SHANNON & WILSON
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

April 13, 2020

Mr. Roger Burggraf
830 Sheep Creek Road
Fairbanks, Alaska 99709-6130

RE: POST-EXCAVATION SAMPLING, SECONDARY TAILINGS IMPOUNDMENT REVISION 2, GRANT MINE, ESTER DOME, ALASKA, ADEC FILE #100.38.182, HAZARD ID 731

Dear Mr. Burggraf,

We are pleased to present this revised letter report with the results of our confirmation sampling following the removal of arsenic-rich tailings from the Secondary Tailings Impoundment (STI) at the Grant Mine. The conclusions supersede those provided in previous versions of this letter report. The tailings removal was part of the overall closure of the primary tailings impoundment at the Grant Mine on Ester Dome near Fairbanks, Alaska (Figure 1). Our post-excavation sampling methodology was outlined in our letter *Post-Excavation Sampling Plan, Secondary Tailing Impoundment, Grant Mine, Ester Dome, Alaska, ADEC File #100.38.182, Hazard ID 731* dated October 18, 2019. The Alaska Department of Environmental Conservation (ADEC) approved our sampling approach in an e-mail dated October 22, 2019.

BACKGROUND

Roger Burggraf has held the mining claims since 1972. Between 1980 and 1983, Silverado operated a pilot mill at the site for metallurgical testing. The pilot mill recovered free gold through gravity separation; no cyanide was used during the operation of the pilot mill. Tailings from the pilot mill were placed in the initial tailings area also known as the Secondary Tailings Impoundment (Figure 2). Records show 4,723 dry tons of ore were processed through the pilot mill from 1980 through 1983. The volume of the tailings generated would be about 2,100 cubic yards assuming a conservative specific gravity 2.65 grams/cubic centimeter (specific gravity of quartz). According to Mr. Burggraf, cyanide was not used during the pilot study and therefore was not discharged to the STI.

Based on our field observations and a 1986 aerial photograph, the STI was an unlined, bermed area prior to the placement of the tailings. It appears that the organic mat was stripped and several feet of the underlying soil was pushed to the perimeter of the STI to create the berms. The tailings occupied about 2,200 square feet with a thickness of up to 4 feet. Since the tailings were deposited as a slurry, the coarser sandy tailings accumulated near the discharge point to the north and finer grained material flowed further south.

Shannon & Wilson prepared a *Revised Site Characterization Report, Grant Mine Tailings Impoundment, 1.2 Mile St. Patrick Road, Fairbanks, Alaska*, dated August 2019, and concluded the tailings in the secondary impoundment exceeded ADEC human health cleanup levels for arsenic and were not contained. Samples of the tailings and fine-grained runoff contained arsenic, antimony, and silver exceeding the ADEC cleanup level. In addition, the soil samples had Synthetic Precipitation Leaching Procedure (SPLP) exceedances for arsenic, antimony, and lead.

To mitigate the exposure risk, Shannon & Wilson recommended excavating the tailings in the STI and moving them to the primary tailings impoundment before capping the primary tailings impoundment. In their letter dated September 19, 2019, the ADEC agreed with Shannon & Wilson's recommendation.

Mr. Burggraf revised his Annual Placer Mining Application (APMA #F16-7130) to include this tailings removal.

FIELD ACTIVITIES

Mr. Burggraf used an excavator, front-end loader, and dump truck to remove of the tailings from the secondary impoundment between October 8, 2019 and October 21, 2019. The removal was based on visual segregation of the tailings from the underlying native silt. Exhibit 1 illustrates the difference between the dark brown native silt on the left and the tan runoff material on the right. The excavation area was approximately 20,000 square feet. Based on this area and an average depth of removal of 3.5 feet, the volume of tailings removed was about 2,500 cubic yards. Mr. Burggraf placed the tailings into the center of the primary tailings impoundment. Following the removal, we observed the limits of the excavation and determined the tailings had been removed to the extent practicable.

Exhibit 1: Comparison of native soil (left) with tailings (right) within the secondary tailings impoundment.

Confirmation Sampling

To assess the concentrations of RCRA (Resource Conservation and Recovery Act) metals at the limits of the excavation, and to confirm the complete removal of the tailings, we used a combination of Incremental Sampling Methodology (ISM) and discrete sampling. ISM samples were collected to characterize the surface area of the tailings excavation while discrete samples were collected from locations around the perimeter of the tailings excavation. We collected the soil samples on October 22 and 23, 2019.

Incremental Sampling

We divided the tailings excavation into three decision units (DUs), as shown in Figure 2. Each DU was then divided into 30 equivalently sized sample units (SU), aligned in a grid configuration. A random number generator was used to select X and Y coordinates within these SUs from which a subsample was collected. We used TerraCore Sampler™ to collect a 30- to 35-gram subsample from the random location selected within each SU. The subsamples were then composited into a single soil sample container representing the entire DU. Photos of the sampling grid and the sampling process are attached.

We submitted the composited samples to SGS North America for sample processing which included drying, sieving, and random subsampling. SGS analyzed the processed sample for RCRA Metals plus antimony by EPA Method 6000/7000 Series.

We collected replicate ISM samples from DU3 to verify the representativeness of the sampling methodology. To accomplish this, three sets of random coordinates were generated for DU3. Subsamples were collected from these three locations within each of the 30 increments of DU3. These subsamples were then composited into three unique soil masses and submitted to the laboratory as three distinct ISM samples. We assessed the representativeness of the data by calculating the relative standard deviation (RSD) for each of the detected analytes in the replicate ISM samples. Per ADEC guidance, we consider an RSD of less than or equal to 30% to meet our data quality objectives (DQOs).

The following guidance documents were used to develop our approach to multi-increment sampling:

- *Draft Guidance on Multi Increment Soil Sampling*, Alaska Department of Environmental Conservation, March 2009.
- *Incremental Sampling Methodology*, The Interstate Technology & Regulatory Council, February 2012.

Discrete Sampling

We collected three discrete samples from the area around the small body of water in the STI and six discrete samples plus a field duplicate sample from around the perimeter of the STI excavation. The purpose of these samples was to provide confirmation to show that the extent of the tailings did not extend to these areas. We collected the samples from a depth of six inches below ground surface. We submitted the samples to SGS North America, Inc. (SGS) for the analysis of RCRA Metals plus antimony by EPA Method 6000/7000 Series.

ANALYTICAL RESULTS

The analytical results were compared with ADEC cleanup levels in 18 AAC 75 Table B1 Method Two – Human Health (Under 40-Inch Zone) and are summarized in Table 1. Arsenic was the only metal that exceeded the ADEC human health cleanup levels, and arsenic exceeded the cleanup level in all but one of the 12 samples we collected.

Barium, chromium, and lead were detected in all samples below the ADEC Human Health cleanup level. Cadmium was detected below the cleanup level in about half of the samples and silver was detected in two samples; the remainder of samples had estimated detections for cadmium and silver below the laboratory limit of quantitation (LOQ). Mercury and selenium were detected at estimated concentrations below the LOQ in all samples. Antimony was detected at an estimated concentration below the LOQ in two samples and was not detected in the remainder.

STATISTICAL ANALYSIS OF BACKGROUND METALS

To assess if the STI was excavated sufficiently and that the area does not pose a risk over background conditions for the area, the 95-percent upper confidence limit (UCL) for the ISM samples collected at the three decision units were compared to the background 95-precent UCLs. Statistical evaluations were conducted using the EPA statistics software package ProUCL® Version 5.1. We first provide evidence for establishing background, then calculate the background 95-percent UCLs, and finally establish 95-percent UCLs for the ISM samples to complete this assessment.

