corp. discovered an additional gold resource, which may contain as much as 600,000 additional ounces of gold; however, no further mining has occurred at the mine (Terra-Gen Power, 2009).

Sample Locations and Methods

Sample Locations and Conditions

Samples were collected to assess the concentrations of As and associated elements in sediments, tailings, and waters on Federal land at the Cactus Queen Mine. The tailings occur in a heap leach pad, and stream sediment samples were taken from a channel constructed at the base of the leach pad (figs. 6 and 7). The tailings sample sites have a prefix T and sediment samples have a prefix S, as shown in figure 5 and listed in table 1. A naturally occurring drainage channel occurs below and runs roughly parallel to the tailings pad (figs. 6 and 7); sediment sample sites with prefix D were taken from this channel. Samples were collected at 500-foot intervals along the heap leach pad, the constructed stream channel beneath the tailings, and the natural drainage channel (fig. 5, table 1). During sampling a brief rainstorm resulted in significant runoff from the heap leach pad and resulted in water flow in the constructed channel at the base of the pad (fig. 8). Samples of filtered and unfiltered water were collected at stream sites 08CT_S12 and 08CT_S18 during this storm event (fig. 5, table 4).

Field Sampling Methods

Tailings and Sediments

Samples consisting of 100 to 500 g of mine tailings were collected from the heap leach pad and sediments from the constructed and natural drainage channels below the heap leach pad at the Cactus Queen Mine. Tailings and sediment were stored and shipped in Ziploc® bags at ambient temperature. Before chemical analysis, samples were air-dried in a laboratory fume hood at room temperature. One sample of tailings from the heap leach pad was weighed and then sieved into 10 size fractions to evaluate the concentration of As as a function of grain size. The sample was 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 10 distinct size fractions (table 3); no material was observed to pass through the 10th sieve. Splits of 5-10 g from the initial bulk sample and from each fraction size weighing >5 g were analyzed by ICP-MS.

Water

Stream samples were collected with new 60-mL sterile polypropylene syringes. Bulk water samples were subsampled for analysis of metal(loid)s and anions. Subsamples for metal(loid) determinations were acidified to pH<2 with trace metal (*Ultrex*, J.T. Baker)-grade HNO_3 and stored in acid-washed, high-density polyethylene (HDPE) bottles. Subsamples for anion and alkalinity measurements were filtered, stored in HDPE bottles, and refrigerated at approximately 4°C until analysis, in accordance with USGS protocols for trace metals (*http://pubs.water.usgs.gov/twri9A*). Water samples were filtered with disposable 25 mm-diameter sterile cellulose acetate filters (0.45 µm and 0.20 µm pore size) in the field for analysis of anions, alkalinity, and ICP-MS and -AES analysis.

Water variables including pH, conductivity, and temperature were measured in the field with a battery-powered pH meter (Orion Model 290, with low-maintenance sealed gel triode electrode) and a specific conductivity meter (Orion Model 120). The pH triode, which has automatic temperature compensation, was also used for temperature measurements. Measurements were taken by placing the probe directly into the flowing stream water.

Analytical Methods

Tailings and Sediment

Multi-element analyses for all dry sediments and tailings were performed in the laboratories of ALS Chemex. Bulk samples were ground in a zirconia ring mill and subjected to a near-total four-acid digestion. Major elements were determined by ICP-AES. Minor elements, other than Hg, were determined by ICP–MS. Mercury concentrations were determined by cold vapor atomic absorption spectroscopy (CVAAS) following methods similar to those described by Crock (1996) and O'Leary and others (1996).

The bioaccessibility of As in each size fraction of the tailings that was prepared by sieving was evaluated by leach experiments. The leach experiments used water and simulated gastric fluid (SGF) to assess the amount of As released from the tailings. The water-based extractions simulate the natural leaching of As by rainfall and were conducted by exposing 3.0 g of each size fraction to 12.0 mL of slightly acidified water (pH=5.5, the pH of rainfall) for 18 hours. Samples were rotated end-over-end at room temperature.

The *in vitro* simulated gastric fluid (SGF) extractions mimic the acidity of the human stomach at an internal core temperature. SGF was synthesized by mixing 2.0 L of deionized water with 60.06 g glycine and heating in a 37.0°C water bath. The SGF fluid was then acidified to pH 1.50 ± 0.05 using Ultrex concentrated nitric acid. A 0.5 g aliquot of each size fraction was then exposed to 50.0 mL SGF at pH 1.50 for a period of one hour to reflect human stomach pH and the time allotted for absorption in the stomach. Samples were agitated and incubated at 37.0°C, the body's resting internal temperature.

Following exposure to each leach fluid, all samples were centrifuged at 3,000 revolutions per minuteRPM for 15 minutes and the supernatants passed through 0.45 µm filters before acidification with a small volume of concentrated nitric acid. The fluid supernatants were then analyzed for extracted metal concentrations using ICP-MS. The elemental concentrations in the supernatants were then taken to reflect the corresponding amount of metals leached into rainwater or the body via the gastrointestinal system.

Waters

Alkalinity as $CaCO_3$ was determined in the laboratory by titration with H_2SO_4 using Gran's technique (Orion Research, Inc., 1978) within 2-4 days after sample collection. Sulfate, chloride, nitrate, and fluoride concentrations were determined by ion chromatography (Fishman and Pyen, 1979).

Cations were analyzed by inductively coupled plasma–atomic emission spectrometry (ICP–AES) and inductively coupled plasma–mass spectrometry (ICP–MS). Ion chromatography and alkalinity analyses were performed by USGS laboratories under the direction of Paul Lamothe. The ICP-AES analyses were determined by USGS laboratories under the direction of Monique Adams.

Extended X-ray Absorption Fine Structure (EXAFS) Spectroscopy

Bulk As K-edge EXAFS spectroscopic analysis was conducted at the Stanford Synchrotron Radiation Lightsource (SSRL) at room temperature in fluorescence mode with a Lytle detector (for high-concentration samples, that is, $[As]_T > 1,000$ ppm) or Ge 30-element detector (for low-concentration samples, that is $[As]_T < 1,000$ ppm). The speciation of arsenic in the S3, S5, S7, and S9 size fractions of the size-separated tailings sample and the S9 size fraction following SGF extraction was then determined by comparison of its EXAFS spectrum with those from an arsenic model compound EXAFS library of 16 homogeneous As(-I), 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 fit over a k-range of 3-12 Å^{-1} using the SixPack software program (Webb, S.M., 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 paired with the first component to generate two-component fits, repeating the process until no more significant contributors, 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 arsenic speciation of that sample. This method, while providing a direct, non-destructive route to characterizing arsenic 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 others, 2008; Kim and others, 2000).

Results

Concentration of As in Tailings and Sediment

The concentrations of As in tailings in the heap leach pad at the Cactus Queen Mine range from 254 to 8,850 ppm with most samples containing over 2000 ppm As (table 2). The As concentrations are comparable to As concentrations in the initial samples collected by the BLM staff, which ranged from 783 to 7,890 ppm (samples CMH1-5, table 2). Sediments in the channel constructed at the base of the heap leach pad to collect runoff from the pad have comparable concentrations of As to that in the tailings, ranging from 775 to 6,690 ppm (fig. 5, table 2). Sediment samples from the natural drainage channel that occurs to the west of the heap leach pad also have elevated concentrations of As, 139 to 2,200 ppm, but are consistently lower in concentration than those in the constructed channel (figs. 5 and 9, table 2). Base metal concentrations in the tailings and sediments are all relatively low. The mean concentration of As is highest in sediment from the constructed channel in comparison to the mean concentration in the tailings and sediment in the natural drainage channel (fig. 10). The majority of the stream sediment samples from the constructed channel exceed the As concentrations present in the tailings from which the sediment is derived (fig. 11). The sediment samples from the natural drainage channel, however, are consistently lower in As concentration than either the tailings or the sediments from the engineered stream channel.

The results of grain size analysis are listed in table 3. The As concentration in the bulk sample was 4740 ppm. The As concentration in the largest grain size fraction was 2,710 ppm and As concentration increased with decreasing grain size, reaching a maximum concentration of 8,540 ppm in the S7 size fraction 125 µm to 75 µm. The As concentration then decreased with decreasing grain size to 5,740 ppm in the smallest grain size fraction, 32 µm to 20 µm (fig. 13*A*). However, the surface area of the particles as measured by N_2 adsorption using the BET method increased linearly with decreasing grain size (fig. 13*B*).

Concentration of As Stream Water

During the rainstorm event, runoff from the tailings in the heap leach pad collected in and flowed along the constructed stream channel at the base of the pad. The two water samples collected from the stream channel have a pH of 7.2 and high concentrations of suspended sediment. The concentrations of As in the unfiltered water samples are extremely high and range from 84,000 to 97,600 µg/L (table 5, fig. 12). Concentrations of iron (Fe) and aluminum (Al) are also very high in the unfiltered water samples. Filtration of the runoff water by 0.45 µm and 0.2 µm filters effectively removes approximately 90% of the As, which is presumed to be in the solid phase (table 6, fig. 11). However, with concentrations of As in the filtered samples between 9,540-10,100 µg/L, the presumed dissolved As is still well above environmental regulatory levels. In contrast, more than 99 percent of Al and Fe is removed through filtration, with Fe concentrations below the detection limit in the 0.2 µm filtered fractions. This indicates that As in the water is not primarily sorbed to particles of Fe or Al oxyhydroxides.

As Released in Leach Experiments

The results of the leach experiments are presented in figures 13 and 14. The amount of As released from the water leach was relatively low, ranging from 0.64 to 1.08 percent of the As present in the tailings (fig. 14*A*). The percentage of As released is inversely correlated with the amount of As in each grain size fraction with the least percentage released in the size fraction 125 µm to 75 µm which has the highest As concentration (S7, fig. 14*A*). However, when normalized to surface area, the percentage of As released in water decreases with decreasing grain size (fig. 14*C*). The percentage of As released from the SGF leaches ranges from 6 percent to 46 percent and increases with decreasing grain size (fig. 14*B*). However, when normalized to surface area, the trend is largely reduced, indicating that surface area is the primary factor affecting As solubility when exposed to gastric fluid (fig. 14*D*). Even after surface area normalization, however, there is still a slight inverse trend between particle size and As released, suggesting that other factors such as the chemical speciation of As may play a role in As solubility.

Speciation of Arsenic in Tailings

Fits of the As EXAFS spectra collected from different size fractions of the size-separated tailings sample are shown in figure 15 with quantitative fits provided in table 7. All samples reveal a significant proportion of scorodite ($FeAsO_4 \cdot 2H_2O$), while 3 of the 4 samples also show evidence for the existence of As(V) sorbed to goethite (FeOOH) and 2 of the samples indicate the presence of amorphous ferric arsenate. No strong trends can be observed in As speciation as a function of particle size, although there is a general decline in the proportion of scorodite present with decreasing particle size. Additionally, the finest grain size fraction (S9) is the only size fraction to contain all three identified phases and features the lowest proportion of scorodite of all samples. This suggests that at very fine particle sizes, scorodite (which is among the least soluble oxidized arsenic phases) may be more readily solublized, with released arsenic sorbing to goethite and/or forming amorphous ferric arsenate.

Comparison of the speciation of the S9 size fraction before and after the SGF extraction indicates that the SGF remobilizes all of the As sorbed to goethite and a portion of the amorphous ferric arsenate, while leaving the amount of scorodite relatively constant. This shows the differential solubility of the various As-bearing phases and might have implications for the variable percentages of As released as a function of (surface area-normalized) particle size in figure 14*D*.