The data were first segregated into groups: Grant Mine limit-of-excavation ISM samples, Grant Mine discrete grab samples, Ester Dome background samples (B horizon), and Ester Dome background samples (A_1 horizon). Statistical assessments were conducted in accordance with DEC Technical Memorandum *Guidance for Evaluating Metals at Contaminated Sites* (August 2018) and EPA's *Guidance for Comparing Background and Chemical*

Concentrations in Soil for CERCLA Sites (EPA 540-R-01-003; September 2002) document. Data reduction was conducted in accordance with the DEC Technical Memorandum *Treatment of Non-Detect Values, Data Reduction for Multiple-Detections and Comparison of Quantitation Limits to Cleanup Values* (April 2017). The ISM field-triplicate samples were all used for statistical evaluations. Field-duplicate samples were reduced by only reporting the highest detected result for statistical evaluations.

As mentioned previously, the purpose of the discrete grab samples was to provide confirmation to show that the extent of the tailings did not extend to these areas sampled. The detected analytes were not present at concentrations similar to initial testing under the existing tailing areas. The EPA's *Guidance for comparing Background Chemical Concentrations in Soil for CERCLA Sites* dated September 2002 recommends that selecting "the locations of the background samples must be areas that have not received contamination from the site, but that have the same basic characteristics as the medium of concern at the site. Since these samples were collected from similar horizons as those collected from the STI and did not show evidence of contamination from the site, we consider the discrete grab samples to be representative of background conditions for this site.

This is further supported by the Ester Dome background soil data from the A1 (surface) and B (subsurface) soil horizons published by the University of Alaska Fairbanks Institute of Water Resources (Hawkins et al.,1982; Figure 3 and 4). The data reported by Hawkins is similar to the discrete grab samples we present here as background. While the quality control information was not presented in the Hawkins report, discussions with the author identified the laboratory was contracted by the USGS to perform the study and was required to follow the necessary laboratory protocols of the time. The laboratory protocols included analysis of laboratory quality control samples (calibration, method blanks, blank spikes, matrix spikes, etc.). However, this information is not available in the report and the data is used here as a qualitative comparison of our background data set and the ISM data sets.

First, we compared the discrete grab samples from the Grant Mine and qualitatively compared the data Ester Dome background soil data from the A_1 (surface) and B (subsurface) soil horizons using box plots (Figure 5). Box plots are used as a cursory evaluation of the data and comparison of the data sets. The upper and lower limits of the boxes show the data divided into quartiles (the upper and lower 25th percentiles of the data) and the lines near the middle of the boxes represent the median values. The "whiskers" extending from the ends of the boxes represent the maximum and minimum values. Data that fall outside the "whiskers" are assumed to be outliers and depicted as single points outside the "whiskers."

A review of the box plots show that the data are similar with some elevated data above 100 mg/kg in each data set. The box plots suggest that these data are statistical outliers. However, since similar data is observed in all three background data sets and a review of the analytical QC information and our field sheets do not provide justification for removing the Grant Mine discrete grab sample data, these data were not removed for further statistical assessment.

We then conducted a non-parametric evaluation of the 95% UCL (95% Chebyshev (Mean, SD)) of the mean for the three background data sets (Exhibit 2), because the analytical data for the background data sets do not follow a discernable pattern. The normal 95% UCLs are a presented in Exhibit 2 for comparative purposes regardless of whether or not the data follow that particular distribution. The non-parametric 95% UCL for the A_1 soil horizon is 63.16 mg/kg arsenic and 84.27 mg/kg for the B soil horizon. The non-parametric 95% UCL for the discrete soil samples from the Grant Mine is 76.07 mg/kg arsenic.

Exhibit **2**: Summary of 95% UCL Statistics

Location Description	Mean[1] (mg/kg)	Standard Deviation[1] (mg/kg)	Coefficient of Variation	95% Chebyshev UCL[2]	Normal[3]	**95% Student's t-Test UCL[3] (mg/kg)**
Grant Mine – DU1	13.8	NA	NA	19.9	NA	17.88
Grant Mine – DU2	55.1	NA	NA	59.18	NA	59.18
Grant Mine – DU3	18.0	2.4	0.136	24.10	Yes	22.08
Grant Mine background– Discrete	27.6	33.4	1.21	76.07	No	48.25
Ester Dome background– Horizon A_1	28.1	30.1	1.07	63.16	No	42.32
Ester Dome background– Horizon B	45.4	33.4	0.736	84.27	No	61.17

NOTES:

Statistical analyses were obtained using the EPA statistics software ProUCL Version 5.1. Significant digits were reported without modification from the ProUCL software.

1 The mean and standard deviations were calculated using the final data set.

2 The 95% Chebyshev (mean, sd) UCL was used for statistical assessment to compare the Grant Mine ISM data to the background data sets.

3 The UCLs for normally distributed data (95% Student's t-Test) are presented for comparison purposes. Highlighted cells do not follow the given distribution and should be considered unusable for the purposes of statistical comparison.

Triplicate samples were collected for the third decision unit (DU3). A 95% UCL was calculated for DU3 and is presented in Exhibit 2. Based on conversations with ADEC, the standard deviation (SD) can be used for the remaining decision units to create a 95% UCL for these areas. From the ProUCL User Manual, the formula for calculating a 95% UCL is presented in Exhibit 3.

Exhibit 3: Equation for 95-Percent UCL

Equation	Variable and Definition	
$UCL_{95\%} = \mu + t\left(\frac{SD}{\sqrt{n}}\right)$	$UCL_{95\%}$	95% Upper Confidence Limit
	μ	Mean
	t	Student's t-value with n-1 degrees of freedom
	SD	standard deviation
	n	number of data points

We assume the "true" mean for the DU1 and DU2 is the ISM sample result and the t and n used for DU3 will are used for these calculations (t = 2.99 and n = 3). These data are presented in Exhibit 2 alongside the background 95% UCLs. There is sufficient evidence to suggest at the mean for the Grant Mine data from the three decision units are not statistically greater than the means of the background data sets. Being that the 95% UCLs for the decision units do not exceed the background 95% UCLs, we conclude that the soil collected from the three Grant Mine decision units do not exceed background conditions for the site and overall Ester Dome areas.

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA)/quality control (QC) procedures assist in producing data of acceptable quality and reliability. Analytical results for laboratory QC samples were reviewed and a QA assessment of the data was conducted as the data were generated. The QA review procedure provided documentation of the accuracy and precision of the analytical data and confirmed that the analyses were sufficiently sensitive to detect analytes at levels below suggested action levels or regulatory standards, where such standards exist. Shannon & Wilson conducted a QA assessment of SGS laboratory report 1199895, following the ADEC's laboratory data review checklist (LDRC).

Sample Handling

Soil samples collected by Shannon & Wilson personnel were hand delivered to the SGS receiving office in Fairbanks, Alaska. SGS then shipped the samples to their laboratory in

Anchorage, Alaska to perform the requested analyses, using the methods specified in the Chain-of-Custody (COC) records.

Sample-receipt forms provided by SGS were reviewed and checked to verify samples were received in good condition and within the acceptable temperature range. The ADEC considers samples received free of ice and at temperatures between 0 °C and 6 °C as acceptable.

Samples were generally received in good condition, properly preserved, and within the acceptable temperature range upon arrival at the laboratory. COC records were also reviewed to confirm information was complete, custody was not breached, and samples were analyzed within the acceptable holding times required by the requested analytical methods.

Analytical Sensitivity and Blanks

Reported limits of detection (LODs) for regulated analytes were below applicable ADEC cleanup levels for the samples included with this work order.

Laboratory method blanks were analyzed in conjunction with samples collected for this project to check for contributions to the analytical results possibly attributable to laboratory-based contamination. There were no method blank detections for the reported results included with this data set.

Laboratory QC Samples

In order to evaluate the accuracy and precision of the analytical method, the laboratory analyzed QC samples for each preparatory batch. These QC samples consist of laboratory control samples (LCS), matrix spike (MS) and MS duplicate (MSD) samples, and bench spike samples. We reviewed the results of the laboratory QC samples to verify that the reported accuracy and precision were within acceptable limits. We identified several QC irregularities relating to MS/MSD recovery. However, the none of the identified irregularities had an adverse effect on data quality/usability. All instances of analyte recovery failure in the MS/MSD samples were accompanied by LCS and/or bench spike samples which demonstrated method accuracy for all reported analytes.

ISM Sample Representativeness

The amount of agreement between the detected results of the replicate ISM samples was evaluated by calculating the RSD. The RSD is defined as:

$$RSD(\%) = \frac{Standard\ Deviation}{Arithmetic\ Mean\ of\ Target\ Analyte} \times 100$$

The RSD for each detected target analyte was compared to the project specific DQO of 30% maximum deviation. Our review revealed that all target analytes reported for the replicate ISM samples met this DQO.

DATA QUALITY SUMMARY

Based on the methods outlined in our Grant Mine Tailings Impoundment Closure approved work plan, the samples detailed in the SGS laboratory report 1199895 are considered to be representative of site conditions at the locations and times they were obtained. The quality of the analytical data for these samples does not appear to have been compromised by analytical irregularities.

DISCUSSION

Many investigators have documented anomalous arsenic and other metals concentrations in surface and subsurface soil, rock, and groundwater on and around Ester Dome.

Samples collected from the limits of the excavation following the removal tailings from the STI contained arsenic in concentrations exceeding the human health cleanup levels. The concentrations present in the samples are comparable to those detected in samples collected by others in adjacent areas on Ester Dome. Hawkins, et al. (1982) collected soil from various soil horizons along the ridge to the northwest of the Grant Mine (Figure 3). Arsenic in sediment samples they collected from streams draining the eastern side of Ester Dome ranged from 350 mg/kg to 1,389 mg/kg. Stevens et al. (1969) collected hundreds of soil and rock samples along Ester Dome Road after it was constructed in 1968; arsenic was detected as high as 4,500 mg/kg. According to Verplanck et al. (2003), Ester Dome is known to contain groundwater with high dissolved arsenic concentrations in excess of 1 milligram per liter (mg/L).

The mean concentration of arsenic detected in our ISM soil samples from the three decision units beneath the STI are less than the mean soil arsenic concentration for the site (the discrete soil samples) and in the A_1 and B soil horizons reported by Hawkins et al. Based on the results of the regional and local studies, we believe that the arsenic exceedances measured in soil samples collected from the STI following the removal of the tailings are consistent with naturally occurring background levels. In addition, there are naturally occurring high concentrations of arsenic and other metals in groundwater that make it non-potable.

CONCLUSIONS AND RECOMMENDATIONS

The observations we made and samples we collected from the base of the excavation and the areas adjacent to the excavation show Mr. Burggraf was successful in moving the tailings from the STI to the primary tailings impoundment. The combined tailings will be capped to during the closure of the impoundment. The concentration of arsenic detected in the samples from the limits of the excavation were comparable to the background concentrations expected on Ester Dome. We recommend DEC considers cleanup complete status for the STI.

Sincerely,

SHANNON & WILSON

Dana Fjare

Dana Fjare
Environmental Scientist

MSL:CBD/msl

Enc. References
Table 1. Grant Mine Tailings Impoundment Analytical Soil Results October 2019
Figure 1. Site Location
Figure 2. Decision Units and Discrete Sample Locations
Figure 3. Hawkins et al. 1982 Background Soil Sample Locations
Figure 4. Hawkins et al. 1982 Background Data
Figure 5. Box Plots
ProUCL Statistical Input and Output Summaries
Field Forms
SGS Laboratory Report 1199895
ADEC Laboratory Data Review Checklist
Hawkins, D.B., R.B. Forbes, C.I. Hok, and D. Dinkel. *Arsenic in the Water, Soil, Bedrock*

REFERENCES

Alaska Department of Environmental Conservation. Technical Memorandum *Guidance for Evaluating Metals at Contaminated Sites*, August 2018.

Alaska Department of Environmental Conservation. Technical Memorandum *Treatment of Non-Detect Values, Data Reduction for Multiple-Detections and Comparison of Quantitation Limits to Cleanup Values*, April 2017.

Interstate Technology Research Council. *Incremental Sampling Methodology,* February 2012.

Hawkins, D.B., R.B. Forbes, C.I. Hok, and D. Dinkel. *Arsenic in the Water, Soil, Bedrock, IWR-103 and Plants of the Ester Dome Area of Alaska.* University of Alaska Fairbanks Institute of Water Resources, 1982, IWR-103.

Stevens, D.L., R.B. Forbes, and D.B. Hawkins. *Gold Anomalies and Magnetometer Profile Data Ester Dome Area, Fairbanks District, Alaska.* University of Alaska Fairbanks, 1969.

U.S. Geological Survey. *Element Concentrations in Soils and Other Surficial Materials of Alaska, 1988.*

U.S. Environmental Protection Agency. *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*. EPA 540-R-01-003, September 2002.

Verplanck, P.L., S.H. Mueller, E.K. Youcha, R.J. Goldfarb, R.F. Sanzolone, R.B. McCleskey, P.H. Briggs, M. Roller, M. Adams, and D.K. Nordstrom. *Chemical Analyses of Ground and Surface Waters, Ester Dome, Central Alaska, 2000-2001*. U.S. Geological Survey, 2003.