Conclusions

Highly elevated concentrations of As are present in the gold-mine tailings in the heap leach pad at the Cactus Queen Mine. The As concentrations in tailings are generally above 2,000 ppm and as high as 8,850 ppm. The As concentration in tailings is a function of grain size and increases with decreasing grain size, reaching a maximum concentration in the size fraction 250 µm to 125 µm. The As concentration decreases in the finest two grain size fractions but still remains higher than the As concentration in the bulk sample. In the 250 µm to 125 µm grain size fraction, the concentration is two times higher than in the bulk concentration (8,540 ppm and 4,740 ppm, respectively). During rainstorms, As-enriched sediment is eroded from the tailings in the heap leach pad and collects in the constructed stream channel at the base of the leach pad. The As concentration of sediment in this channel is typically above 4,000 ppm. The generally higher As concentration in the sediment as compared to that in the tailings results from erosion and release of fine-grained tailings particles that are enriched in As above that in bulk tailings concentrations. Unfiltered water samples from the stream channel sampled during a storm event had concentrations of As from 84,000 to 97,600 µg/L. The high As concentration in the unfiltered water results from the suspension of fine-grained As-enriched particles released from the tailings. In filtered waters, the As concentration decreases to about one-tenth of that present in the unfiltered water indicating that a substantial amount of the As present occurs as particulates. However, the concentration of As in the filtered waters is still relatively high (~10,000 µg/L) in both the 0.45 µm and 0.20 µm filtered waters.

The results of the water leach experiments indicate that only a small amount of the As in the tailings is released into water, typically less than 1.1 precent. In SGF leach experiments, much higher concentrations of As are released. The percentage of As released in the SGF leach increases with decreasing grain size of the tailings, ranging from 6 percent in the largest grain-size fraction to 46 percent in the finest grain size fraction. Thus the As phases in the tailings are bioaccessible if the pathway of exposure to humans and biota is by ingestion.

The high concentrations of As in tailings and sediments at the Cactus Queen Mine are similar to other mineralized areas in the western Mojave Desert that have As-enriched sediments and soils present (fig. 16). Hydrothermal systems associated with emplacement of volcanic centers have mobilized As and concentrated it in and adjacent to Au-Ag deposits. Erosion of these As-enriched mineralized and altered areas has resulted in areas with anomalously high As in sediment and soils (fig. 16). In mine and mill site areas, such as the Cactus Queen Mine, processing of Au-Ag ores has resulted in tailings with exceptionally high As concentrations that are released during storm events into adjacent streams. The As-enriched sediments and tailings are of potential environmental concern to both humans and biota.

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Table 1. Locations and descriptions of samples from the Cactus Queen Mine.

Field Number	Latitude	Longitude	Sampling Date	Notes
Stream Samples				
08CT_S0	34.96689	118.28435	1/27/08	Stream sediment sample directly below T1 sample
08CT_S3	34.97123	118.27912	1/28/08	Stream, some small rocks
08CT_S6	34.97026	118.28027		Stream, sand, light brown
08CT_S9	34.96925	118.28147		Stream, sand, light brown
08CT_S12	34.96836	118.28256		Stream sample
08CT_S15	34.96734	118.28377		Stream sample
08CT_S18	34.96639	118.28497		Stream sample
08CT_S21	34.96534	118.28618		Stream sample
08CT_S24	34.9645	118.28728		Stream sample
Drainage Channel				
08CT_D4	34.97154	118.27944	1/28/08	Drainage Channel
08CT_D7	34.97055	118.28054		Drainage Channel
08CT_D10	34.96962	118.28163		Drainage Channel
08CT_D13	34.96858	118.28285		Drainage Channel
08CT_D16	34.96755	118.28391		Drainage Channel
08CT_D19	34.9665	118.28524		Drainage Channel
08CT_D22	34.96553	118.28635		Drainage Channel
08CT_D25	34.96472	118.28756		Drainage Channel
Tailings				
08CT_T1	34.96688	118.28433	1/27/08	From large leach pad (not near breach)
08CT_T2	34.97112	118.27991	1/28/08	Tailings
08CT_T5	34.97046	118.28117		Tailings
08CT_T8	34.9692	118.28221		Tailings
08CT_T11	34.9683	118.28346		Tailings
08CT_T14	34.96733	118.28458		Tailings
08CT_T17	34.96636	118.2858		Tailings
08CT_T20	34.96537	118.28699		Tailings
08CT_T23	34.96448	118.28817		Tailings

Table 2. Major and minor elements in tailings and sediments at the Cactus Queen Mine, Kern County, California.

[ppm: parts per million; %: percent]

Field	Ag	Al	As	Ba	Be	Ca	Co	Cr	Cu	Fe	Hg	K	La	Mg	Mn	Mo	Na	Ni	P	Pb	S	Sb	Sc	Sr	Ti	V	Zn	Au
Number	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	%	ppm	%	ppm	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm
	Stream Sediment																											
08CT-S0	3	1.43	5080	160	0.5	0.54	2	7	31	2.19	4	0.41	10	0.17	149	4	0.05	4	400	26	0.29	43	2	36	0.03	14	49	
08CT-S3	2.8	1.16	5960	110	0.5	0.3	2	8	26	2.06	6	0.36	20	0.17	186	4	0.07	4	460	29	0.06	40	2	27	0.04	16	38	
08CT-S6	2.5	1.54	4380	110	0.6	0.42	4	11	24	2.4	2	0.44	20	0.29	258	4	0.07	6	540	41	0.05	32	3	27	0.08	27	50	
08CT-S9	2.2	1.27	2770	90	0.5	0.33	3	10	18	1.97	2	0.37	20	0.23	230	2	0.08	5	450	18	0.05	18	2	26	0.06	20	40	
08CT-S12	3	0.97	6690	80	<0.5	0.28	2	7	22	1.93	3	0.29	20	0.18	171	3	0.05	5	620	22	0.05	37	2	23	0.04	17	39	
08CT-S15	0.5	1.75	775	100	0.7	0.46	4	13	12	2.17	<1	0.47	20	0.38	321	2	0.08	8	510	10	0.02	6	4	33	0.1	31	43	
08CT-S18	3.5	2.81	5070	420	0.7	0.35	3	9	29	2.6	7	0.72	20	0.21	213	4	0.12	6	420	24	0.34	38	3	54	0.06	23	44	
08CT-S21	3.1	0.84	5360	170	<0.5	0.23	2	5	26	1.87	4	0.23	10	0.12	112	3	0.03	3	390	20	0.09	41	2	22	0.02	12	36	
08CT-S24	3	0.87	4820	130	<0.5	0.28	2	6	25	1.77	3	0.25	10	0.15	133	3	0.04	3	370	21	0.08	39	2	24	0.03	13	37	
	Tailings																											
08CT-T2	1	2.07	852	120	0.7	0.61	5	15	16	2.53	<1	0.51	20	0.46	377	2	0.11	8	670	11	0.03	8	4	38	0.13	37	60	
08CT-T5	5.5	2.29	8850	150	0.8	0.39	3	11	43	2.77	6	0.78	20	0.26	211	7	0.08	6	580	86	0.08	69	3	31	0.04	25	68	
08CT-T8	0.3	1.88	254	90	0.7	0.43	6	13	11	2.19	<1	0.42	20	0.39	355	1	0.09	8	540	7	0.01	3	4	31	0.12	34	47	
08CT-T11	2	1.99	2790	120	0.7	0.52	5	14	21	2.59	3	0.54	20	0.4	335	2	0.1	8	700	22	0.04	21	4	38	0.1	33	58	
08CT-T14	1.1	1.9	1525	120	0.6	0.46	5	12	16	2.27	2	0.44	20	0.37	313	2	0.09	7	560	13	0.07	15	4	35	0.1	31	49	
08CT-T17	3.4	1.99	2430	190	0.6	0.46	5	11	27	2.49	5	0.51	20	0.33	274	2	0.08	7	680	19	0.21	32	3	41	0.07	27	66	
08CT-T20	2.6	2.29	2330	180	0.6	0.6	4	12	24	2.37	3	0.49	20	0.34	279	3	0.1	8	550	18	0.18	24	4	39	0.09	29	51	
08CT-T23	2.3	1.53	4220	190	0.5	0.39	2	8	22	2.02	2	0.45	20	0.21	183	3	0.09	5	380	22	0.05	30	3	32	0.06	20	35	
	Sediment from Drainage																											
08CT-D4	0.2	2.35	139	110	0.9	0.78	9	18	17	3.16	<1	0.52	20	0.73	574	1	0.07	10	940	9	0.01	2	6	44	0.15	47	81	
08CT-D7	0.5	2.1	1430	100	0.8	0.83	7	15	15	2.87	<1	0.45	20	0.63	452	1	0.08	8	800	14	0.02	10	5	43	0.12	42	67	
08CT-D10	0.3	3.27	258	140	1	1.41	9	23	18	3.5	<1	0.63	20	0.88	582	1	0.14	11	780	11	0.02	5	7	74	0.18	56	79	
08CT-D13	0.6	1.88	1410	120	0.6	0.62	4	12	11	2.18	<1	0.48	20	0.35	306	1	0.2	7	420	9	0.03	7	4	45	0.12	31	36	
08CT-D16	0.2	2.64	259	110	1	1.83	8	17	16	3.18	<1	0.36	30	0.75	544	1	0.09	8	690	8	0.01	4	6	75	0.15	48	77	
08CT-D19	0.7	1.94	2200	280	0.7	1	5	15	17	2.91	1	0.38	40	0.42	382	2	0.17	8	510	11	0.08	14	5	51	0.21	44	43	
08CT-D22	1.3	1.93	2010	140	0.7	0.79	4	14	19	2.57	1	0.4	20	0.39	349	2	0.09	7	560	18	0.06	17	4	42	0.12	35	54	
08CT-D25	1.3	3.22	1225	200	0.9	1.19	6	18	17	3.36	2	0.65	30	0.54	436	2	0.24	9	560	15	0.11	13	6	74	0.21	55	55	

Table 2. Major and minor elements in tailings and sediments at the Cactus Queen Mine, Kern County, California-Continued.

[ppm, parts per million; %, percent]

Field Number	Ag ppm	Al %	As ppm	Ba ppm	Ca %	Co ppm	Cr ppm	Cu ppm	Fe %	Hg ppm	K %	La ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm	P ppm	Pb ppm	S %	Sb ppm	Sc ppm	Sr ppm	Ti %	V ppm	Zn ppm	Au ppm
	BLM Samples																										
CMH 1	0.9	1.47	783	100	0.88	5	15	13	2.03	2	0.17	20	0.16	212	1	0.22	9	1180	14	0.08	9	2	171	0.07	46	45	0.02
CMH 2	3.5	0.66	1960	60	0.2	3	5	12	1.34	6	0.18	10	0.14	148	1	0.01	3	350	18	0.02	23	1	19	0.03	12	31	0.062
CMH 3	5	0.6	5540	40	0.11	9	4	96	1.32	3	0.14	10	0.05	67	9	0.02	13	190	50	0.82	38	1	10	0.01	5	101	0.123
CMH 4	10	0.87	7890	90	0.33	4	5	66	1.88	4	0.31	20	0.11	114	9	0.03	4	510	98	0.14	79	1	26	0.01	12	107	0.276
CMH 5	5.5	1.37	5130	140	0.43	5	8	49	2.75	4	0.46	30	0.27	246	5	0.01	6	700	52	0.13	61	2	34	0.04	22	105	0.178
CMWB 1	0.2	1.67	43	60	3.13	7	11	12	2.34	<1	0.18	10	0.62	359	<1	0.03	11	570	13	0.01	3	3	92	0.09	31	70	0.005
CMW 1	1.5	0.73	2270	80	0.37	2	4	14	1.41	4	0.17	10	0.15	142	2	0.01	2	330	12	0.04	22	1	23	0.03	12	30	0.067
CMW 2	2.9	0.49	3290	130	0.19	1	3	18	1.29	5	0.14	10	0.07	79	2	0.01	1	240	17	0.05	35	1	17	0.01	7	24	0.33
CMW 3	2.5	0.47	2310	80	0.16	1	3	12	1.17	3	0.14	10	0.06	101	1	0.01	3	200	14	0.06	19	1	16	0.01	7	21	0.077
CMF 1	4.8	0.45	1935	130	0.11	2	3	13	1.23	7	0.12	10	0.06	95	1	0.01	3	220	10	0.03	26	1	16	0.01	7	21	0.082
CMDITCH 1	4.4	0.42	3210	200	0.13	1	2	18	1.39	7	0.14	10	0.04	60	3	0.02	2	170	11	0.09	30	1	16	0.01	5	19	0.307
CMDITCH 2	5.6	0.59	3830	140	0.22	3	4	27	1.75	8	0.2	10	0.08	87	4	0.01	3	270	27	0.13	39	1	23	0.01	8	41	0.211

(*Not detected: B (<10ppm), Bi <2ppm, Cd <0.5 ppm, Ga (<10ppm), Th (<20ppm), Tl (<10ppm), U (<10ppm), W (<10ppm)

Table 3. Concentration of elements in sieved size fractions of tailings sample 08CT-T1 from the Cactus Queen Mine.