TABLE 1
GRANT MINE SECONDARY TAILINGS IMPOUNDMENT ANALYTICAL SOIL RESULTS
OCTOBER 2019

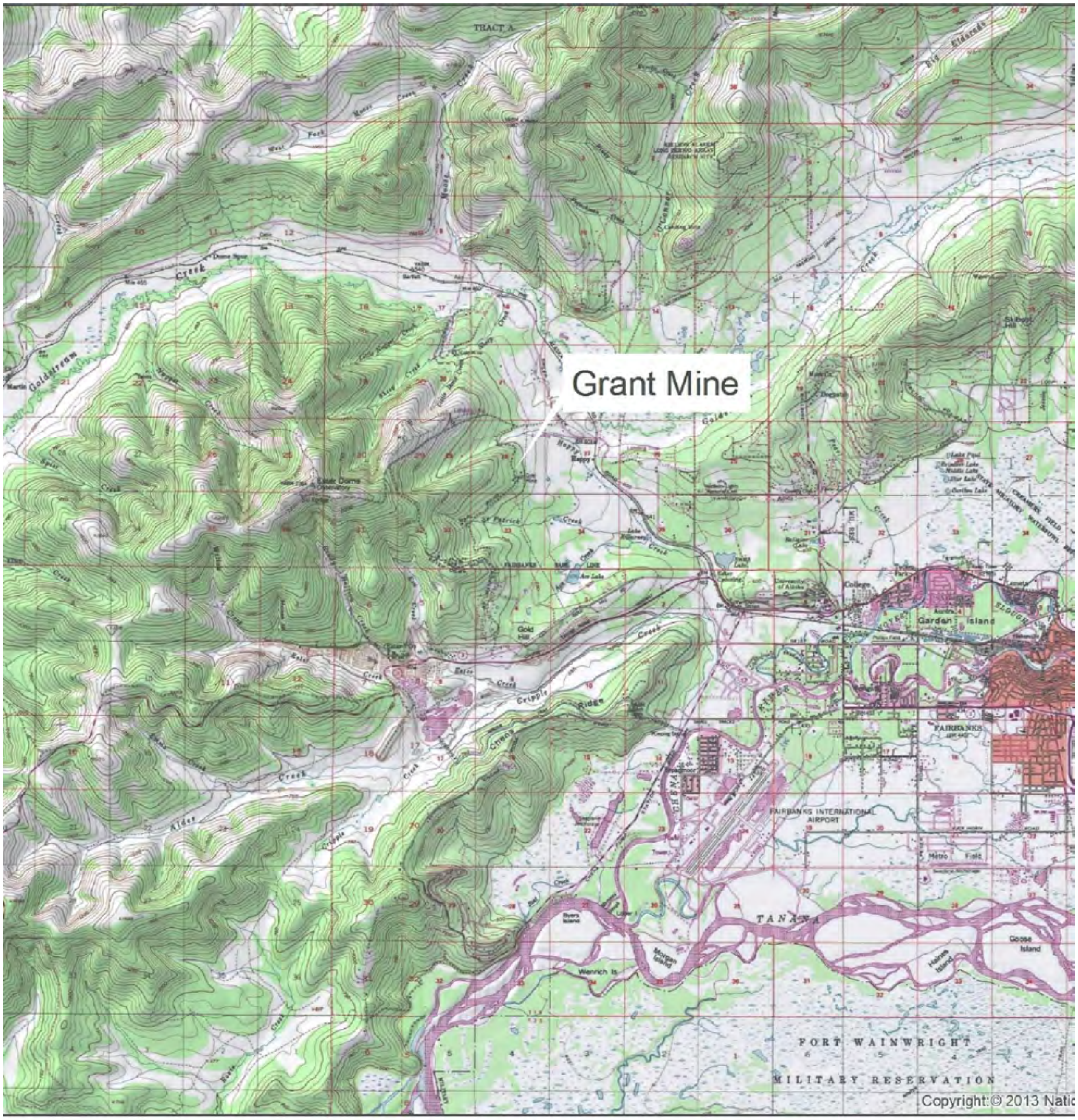
		Antimony	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
	ADEC Cleanup Level →	41 mg/kg	8.8 mg/kg	20,000 mg/kg	92 mg/kg	100,000 mg/kg	400 mg/kg	32 mg/kg	510 mg/kg	510 mg/kg
19GM-DU1		<0.560	**13.8**	184	0.268	26.8	9.85	0.0496 J	0.733 J	0.115 J
19GM-DU2		0.601 J	**55.1**	174	0.251	26.8	14.1	0.0436 J	0.705 J	0.28
19GM-DU3	Replicate A	<0.565	**15.2**	178	0.26	26.2	11.6	0.0400 J	0.741 J	0.117 J
	Replicate B	<0.565	**18.9**	205	0.284	26.5	11	0.0401 J	0.694 J	0.130 J
	Replicate C	<0.565	**19.8**	176	0.235	25.9	9.95	0.0454 J	0.631 J	0.137 J
	95% UCL	<0.565	**24.1**	227	0.321	27.0	12.95	0.0496 J	0.828 J	0.154 J
GM19-1		<0.570	**11.5**	194	0.161 J	28.6	9.46	0.0407 J	0.607 J	0.118 J
GM19-10		<0.545	**15.0**	184	0.247	25.7	10.3	0.0409 J	0.464 J	0.136 J
GM19-2		<0.580	**9.09**	183	0.252	31.4	9.75	0.0468 J	0.518 J	0.101 J
GM19-3		0.763 J	**110**	171	0.177 J	28.9	15.1	0.0629 J	0.740 J	0.324
GM19-4		<0.595	**50.0**	152	0.157 J	31.5	8.82	0.0721 J	0.836 J	0.150 J
GM19-5		<0.565	8.22	168	0.188 J	28.3	9.38	0.0423 J	0.544 J	0.127 J
GM19-6		<0.575	**13.9**	209	0.205 J	28.8	9.53	0.0332 J	0.696 J	0.117 J
GM19-7		<0.620	**12.3**	216	0.217 J	30.4	9.41	0.0349 J	0.527 J	0.0899 J
GM19-8		<0.575	**14.6**	211	0.163 J	28.7	9.94	0.0323 J	0.644 J	0.113 J
GM19-9		<0.565	**14.8**	186	0.254	26.8	10.4	0.0450 J	0.517 J	0.144 J

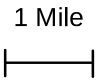
Notes: Analytical results reported from SGS North America, Inc. work order 1199895.

ADEC Soil Cleanup Levels from 18 AAC 75.341 Table B1 Method Two - Human Health (Under 40-Inch Zone)

Sample *GM19-10* is a field duplicate of sample *GM19-1* .

ADEC	Alaska Department of Environmental Conservation
mg/kg	milligrams per kilogram
UCL	upper confidence limit
J	Estimated concentration, detected greater than the limit of detection (LOD) and less than the limit of quantitation (LOQ). Flag applied by the laboratory.
<	Analyte was not detected; reported as <LOD.
Bold	Detected concentration exceeds the ADEC Human Health (Under 40-Inch Zone) soil cleanup level.





Grant Mine Secondary Tailings Impoundment
Post-Excavation Sampling
Ester Dome, Alaska

SITE LOCATION

April 2020

31-1-20094 R2

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Figure 1

Quantum Spatial - June 14, 1986

LEGEND

Discrete Sample Locations

●	Excavation Perimeter
△	Surface Water Body Perimeter
🟩	Decision Units
🟥	Excavation Limits

Grant Mine Secondary Tailings Impoundment
Post-Excavation Sampling
Ester Dome, Alaska