[ppm: parts per million; %: percent]

Field Number	Size Range	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 %	Ga ppm	Ge ppm	Hf ppm
Bulk		5.88	6.56	4740	620	1.42	0.2	0.15	0.03	42.5	0.9	104	4.35	26.9	1.58	14.4	0.08	1.3
S1	> 2830 µm	23	5.62	2710	470	1.35	0.11	0.06	0.09	36.7	0.4	8	2.83	84.3	2.64	12.8	0.09	1.4
S2	2830 µm -1700 µm	13.7	5.58	5660	450	1.55	0.14	0.09	0.02	45.7	0.8	101	4.45	24.4	1.6	13.35	0.08	1.3
S3	1700 µm -1000 µm	10.5	6.15	5910	620	1.34	0.16	0.13	0.04	44	0.9	7	4.73	47.4	2.11	13.6	0.09	1.3
S4	1000 µm -500 µm	7.55	7.08	6890	590	1.37	0.17	0.18	0.02	53.8	1.6	428	5.13	34.4	2.3	14.8	0.11	1.3
S5	500 µm -250 µm	7.88	7.53	7650	620	1.49	0.2	0.23	0.04	53.6	1.2	9	5.77	50.1	2.36	16.3	0.12	1.3
S6	250 µm - 125 µm	6.8	8.42	8110	710	1.45	0.2	0.31	0.04	52.9	1.3	90	6.31	57.7	2.33	17.5	0.12	1.2
S7	125 µm - 75 µm	6.33	8.69	8540	720	1.43	0.23	0.37	0.06	60.3	2.8	24	6.89	73.1	2.68	19.75	0.15	1.5
S8	75 µm -45 µm	7.06	10.05	6930	690	1.34	0.23	0.33	0.05	58.7	1.7	41	7.24	72.4	2.35	21.2	0.13	1.4
S9	45 µm -32 µm	7.9	10.85	5800	700	1.26	0.23	0.29	0.05	50.4	1.8	87	7.17	73.2	2.15	22.3	0.11	1.3
S10	32 µm - 20 µm	6.97	11.1	5740	690	1.29	0.22	0.31	0.09	62.2	1.7	28	6.74	75.3	2.3	20.5	0.13	1.2

Field Number	Size Range	Hg ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	S %	Sb ppm	Sc ppm
Bulk		7.48	0.034	2.24	22.7	56.2	0.16	56	5.05	0.15	9.4	2.6	320	58.8	112	1.4	84.4	3.3
S1	> 2830 µm	29.7	0.019	2.27	19.4	54	0.08	69	3.71	0.07	8.9	3.3	180	121.5	113	0.17	94.5	2.7
S2	2830 µm -1700 µm	13.9	0.032	2.12	23	57.5	0.14	49	4.29	0.11	8.3	2.6	450	42	117	0.63	100	2.8
S3	1700 µm -1000 µm	11.7	0.032	2.18	23.5	48.7	0.14	99	5.1	0.14	8.5	3.8	330	63.9	112	0.91	112.5	3
S4	1000 µm -500 µm	10.9	0.037	2.3	29.1	44.9	0.16	69	5.41	0.18	8.7	7.3	430	40.8	116.5	1.14	113.5	3.2
S5	500 µm -250 µm	10.9	0.044	2.49	28.4	44.3	0.17	86	5.91	0.21	9.5	4.3	470	57.1	124	1.33	118.5	3.6
S6	250 µm - 125 µm	10.9	0.048	2.68	26.8	40.1	0.19	70	5.92	0.27	10	3.9	520	45.1	107.5	1.75	117	3.9
S7	125 µm - 75 µm	10.2	0.051	2.75	31.9	44.5	0.48	97	6.84	0.29	12.8	40.2	530	56.5	138.5	1.88	128	4.7
S8	75 µm -45 µm	12.4	0.052	3	28.5	37.9	0.25	68	6.95	0.37	13.8	10.5	620	52.4	134.5	2.96	124.5	4.9
S9	45 µm -32 µm	12.5	0.048	3.2	22.7	33.9	0.21	63	7.59	0.44	12.6	13.8	640	55.4	128	3.82	120.5	4.6
S10	32 µm - 20 µm	12.6	0.045	3.27	30	33.2	0.2	79	7.98	0.46	13.1	14.8	630	62	125	4.07	111.5	4.8

Table 3. Concentration of elements in sieved size fractions of tailings sample 08CT-T1 from the Cactus Queen Mine-Continued.

[ppm: parts per million; %: percent]

Field Number	Size Range	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
Bulk		2	3.1	206	0.9	0.06	10.5	0.154	1.12	3.9	18	4.9	7.2	39	35.5
S1	> 2830 µm	3	2.7	147.5	0.82	0.08	8.6	0.177	1.42	4	17	3.2	6.4	44	41.7
S2	2830 µm -1700 µm	2	2.8	147.5	0.84	0.07	10.3	0.141	1.18	4.9	15	3.5	7.5	28	35.5
S3	1700 µm -1000 µm	2	2.9	167	0.82	0.08	10.5	0.146	1.22	4.2	16	4.4	7.7	48	36.4
S4	1000 µm -500 µm	3	3.1	202	0.83	0.06	11.9	0.15	1.2	4.3	19	4.6	7.2	48	33.6
S5	500 µm -250 µm	3	3.3	227	0.97	0.08	12	0.167	1.26	4.5	19	7.5	8.2	61	36.6
S6	250 µm - 125 µm	3	3.5	263	0.93	0.09	12	0.183	1.37	4.4	22	6.4	7.4	74	31.3
S7	125 µm - 75 µm	5	3.9	269	1.22	0.09	13.3	0.224	1.38	4.2	25	8.1	9.2	86	37.6
S8	75 µm -45 µm	5	4.2	363	1.25	0.09	13.2	0.244	1.37	4.1	27	9	7.7	86	34.1
S9	45 µm -32 µm	4	4.2	436	1.11	0.08	12.6	0.226	1.27	4.2	31	8.9	6.5	101	31.9
S10	32 µm - 20 µm	4	4.6	436	1.14	0.08	13.2	0.242	1.23	4.4	30	9.3	7.2	96	31.5

Table 4. Concentration of anions and selected cations in filtered waters from Cactus Queen Mine, Kern County, California.

Sample	pH	Temp deg C	Conductivity μS	Cl ppm	F ppm	NO3 ppm	SO4 ppm	CaCO3 ppm	Ca mg/L	Fe ug/L	K mg/L	Li ug/L	Mg mg/L	Na mg/L
08CT-S12	7.2	18	610	18.1	<.08	69.1	191		52.9	43.4	15.3	<5	3.87	52.2
08CT-S18	7.25	18	604	17.8	<.08	65.3	187.4	45.99	56.1	219	12.6	<5	4.24	57.9
08CT-FB	8.02	18	76	<.08	<.08	<.08	<.08	1.295	<0.1	<20	<0.1	<5	<0.1	<0.1

Table 5. Major- and minor- element concentration in unfiltered water at the Cactus Mine, Kern County, California.

Field No.	Ag ug/L	Al ug/L	As ug/L	Ba ug/L	Be ug/L	Ca mg/L	Cd ug/L	Ce ug/L	Co ug/L	Cr ug/L	Cs ug/L	Cu ug/L	Dy ug/L	Er ug/L	Eu ug/L	Fe ug/L	Ga ug/L
08CT-S12	9.87	89100	84000	1060	9	223	2.34	308	95.4	72	3.87	1600	26.2	13.1	6.59	117000	30.2
08CT-S18	16.1	105000	97600	1630	8.8	213	2.25	353	96.2	88.8	7.43	1760	27.8	13.4	7.25	153000	41.5
08CT-FB	<1	<2	13	<0.2	<0.05	<0.2	<0.02	< 0.01	<0.02	<1	< 0.02	<0.5	< 0.005	< 0.005	< 0.005	<50	< 0.05

Field No.	Gd ug/L	Ge ug/L	Ho ug/L	K mg/L	La ug/L	Li ug/L	Lu ug/L	Mg mg/L	Mn ug/L	Mo ug/L	Na mg/L	Nd ug/L	Ni ug/L	P mg/L	Pb ug/L	Pr ug/L	Rb ug/L
08CT-S12	33.8	2	4.66	53.2	136	87.2	1.5	45.2	5800	7.5	59.9	126	85.4	4.8	22.1	33.5	151
08CT-S18	35.6	2.6	4.89	59.5	156	108	1.6	49.8	5560	9.9	62.5	129	87.1	5.9	69.9	34.5	227
08CT-FB	< .005	< 0.05	< .005	<0.03	< 0.01	< 0.1	< 0.1	<0.01	<0.2	< 2	<0.01	< 0.01	<0.4	< 0.01	<0.05	< 0.01	0.01

Field No.	Sb ug/L	Sc ug/L	Se ug/L	SiO2 mg/L	Sm ug/L	SO4 mg/L	Sr ug/L	Tb ug/L	Th ug/L	Ti ug/L	Tl ug/L	Tm ug/L	U ug/L	V ug/L	Y ug/L	Yb ug/L	Zn ug/L
08CT-S12	3.49	38.1	19.5	251	28	144	697	4.75	5.79	96.8	3.7	1.65	34.7	140	135	10.4	3480
08CT-S18	5.88	39.3	20.4	249	28.8	144	734	5.06	10.1	282	4.8	1.74	36.6	179	146	11	3680
08CT-FB	<0.3	< 0.6	< 1	< 0.2	< 0.01	< 2	< 0.5	< 0.005	< 0.2	< 0.5	<0.1	< 0.005	< 0.1	<0.5	< 0.01	< 0.005	<0.5

Field No.	Zr ug/L
08CT-S12	0.4
08CT-S18	0.99
08CT-FB	< 0.2

Not detected: Bi, Nb, Ta, W

Table 6. Major- and minor- element concentration in filtered water at the Cactus Queen Mine, Kern County, California.