DECISION UNITS AND DISCRETE SAMPLE LOCATIONS

April 2020
31-1-20094 R2

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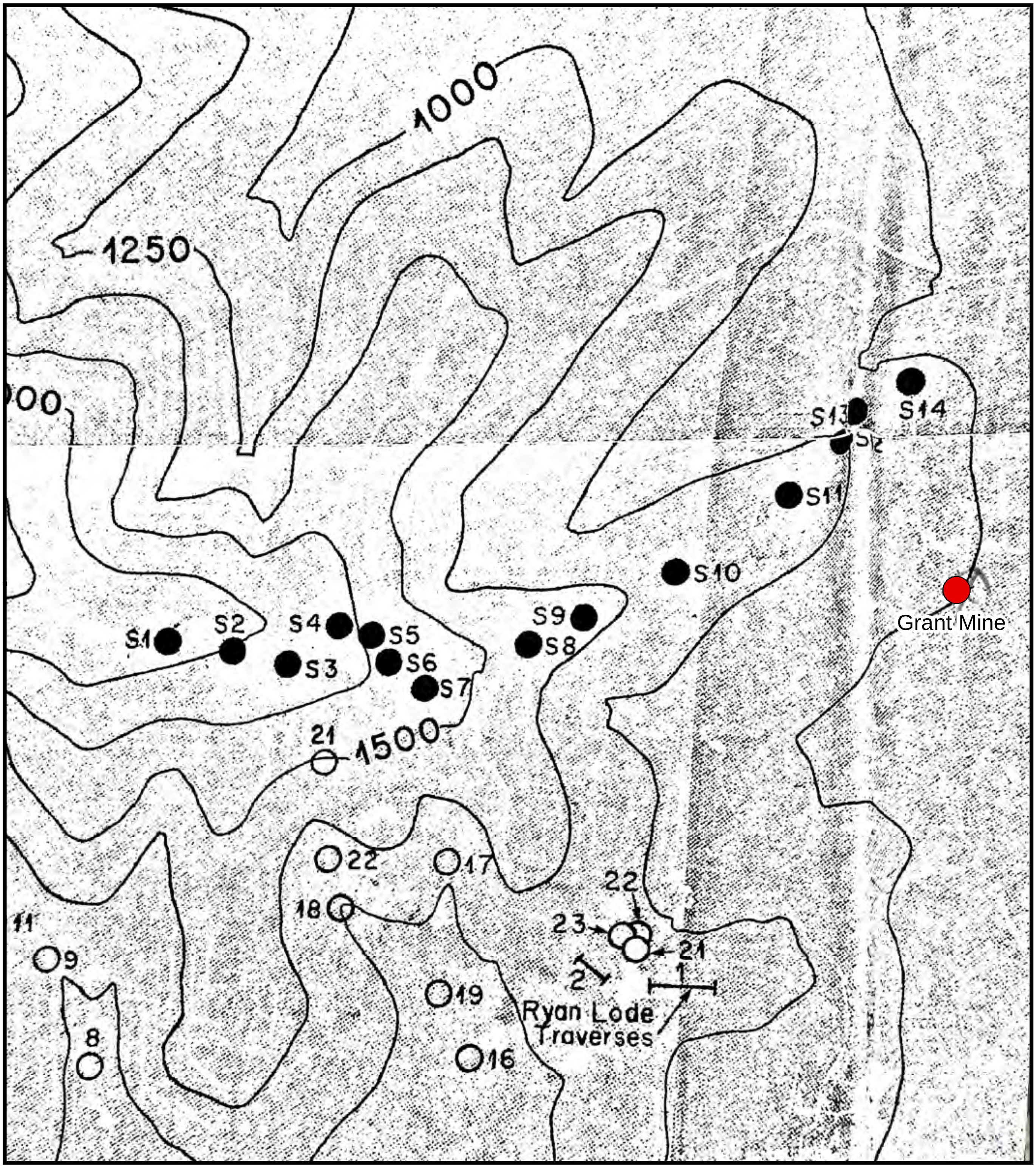
Figure 2



Source: Adapted from Hawkins et al. June 1982

NOTE: Background samples collected for arsenic (S1 through S14) are symbolized as black circles.

Grant Mine Secondary Tailings Impoundment
Post-Excavation Sampling
Ester Dome, Alaska

HAWKINS ET AL. 1982 BACKGROUND SOIL SAMPLE LOCATIONS

April 2020

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Figure 3

Figure 4. Background Arsenic Data from Hawkins et al. 1982

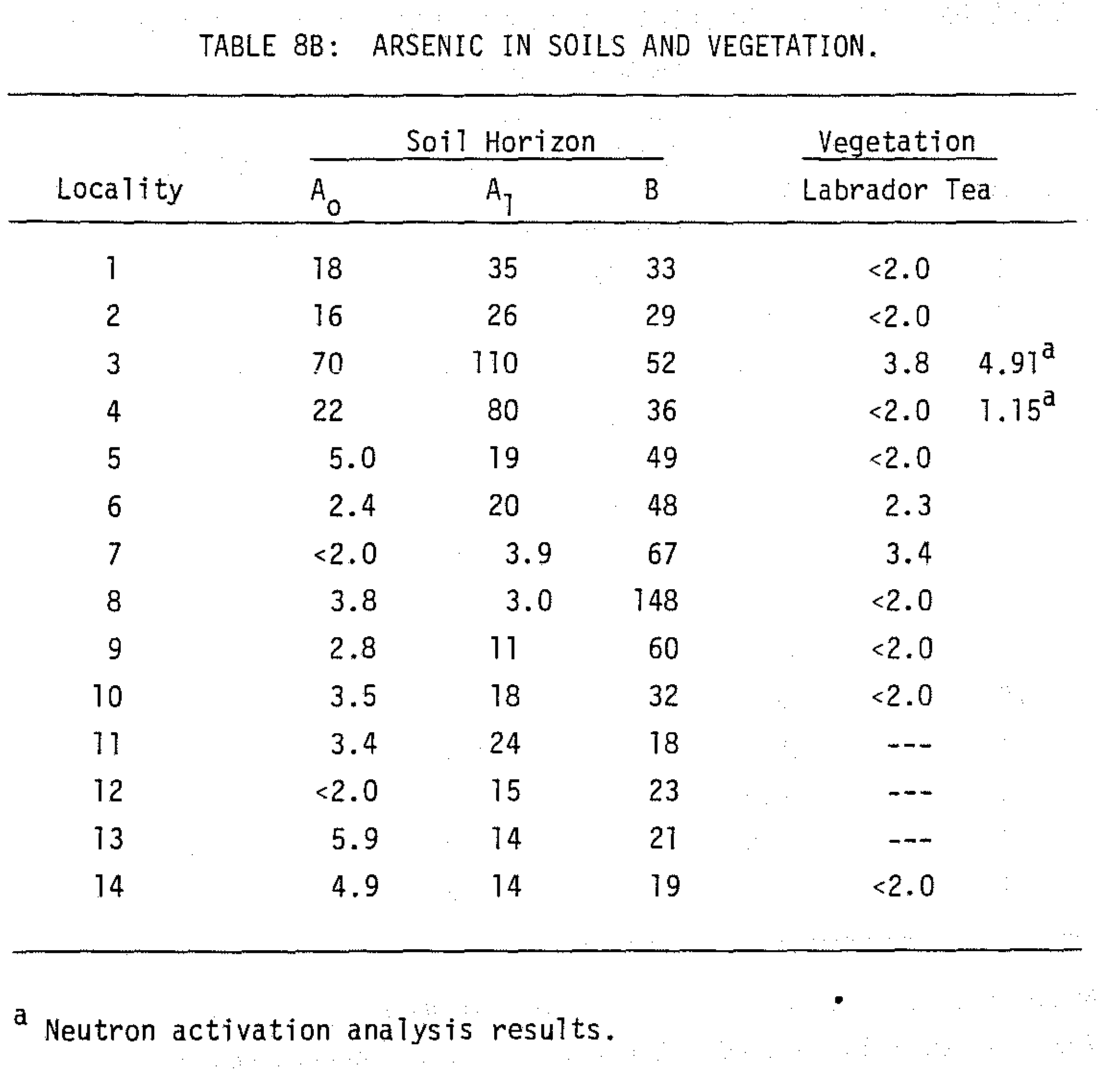
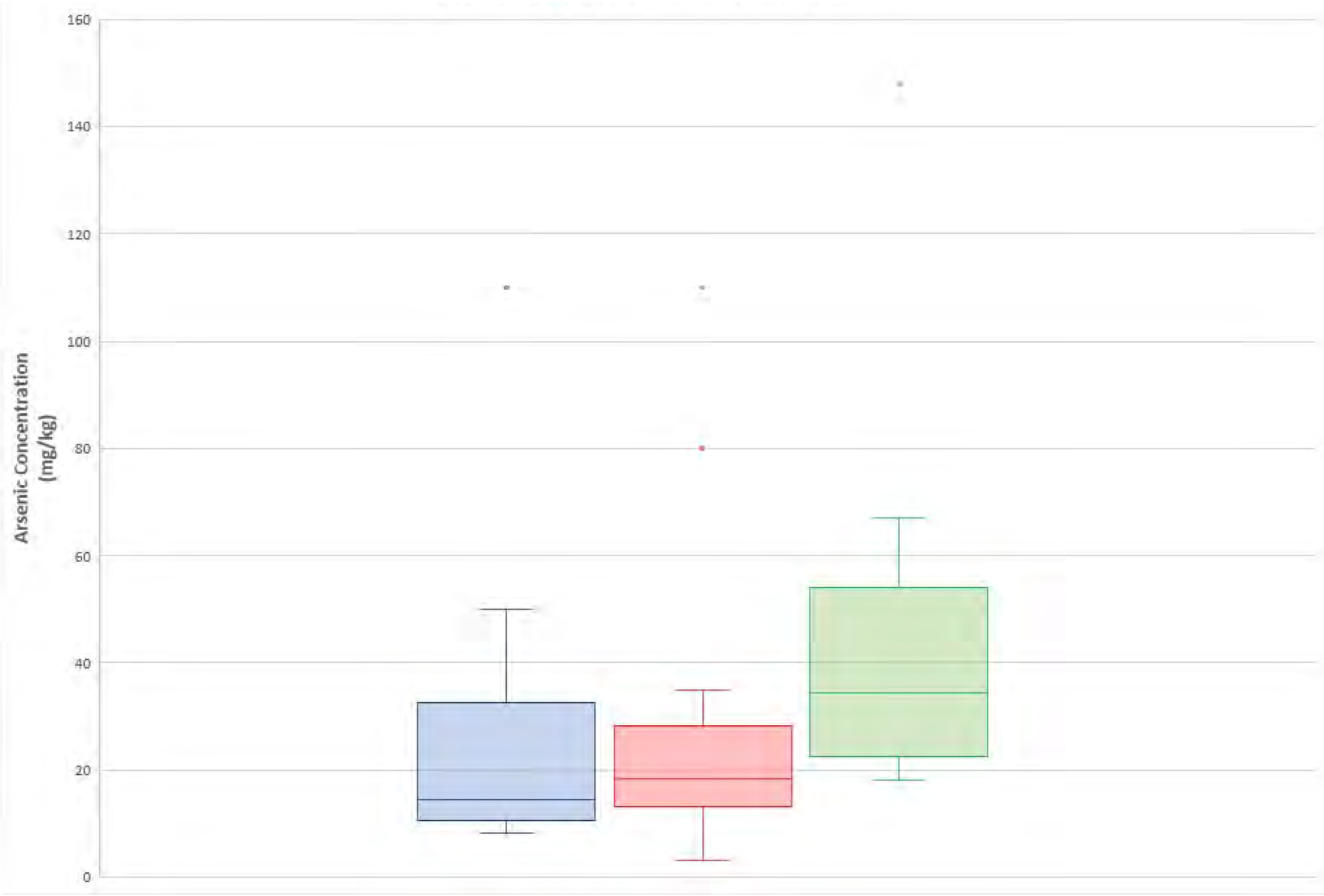