Field No.	Ag	Al	As	Ba	Ca	Cd	Ce	Co	Cs	Cu	Fe	Ge	K	Mg	Mn	Mo	Na	Ni	P
	ug/L	ug/L	ug/L	ug/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	ug/L	ug/L	mg/L	ug/L	mg/L
08CT-S12	<1	12	9540	6.43	52.9	0.09	0.02	6.01	0.04	16.5	43.4	0.1	15.3	3.87	10.9	52.3	52.2	2.2	0.1
08CT-S18	1.29	8.3	10100	5.39	56.1	0.08	0.01	6.4	0.05	18	219	0.2	12.6	4.24	9.6	51.9	57.9	1.8	0.1
08CT-FB	<1	<2	2	<0.2	<0.2	<0.02	<0.02	< 0.02	<0.5	<50	< 0.05	<0.03	< 0.1	<0.01	<0.2	< 2	<0.01	<0.4	< 0.01

Field No.	Pb	Rb	Sb	Se	SiO2	SO4	Sr	Ta	Ti	U	V	W	Zn	Zr
	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
08CT-S12	0.07	6.07	8.61	15.5	4	184	69.4	0.09	2.8	0.9	2	0.56	262	1.5
08CT-S18	<0.05	6.56	10	14	4.4	162	62.9	< 0.02	2.6	0.9	2	0.52	7.3	< 0.2
08CT-FB	0.1	< .01	<0.3	< 1	< 0.2	< 2	< 0.5	< 0.02	< 0.5	< 0.1	<0.5	< 0.5	<0.5	< 0.2

Not detected: Be, Bi, Ce, Cr, Dy, Er, Eu, Ga, Gd, Ho, La, Lu, Nb, Nd, Pr, Sc, Sm, Tb, Th, Tl, Tm, Y, Yb

Table 7. Arsenic speciation determined by Extended x-ray absorption fine structure spectroscopy for selected grain size fractions.

Sample Name	**Size Range**	**[As] (ppm)**	**As Speciation**			**R-factor**
			Scorodite	**As(V)-goethite**	**Amorphous Ferric Arsenate**	
08CT_T1_S3	1000-1700 µm	5910	61%	40%		0.049
08CT_T1_S5	250-500 µm	7650	49%		46%	0.043
08CT_T1_S7	75-125 µm	8540	62%	44%		0.044
08CT_T1_S9	32-45 µm	5800	27%	41%	43%	0.045
08CT_T1_SGF_S9	32-45 µm	3109*	55%		52%	0.046

**Estimated based on SGF extractions.*

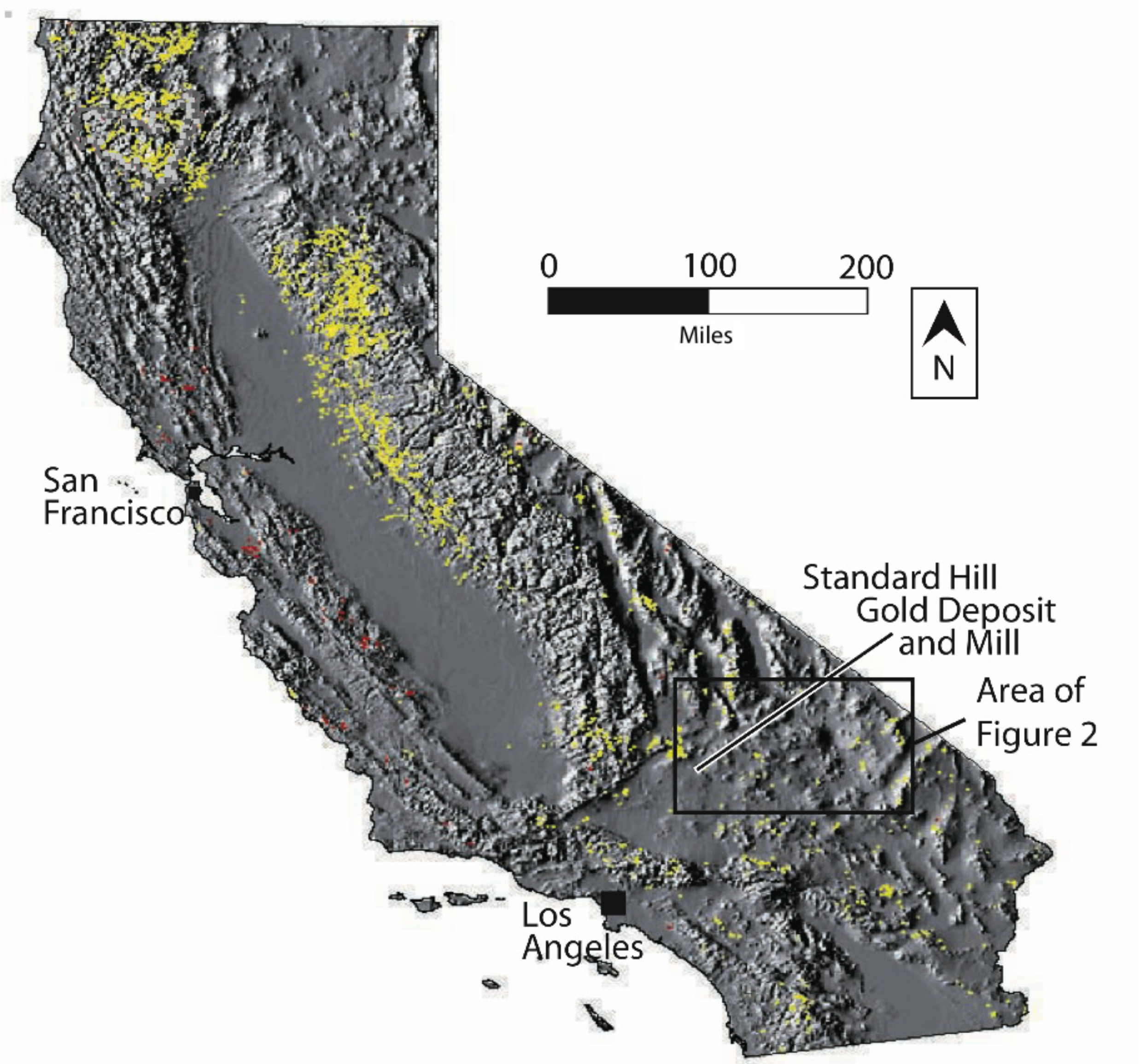


Figure 1. Location map of the Cactus Queen gold mine in the western Mojave Desert. Gold mines are indicated by yellow squares and mercury (Hg) mines by red squares.

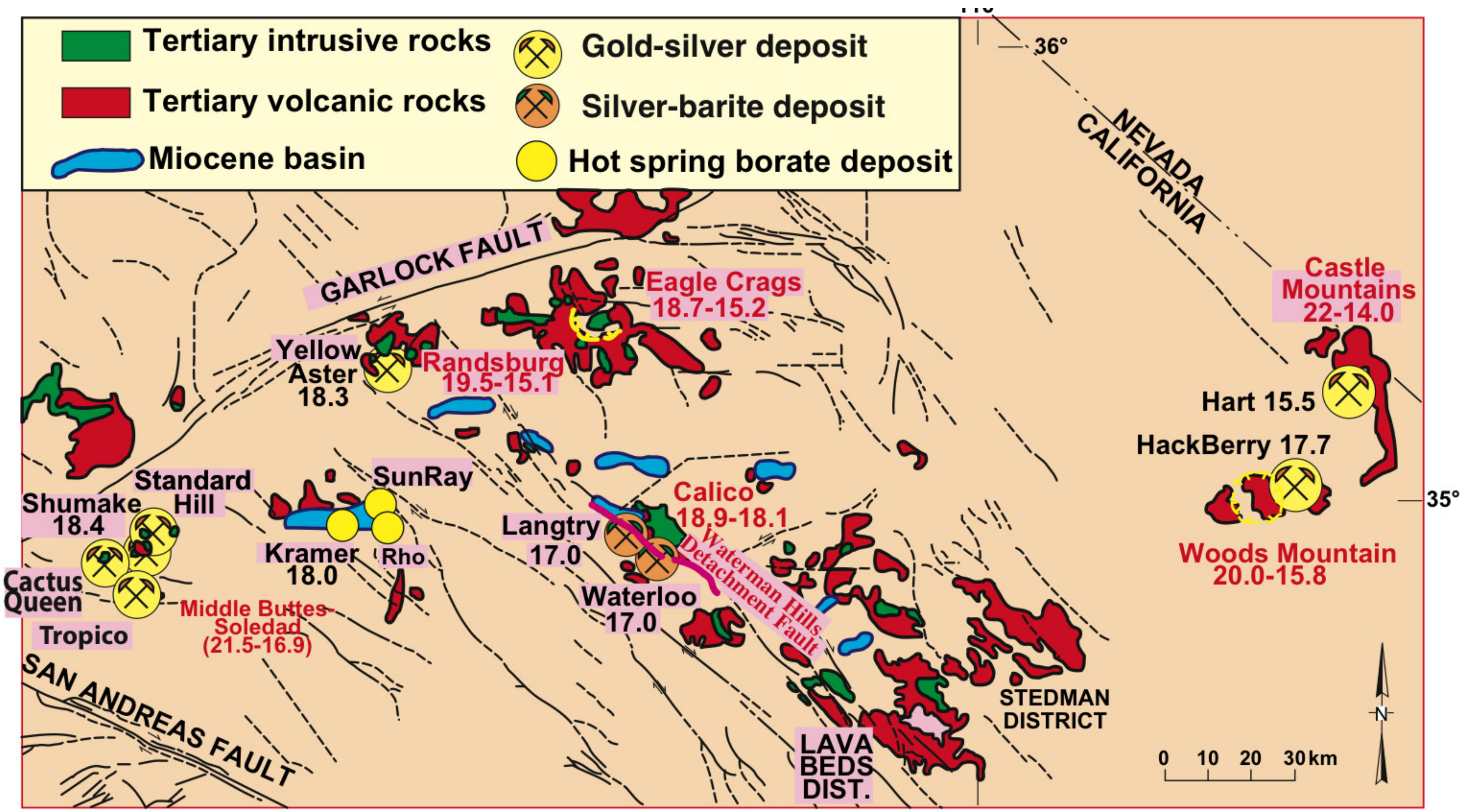


Figure 2. Generalized geologic map showing location of volcanic fields and associated Au-Ag deposits including the Cactus Queen Au deposit located in the western part of the Mojave Desert, Kern County, California.

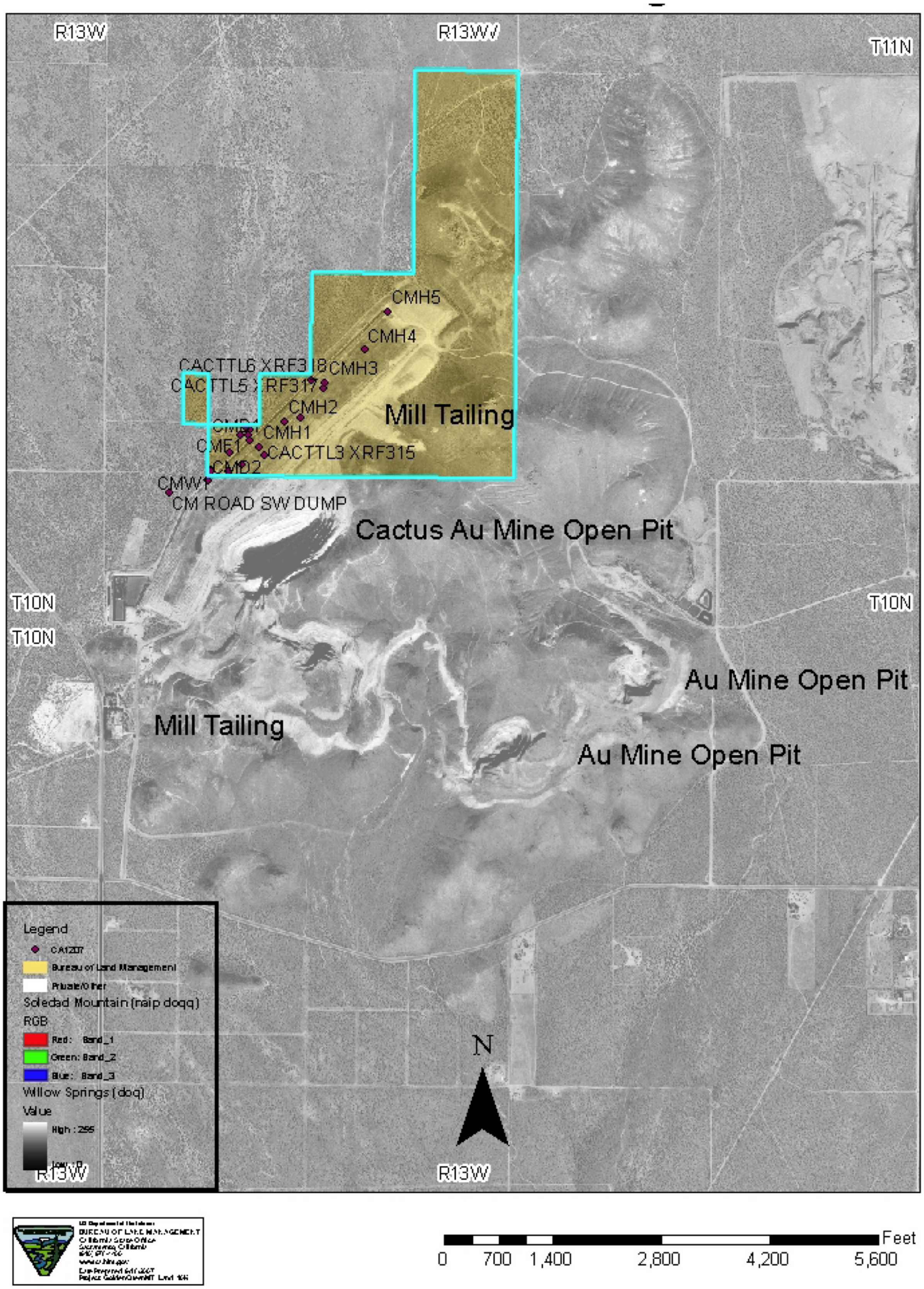


Figure 3. Overview of the Cactus Queen mine, mill site and tailings on photographic base map. The U.S. Bureau of Land Management parcel of land shown in yellow includes the northwest part of the mine and part of the heap leach pad. Samples collected by US BLM staff are shown in purple.

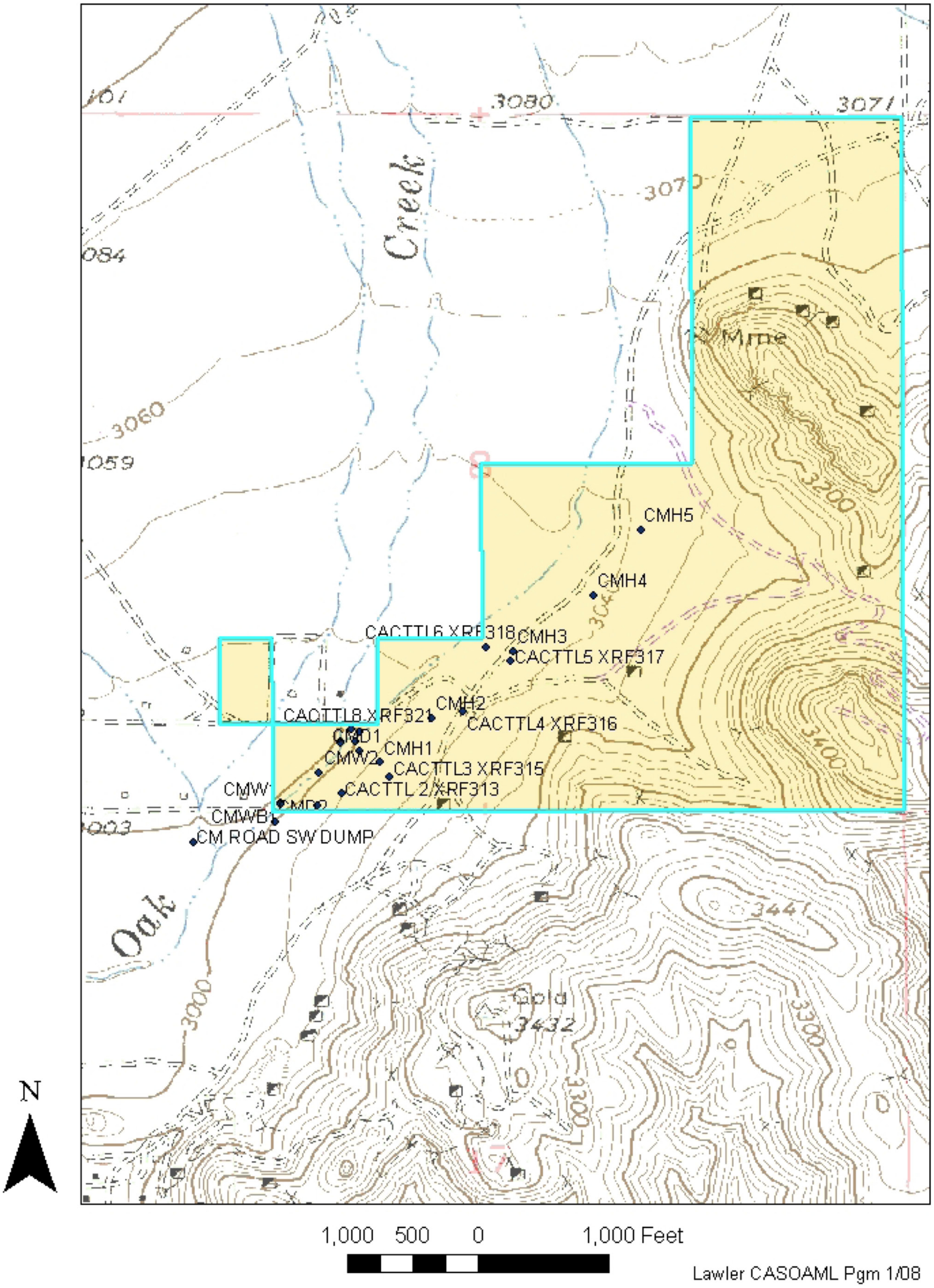


Figure 4. Topographic map of the Cactus Queen Mine before development of the open pits and heap leach pad. The U.S. Bureau of Land Management parcel is shown in yellow. Samples collected by BLM staff are shown in blue.

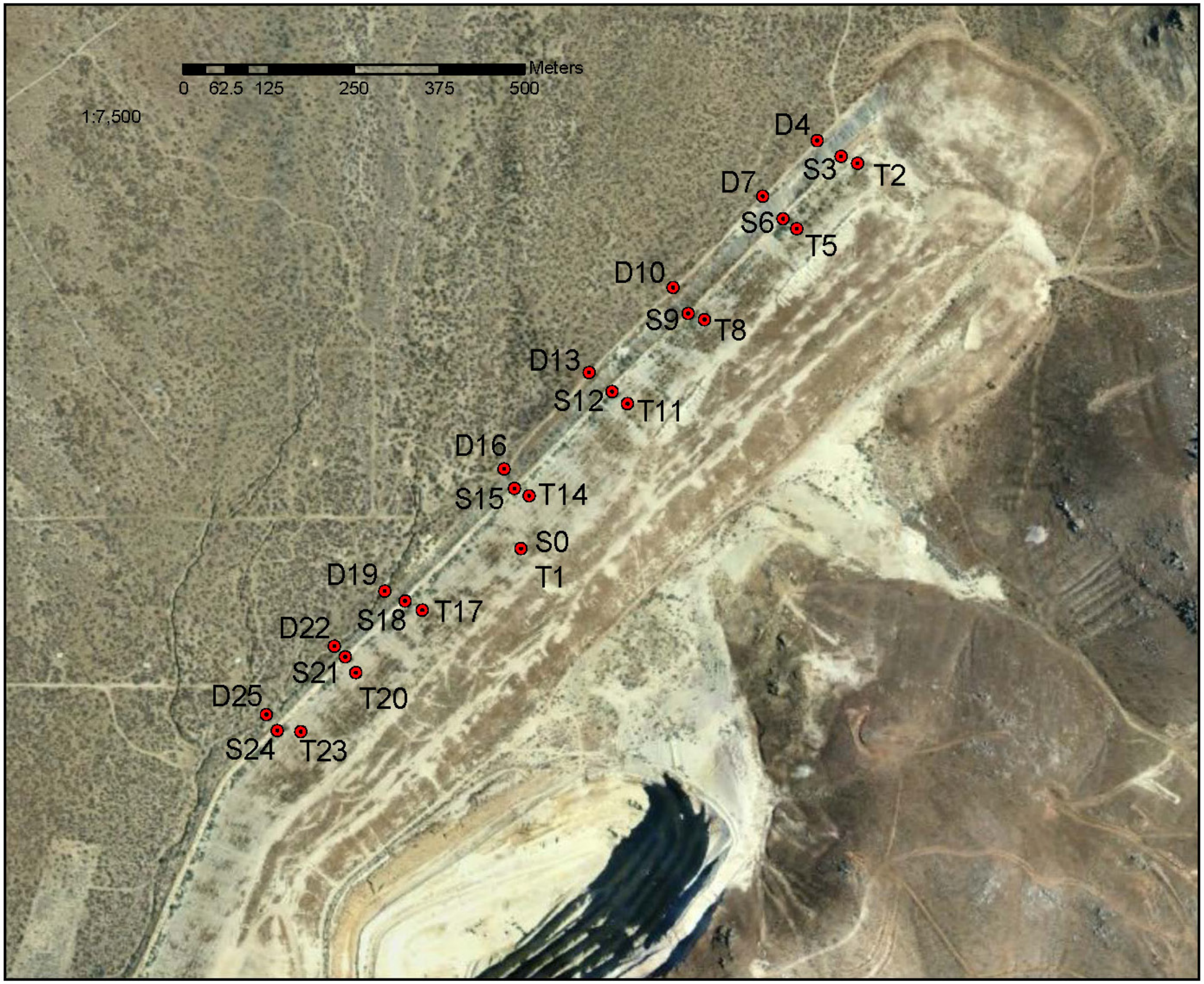


Figure 5. Location of tailings, sediment, and water sample sites collected for geochemical analysis on the U.S. Bureau of Land Management parcel adjacent to the Cactus Queen Mine. The drainage ditch is the white linear line to the west of the heap leach pad containing samples with prefix D.