TABLE 8B: ARSENIC IN SOILS AND VEGETATION.

	Soil Horizon			Vegetation	
Locality	A_0	A_1	B	Labrador Tea	
1	18	35	33	<2.0	
2	16	26	29	<2.0	
3	70	110	52	3.8	4.91[a]
4	22	80	36	<2.0	1.15[a]
5	5.0	19	49	<2.0	
6	2.4	20	48	2.3	
7	<2.0	3.9	67	3.4	
8	3.8	3.0	148	<2.0	
9	2.8	11	60	<2.0	
10	3.5	18	32	<2.0	
11	3.4	24	18	---	
12	<2.0	15	23	---	
13	5.9	14	21	---	
14	4.9	14	19	<2.0	

[a] Neutron activation analysis results.



Notes:

🟦 Grant Mine ISM

🟥 Ester Dome - Horizon A1

🟩 Ester Dome - Horizon B

Grant Mine Secondary Tailings Impoundment
Post-Excavation Sampling
Ester Dome, Alaska

Box Plots

April 2020

31-1-20094_Rev 2

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Figure 5

Attachment 1 - ProUCL Input Table

Sample ID	Type	Location	Arsenic	D_Arsenic
19GM-DU1	ISM	DU1	13.8	1
19GM-DU2	ISM	DU2	55.1	1
19GM-DU3-A	ISM	DU3	15.2	1
19GM-DU3-B	ISM	DU3	18.9	1
19GM-DU3-C	ISM	DU3	19.8	1
GM19-1	Discrete	GM	15	1
GM19-2	Discrete	GM	9.09	1
GM19-3	Discrete	GM	110	1
GM19-4	Discrete	GM	50	1
GM19-5	Discrete	GM	8.22	1
GM19-6	Discrete	GM	13.9	1
GM19-7	Discrete	GM	12.3	1
GM19-8	Discrete	GM	14.6	1
GM19-9	Discrete	GM	14.8	1
Ester Dome B	Background	EDB	33	1
Ester Dome B	Background	EDB	29	1
Ester Dome B	Background	EDB	52	1
Ester Dome B	Background	EDB	36	1
Ester Dome B	Background	EDB	49	1
Ester Dome B	Background	EDB	48	1
Ester Dome B	Background	EDB	67	1
Ester Dome B	Background	EDB	148	1
Ester Dome B	Background	EDB	60	1
Ester Dome B	Background	EDB	32	1
Ester Dome B	Background	EDB	18	1
Ester Dome B	Background	EDB	23	1
Ester Dome B	Background	EDB	21	1
Ester Dome B	Background	EDB	19	1
Ester Dome A	Background	EDA	35	1
Ester Dome A	Background	EDA	26	1
Ester Dome A	Background	EDA	110	1

Attachment 1 - ProUCL Input Table

Sample ID	Type	Location	Arsenic	D_Arsenic
Ester Dome A	Background	EDA	80	1
Ester Dome A	Background	EDA	19	1
Ester Dome A	Background	EDA	20	1
Ester Dome A	Background	EDA	3.9	1
Ester Dome A	Background	EDA	3	1
Ester Dome A	Background	EDA	11	1
Ester Dome A	Background	EDA	18	1
Ester Dome A	Background	EDA	24	1
Ester Dome A	Background	EDA	15	1
Ester Dome A	Background	EDA	14	1
Ester Dome A	Background	EDA	14	1