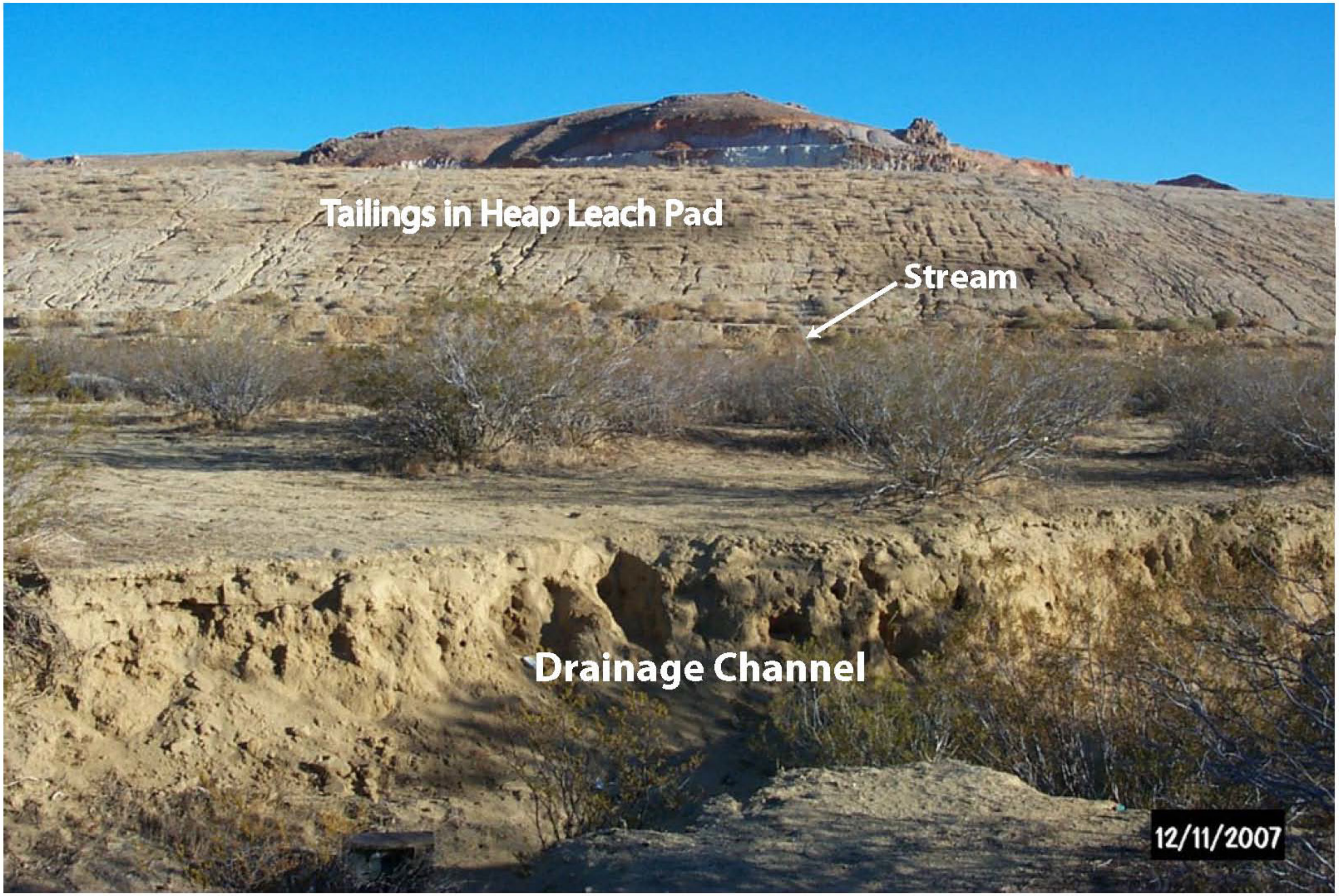


Figure 6. View of tailings in the heap leach pad and the stream at the base of the tailings at the Cactus Queen Gold Mine. In the foreground is a natural drainage channel also sampled in this study.

Figure 7. Sediment in the linear stream constructed in tailings near the base of the heap leach pad at the Cactus Queen Gold Mine.

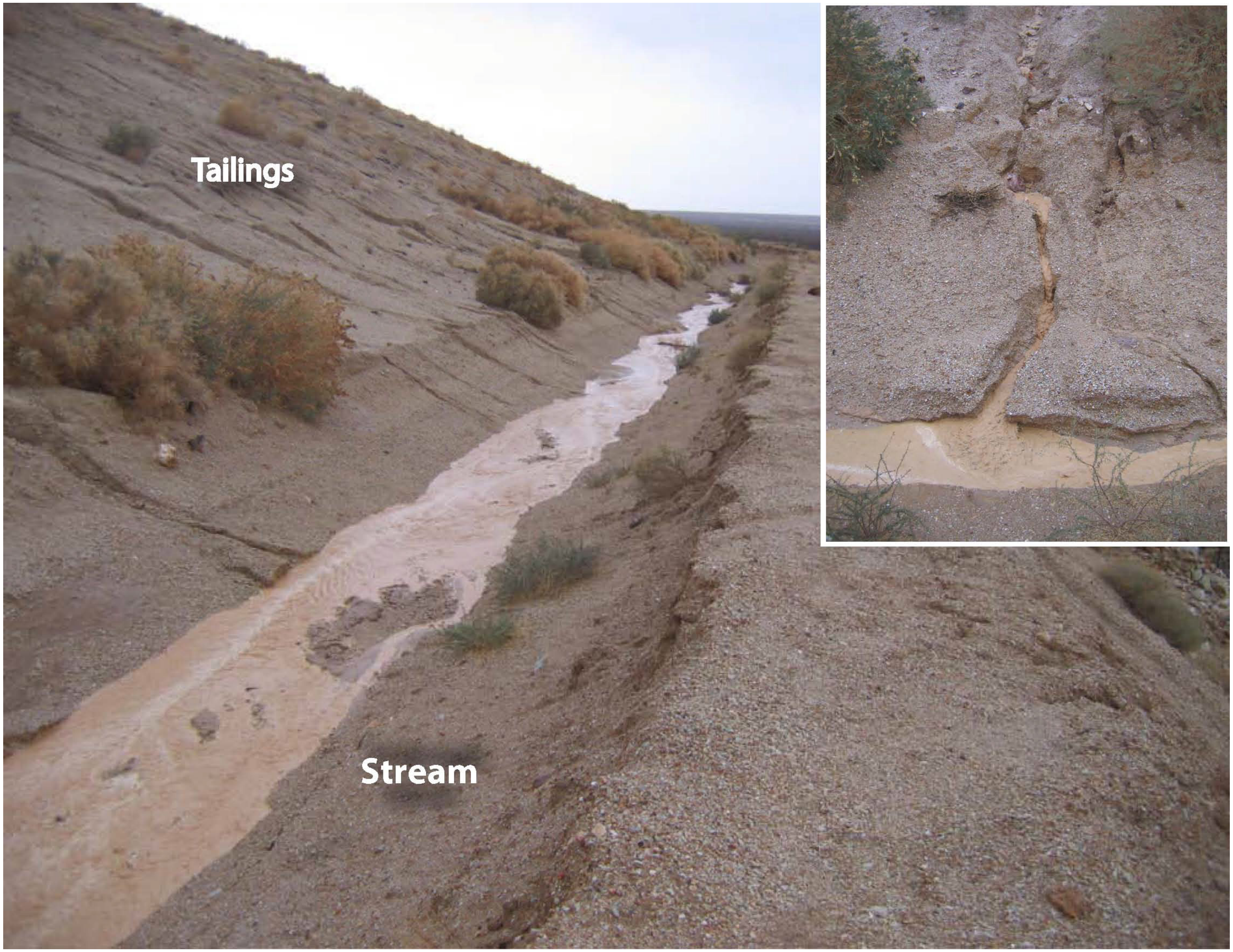


Figure 8. Water in the engineered stream channel collected from runoff on the heap leach pad (insert upper right) at the Cactus Queen Gold Mine was sampled at two locations during a winter storm event. Sample sites for sediment and water in the stream channel are shown in figure 5.

Figure 9. Sediment in drainage channel located to the west of the heap leach pad at the Cactus Queen Gold Mine. Sediment sample sites within the channel are shown in figure 5.

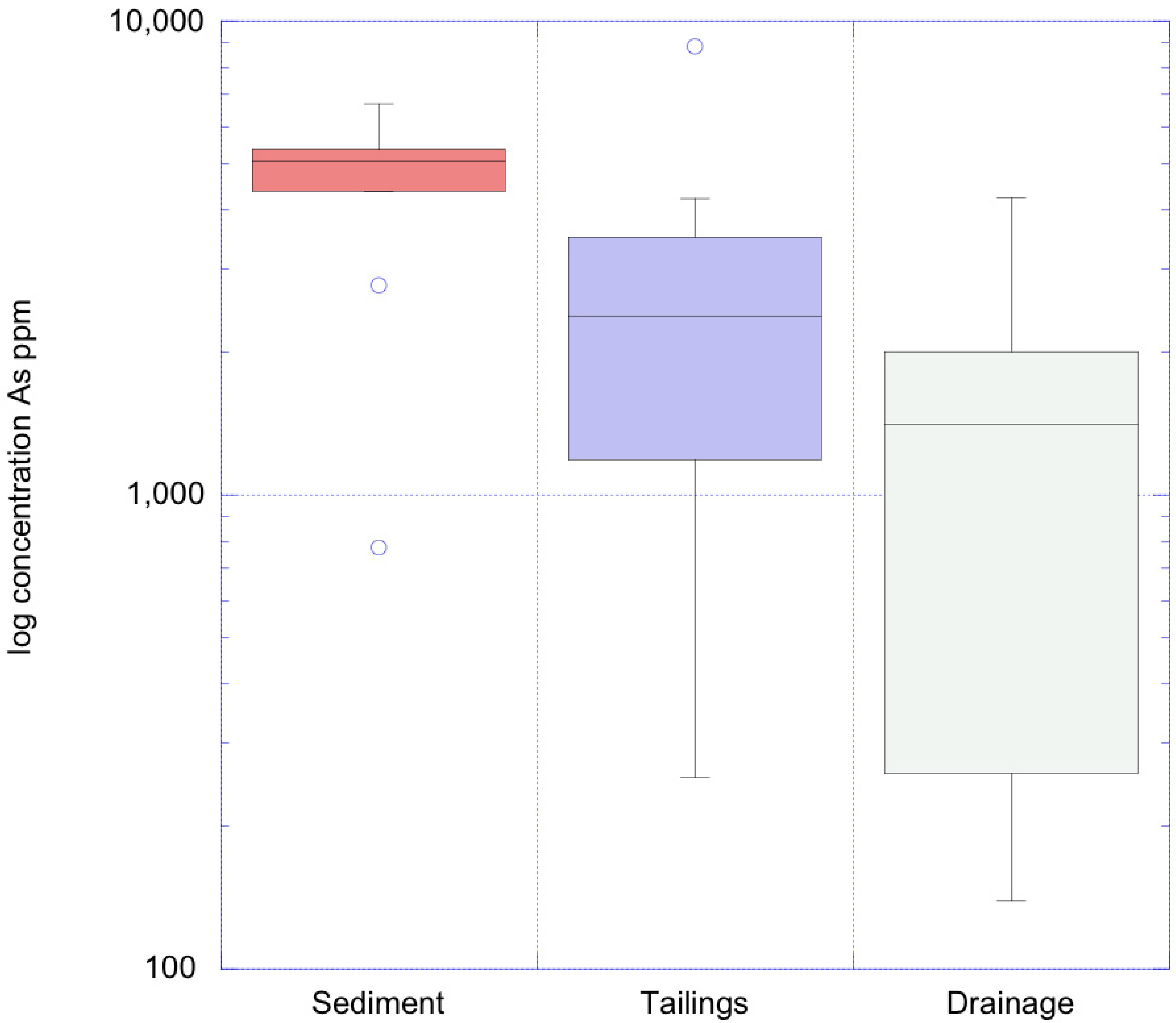


Figure 10. Box plot of As concentration in tailings from the heap leach pad and sediment in the drainage channel and stream at the Cactus Queen Gold Mine.

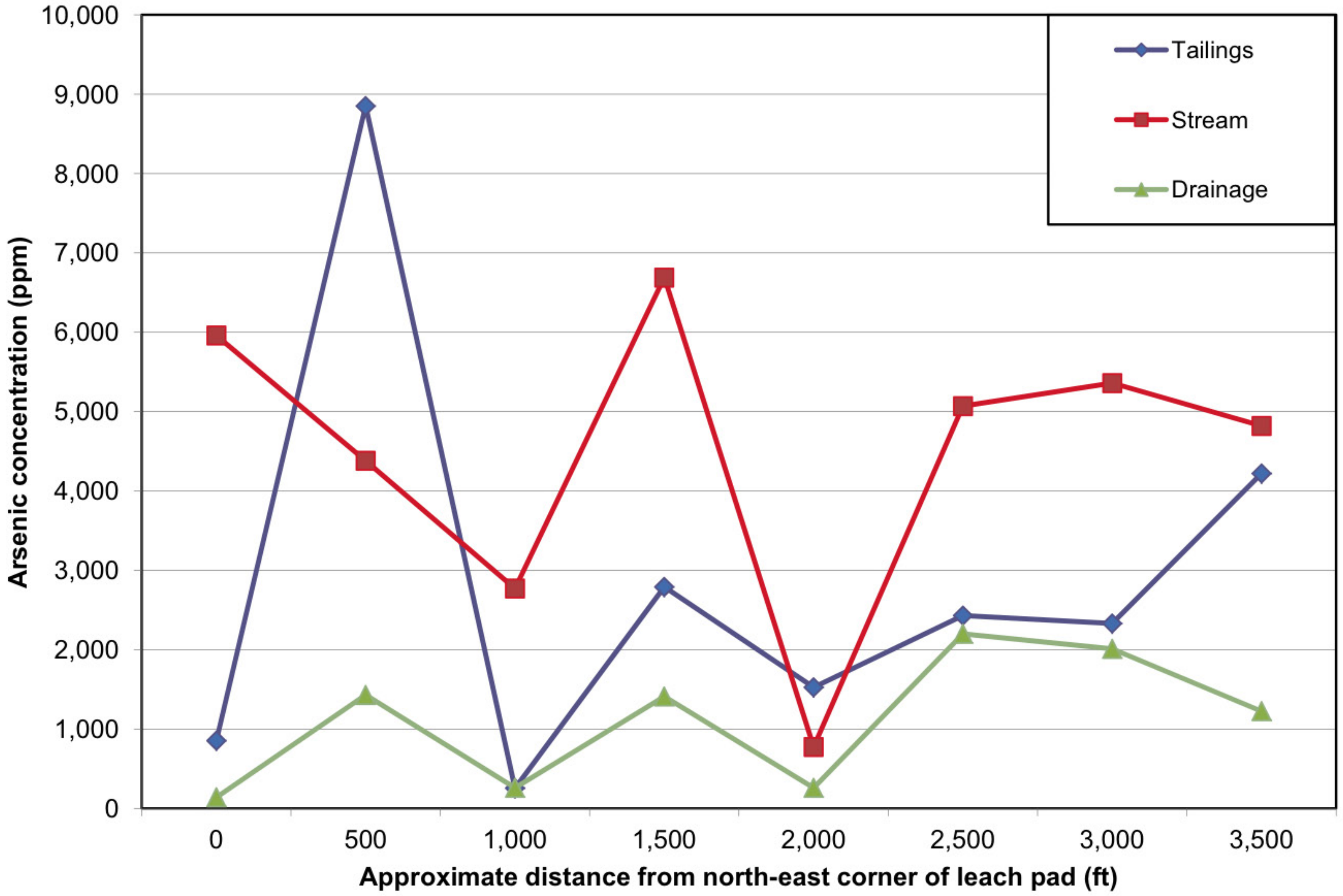


Figure 11. As concentrations as a function of distance in tailings from the heap leach pad, sediment from engineered stream channel, and the natural drainage channel at the Cactus Queen Gold Mine.

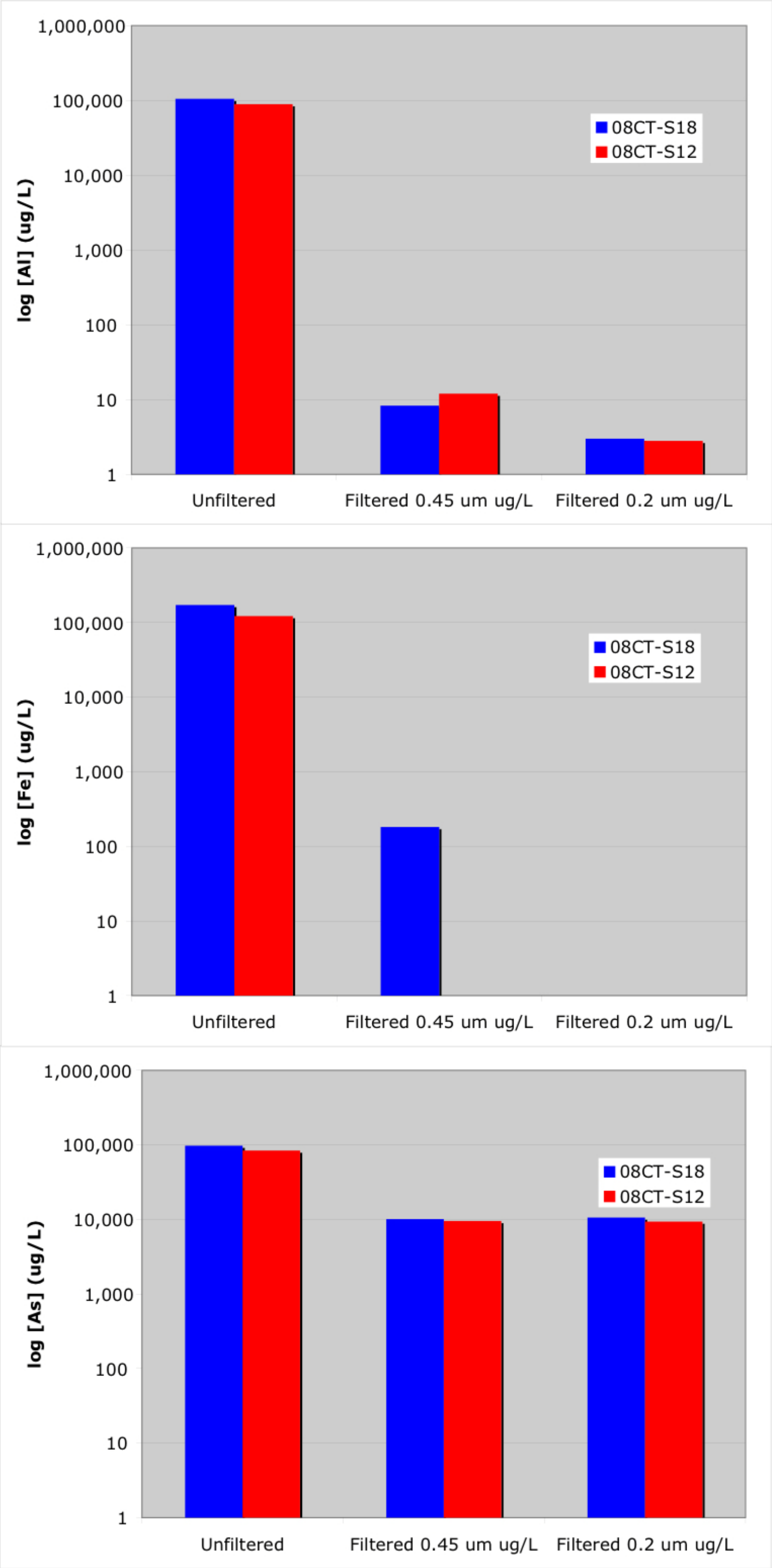
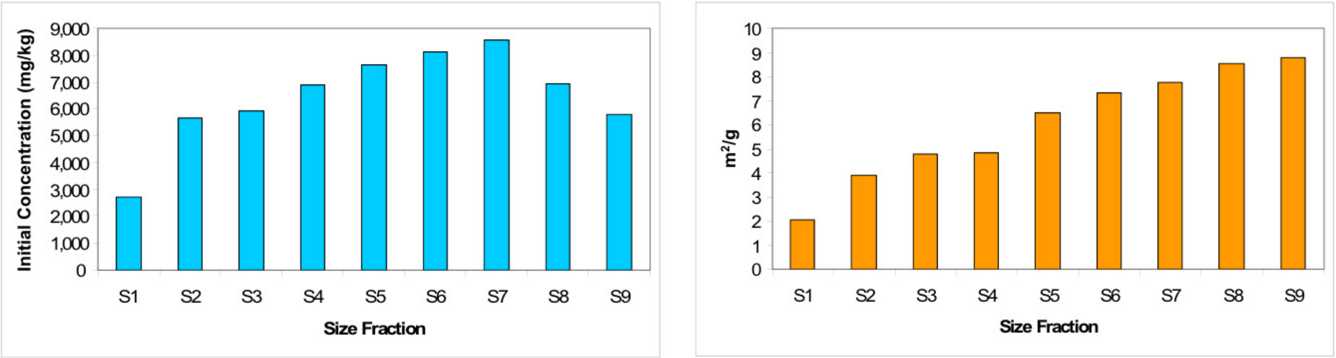
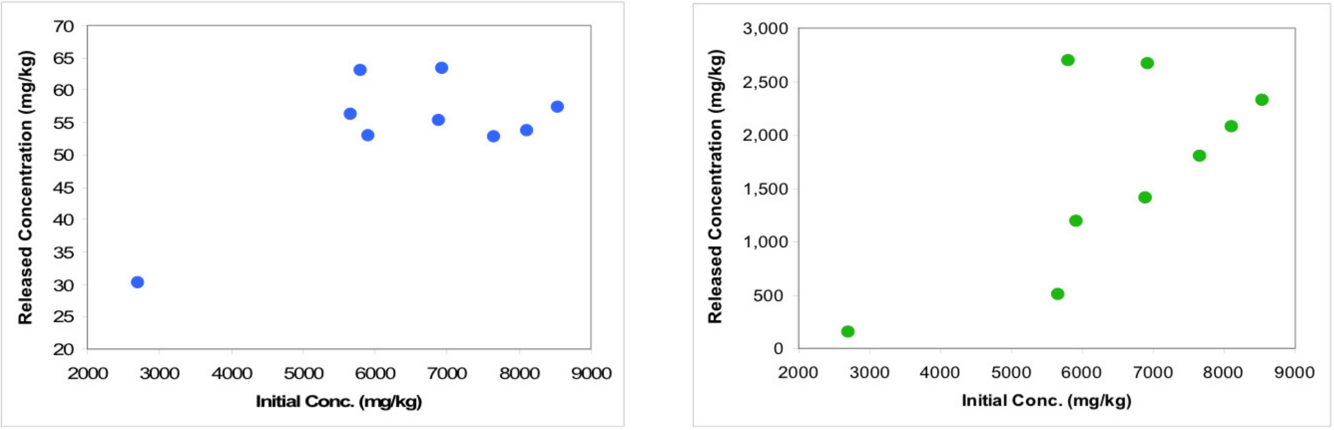


Figure 12. Concentration of selected constituents in unfiltered and filtered rainwater runoff from the Cactus Queen Mine shown on a logarithmic scale. Aluminum and iron (top two panels) decrease dramatically in filtered samples, suggesting both elements are exclusively present in the solid phase. Arsenic (bottom panel) shows a smaller decrease from unfiltered to filtered samples, suggesting a significant proportion (~10%) of the As in the water is dissolved or present as colloidal particles.



A. Initial concentration (mg/kg) of As.

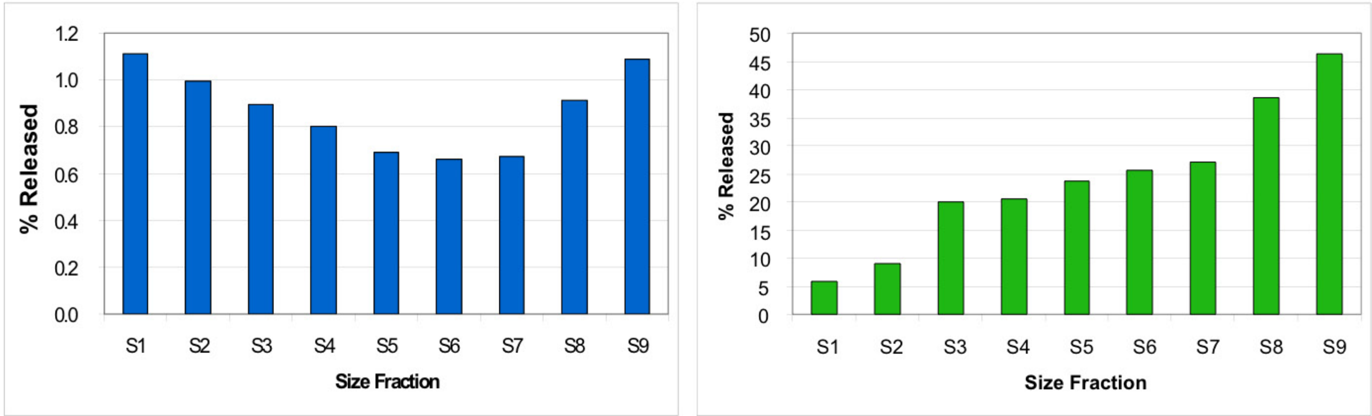
B. Surface area (m^2/g).