UCL Statistics for Data Sets with Non-Detects			
User Selected Options			
Date/Time of Computation	ProUCL 5.14/13/2020 9:32:44 AM		
From File	01) ProUCL Input File_b.xls		
Full Precision	OFF		
Confidence Coefficient	95%		
Number of Bootstrap Operations	2000		
Arsenic (eda)			
General Statistics			
Total Number of Observations	14	Number of Distinct Observations	13
		Number of Missing Observations	0
Minimum	3	Mean	28.06
Maximum	110	Median	18.5
SD	30.13	Std. Error of Mean	8.051
Coefficient of Variation	1.073	Skewness	2.119
Normal GOF Test			
Shapiro Wilk Test Statistic	0.704	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.874	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.313	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.226	Data Not Normal at 5% Significance Level	
Data Not Normal at 5% Significance Level			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	42.32	95% Adjusted-CLT UCL (Chen-1995)	46.18
		95% Modified-t UCL (Johnson-1978)	43.08
Gamma GOF Test			
A-D Test Statistic	0.638	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.754	Detected data appear Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.203	**Kolmogorov-Smirnov Gamma GOF Test**	
5% K-S Critical Value	0.234	Detected data appear Gamma Distributed at 5% Significance Level	
Detected data appear Gamma Distributed at 5% Significance Level			
Gamma Statistics			
k hat (MLE)	1.321	k star (bias corrected MLE)	1.086
Theta hat (MLE)	21.24	Theta star (bias corrected MLE)	25.85
nu hat (MLE)	37	nu star (bias corrected)	30.4
MLE Mean (bias corrected)	28.06	MLE Sd (bias corrected)	26.93
		Approximate Chi Square Value (0.05)	18.81
Adjusted Level of Significance	0.0312	Adjusted Chi Square Value	17.61
Assuming Gamma Distribution			
95% Approximate Gamma UCL (use when n>=50)	45.36	95% Adjusted Gamma UCL (use when n<50)	48.46
Lognormal GOF Test			
Shapiro Wilk Test Statistic	0.942	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.874	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.175	**Lilliefors Lognormal GOF Test**	

5% Lilliefors Critical Value	0.226	Data appear Lognormal at 5% Significance Level	
Data appear Lognormal at 5% Significance Level			
Lognormal Statistics			
Minimum of Logged Data	1.099	Mean of logged Data	2.911
Maximum of Logged Data	4.7	SD of logged Data	0.966
Assuming Lognormal Distribution			
95% H-UCL	60.91	90% Chebyshev (MVUE) UCL	51.43
95% Chebyshev (MVUE) UCL	62.05	97.5% Chebyshev (MVUE) UCL	76.79
99% Chebyshev (MVUE) UCL	105.7		
Nonparametric Distribution Free UCL Statistics			
Data appear to follow a Discernible Distribution at 5% Significance Level			
Nonparametric Distribution Free UCLs			
95% CLT UCL	41.31	95% Jackknife UCL	42.32
95% Standard Bootstrap UCL	41	95% Bootstrap-t UCL	72.3
95% Hall's Bootstrap UCL	119	95% Percentile Bootstrap UCL	40.93
95% BCA Bootstrap UCL	45.36		
90% Chebyshev(Mean, Sd) UCL	52.22	95% Chebyshev(Mean, Sd) UCL	63.16
97.5% Chebyshev(Mean, Sd) UCL	78.34	99% Chebyshev(Mean, Sd) UCL	108.2
Suggested UCL to Use			
95% Adjusted Gamma UCL	48.46		
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
Recommendations are based upon data size, data distribution, and skewness.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).			
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.			
Arsenic (edb)			
General Statistics			
Total Number of Observations	14	Number of Distinct Observations	14
		Number of Missing Observations	0
Minimum	18	Mean	45.36
Maximum	148	Median	34.5
SD	33.4	Std. Error of Mean	8.927
Coefficient of Variation	0.736	Skewness	2.459
Normal GOF Test			
Shapiro Wilk Test Statistic	0.727	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.874	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.207	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.226	Data appear Normal at 5% Significance Level	
Data appear Approximate Normal at 5% Significance Level			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	61.17	95% Adjusted-CLT UCL (Chen-1995)	66.31
		95% Modified-t UCL (Johnson-1978)	62.14

Gamma GOF Test			
A-D Test Statistic	0.479	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.743	Detected data appear Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.146	**Kolmogorov-Smirnov Gamma GOF Test**	
5% K-S Critical Value	0.231	Detected data appear Gamma Distributed at 5% Significance Level	
Detected data appear Gamma Distributed at 5% Significance Level			
Gamma Statistics			
k hat (MLE)	2.995	k star (bias corrected MLE)	2.401
Theta hat (MLE)	15.14	Theta star (bias corrected MLE)	18.89
nu hat (MLE)	83.87	nu star (bias corrected)	67.23
MLE Mean (bias corrected)	45.36	MLE Sd (bias corrected)	29.27
		Approximate Chi Square Value (0.05)	49.36
Adjusted Level of Significance	0.0312	Adjusted Chi Square Value	47.33
Assuming Gamma Distribution			
95% Approximate Gamma UCL (use when n>=50))	61.78	95% Adjusted Gamma UCL (use when n<50)	64.42
Lognormal GOF Test			
Shapiro Wilk Test Statistic	0.941	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.874	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.109	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.226	Data appear Lognormal at 5% Significance Level	
Data appear Lognormal at 5% Significance Level			
Lognormal Statistics			
Minimum of Logged Data	2.89	Mean of logged Data	3.638
Maximum of Logged Data	4.997	SD of logged Data	0.579
Assuming Lognormal Distribution			
95% H-UCL	63.56	90% Chebyshev (MVUE) UCL	65.75
95% Chebyshev (MVUE) UCL	75.43	97.5% Chebyshev (MVUE) UCL	88.86
99% Chebyshev (MVUE) UCL	115.3		
Nonparametric Distribution Free UCL Statistics			
Data appear to follow a Discernible Distribution at 5% Significance Level			
Nonparametric Distribution Free UCLs			
95% CLT UCL	60.04	95% Jackknife UCL	61.17
95% Standard Bootstrap UCL	59.57	95% Bootstrap-t UCL	74.79
95% Hall's Bootstrap UCL	121.8	95% Percentile Bootstrap UCL	60.57
95% BCA Bootstrap UCL	69.71		
90% Chebyshev(Mean, Sd) UCL	72.14	95% Chebyshev(Mean, Sd) UCL	84.27
97.5% Chebyshev(Mean, Sd) UCL	101.1	99% Chebyshev(Mean, Sd) UCL	134.2
Suggested UCL to Use			
95% Student's-t UCL	61.17		
When a data set follows an approximate (e.g., normal) distribution passing one of the GOF test			
When applicable, it is suggested to use a UCL based upon a distribution (e.g., gamma) passing both GOF tests in ProUCL			
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
Recommendations are based upon data size, data distribution, and skewness.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).			