C. Released concentrations (mg/kg) of As versus initial concentrations (mg/kg) in water.

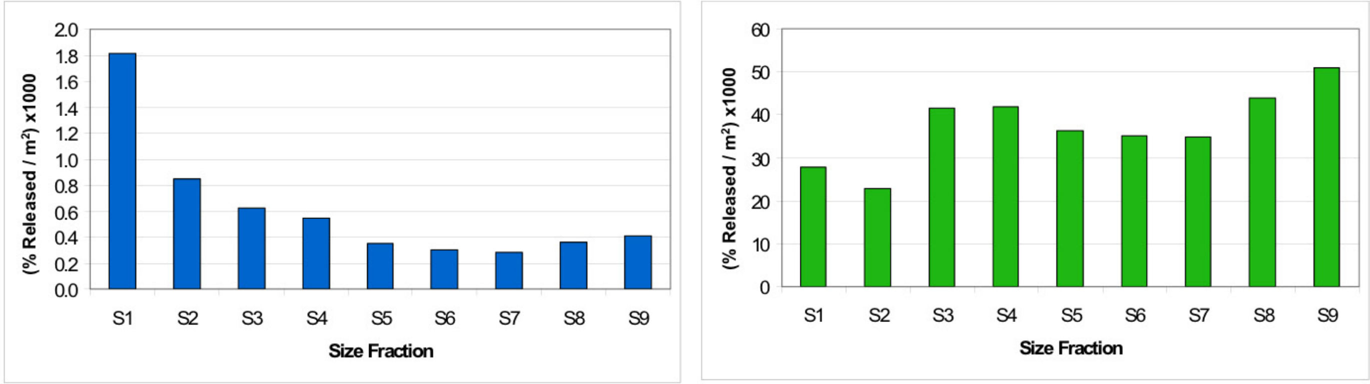
D. Released concentrations (mg/kg) of As versus initial concentrations (mg/kg) in SGF.

Figure 13. Concentration of As in tailings at the Cactus Queen Gold Mine increases with decreasing grain size to the S7 size fraction, then decreases (A) and the surface area of the tailings increases with decreasing grain size (B). The concentration of As in water released during leach experiments increases with increasing concentration of initial As concentration in the tailings (C). The concentration of As released during leach experiments with simulated gastric fluid (SGF) increases with increasing initial As concentration in the tailings (D).



A. Percent As released in water.

B. Percent As released in SGF.



C. Percent As released per m^2 x1000 in water.

D. Percent As released per m2 x1,000 in SGF.

Figure 14. The percentage of As released in water varies as a function of grain size (A) and in simulated gastric fluid (SGF) the percentage released increases linearly with decreasing grain size (B). The percent of As released in water as a function of surface area decreases with decreasing grain size (C) but in simulated gastric fluid the percentage released only gradually increases with decreasing grain size (D).

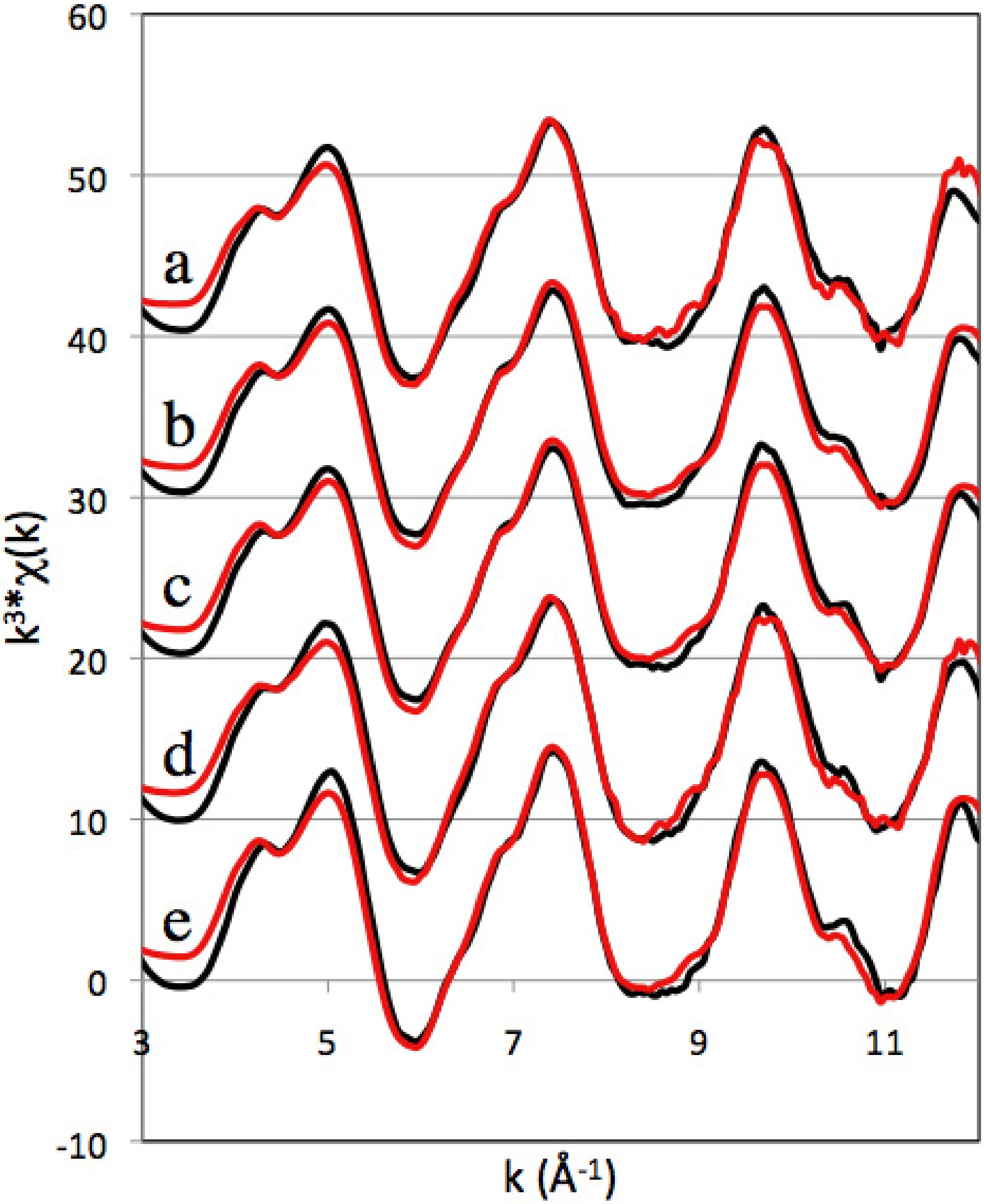


Figure 15. Extended x-ray absorption fine structure (EXAFS) spectroscopy raw spectra (black) and linear combination fits (red) for size fractions of the 08CT_T1 sample from the Cactus Queen Gold Mine, specifically the (a) S3, (b) S5, (c) S7, (d) S9, and (e) S9 (residual after simulated gastric fluid (SGF) extraction). See table 7 for quantitative fitting results.

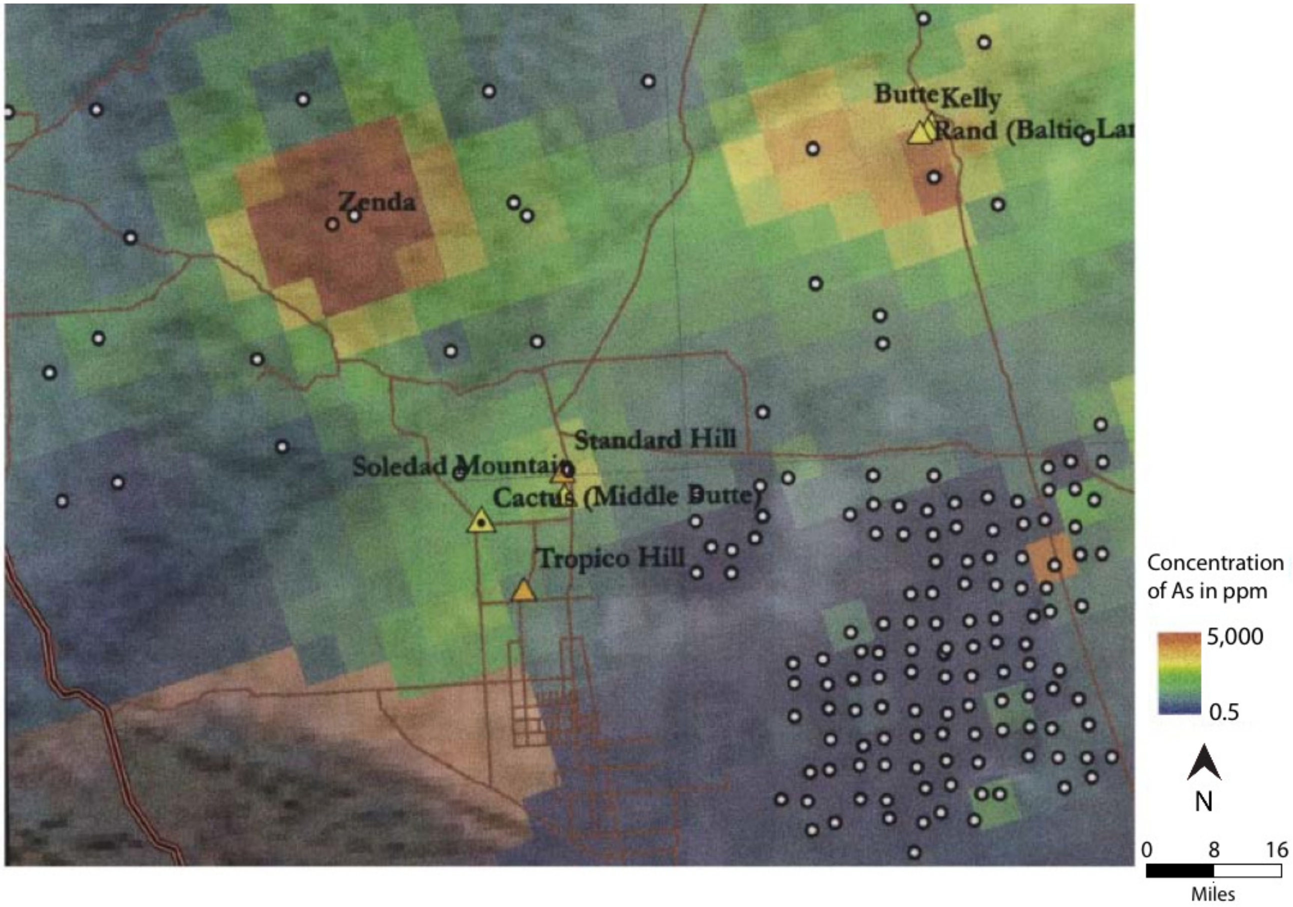


Figure 16. Color contour map of As concentration in stream sediment and soil samples from the NURE sample set. Sample locations show by white circles. Highest concentrations of As shown by red and orange colors (maximum As concentration 5,000 ppm) and low As concentrations shown by blue and green colors (lowest As concentration 0.50 ppm). The locations of the Cactus Queen mine Au and other Au-Ag deposits in the western Mojave Desert are shown by triangles.