However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.			
Arsenic (gm)			
General Statistics			
Total Number of Observations	9	Number of Distinct Observations	9
		Number of Missing Observations	0
Minimum	8.22	Mean	27.55
Maximum	110	Median	14.6
SD	33.4	Std. Error of Mean	11.13
Coefficient of Variation	1.212	Skewness	2.356
Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use			
guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest.			
For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012).			
Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.1			
Normal GOF Test			
Shapiro Wilk Test Statistic	0.611	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.829	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.424	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.274	Data Not Normal at 5% Significance Level	
Data Not Normal at 5% Significance Level			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	48.25	95% Adjusted-CLT UCL (Chen-1995)	55.2
		95% Modified-t UCL (Johnson-1978)	49.7
Gamma GOF Test			
A-D Test Statistic	1.248	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.737	Data Not Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.412	**Kolmogorov-Smirnov Gamma GOF Test**	
5% K-S Critical Value	0.285	Data Not Gamma Distributed at 5% Significance Level	
Data Not Gamma Distributed at 5% Significance Level			
Gamma Statistics			
k hat (MLE)	1.362	k star (bias corrected MLE)	0.982
Theta hat (MLE)	20.23	Theta star (bias corrected MLE)	28.05
nu hat (MLE)	24.51	nu star (bias corrected)	17.67
MLE Mean (bias corrected)	27.55	MLE Sd (bias corrected)	27.8
		Approximate Chi Square Value (0.05)	9.156
Adjusted Level of Significance	0.0231	Adjusted Chi Square Value	7.896
Assuming Gamma Distribution			
95% Approximate Gamma UCL (use when n>=50))	53.17	95% Adjusted Gamma UCL (use when n<50)	61.65
Lognormal GOF Test			
Shapiro Wilk Test Statistic	0.789	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.829	Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.37	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.274	Data Not Lognormal at 5% Significance Level	
Data Not Lognormal at 5% Significance Level			

Lognormal Statistics			
Minimum of Logged Data	2.107	Mean of logged Data	2.906
Maximum of Logged Data	4.7	SD of logged Data	0.846
Assuming Lognormal Distribution			
95% H-UCL	62.38	90% Chebyshev (MVUE) UCL	46.59
95% Chebyshev (MVUE) UCL	56.42	97.5% Chebyshev (MVUE) UCL	70.07
99% Chebyshev (MVUE) UCL	96.87		
Nonparametric Distribution Free UCL Statistics			
Data do not follow a Discernible Distribution (0.05)			
Nonparametric Distribution Free UCLs			
95% CLT UCL	45.86	95% Jackknife UCL	48.25
95% Standard Bootstrap UCL	44.9	95% Bootstrap-t UCL	218.9
95% Hall's Bootstrap UCL	230.1	95% Percentile Bootstrap UCL	46.25
95% BCA Bootstrap UCL	55.55		
90% Chebyshev(Mean, Sd) UCL	60.94	95% Chebyshev(Mean, Sd) UCL	76.07
97.5% Chebyshev(Mean, Sd) UCL	97.07	99% Chebyshev(Mean, Sd) UCL	138.3
Suggested UCL to Use			
95% Chebyshev (Mean, Sd) UCL	76.07		
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
Recommendations are based upon data size, data distribution, and skewness.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).			
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.			

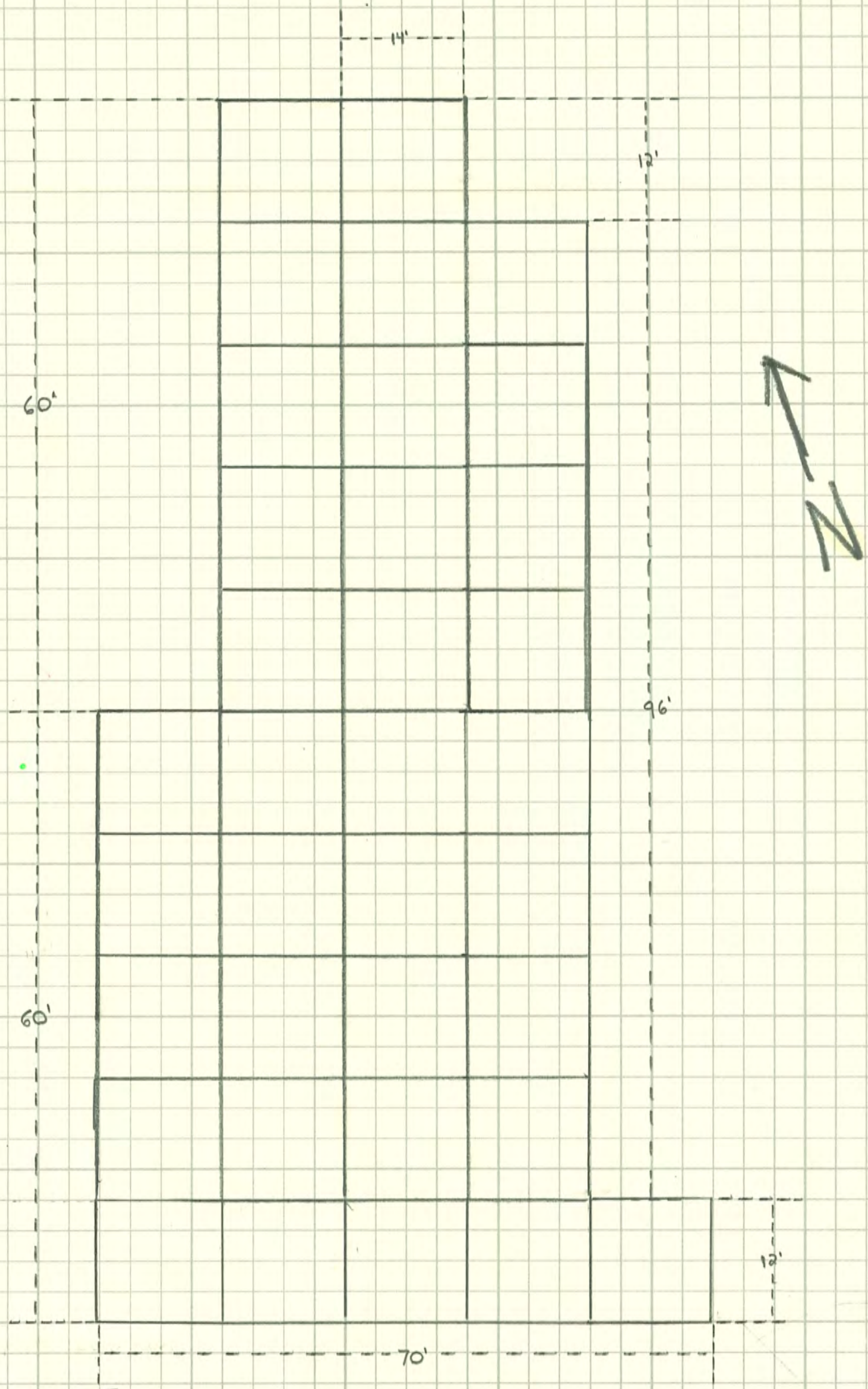
UCL Statistics for Uncensored Full Data Sets			
User Selected Options			
Date/Time of Computation	ProUCL 5.14/13/2020 9:31:56 AM		
From File	01) ProUCL Input File_c.xls		
Full Precision	OFF		
Confidence Coefficient	95%		
Number of Bootstrap Operations	2000		
Arsenic (ism)			
General Statistics			
Total Number of Observations	3	Number of Distinct Observations	3
		Number of Missing Observations	0
Minimum	15.2	Mean	17.97
Maximum	19.8	Median	18.9
SD	2.438	Std. Error of Mean	1.408
Coefficient of Variation	0.136	Skewness	-1.47
Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use			
guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest.			
For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012).			
Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.1			
Normal GOF Test			
Shapiro Wilk Test Statistic	0.89	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.767	Data appear Normal at 5% Significance Level	
Lilliefors Test Statistic	0.316	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.425	Data appear Normal at 5% Significance Level	
Data appear Normal at 5% Significance Level			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	22.08	95% Adjusted-CLT UCL (Chen-1995)	19.01
		95% Modified-t UCL (Johnson-1978)	21.88
Gamma GOF Test			
Not Enough Data to Perform GOF Test			
Gamma Statistics			
k hat (MLE)	77.43	k star (bias corrected MLE)	N/A
Theta hat (MLE)	0.232	Theta star (bias corrected MLE)	N/A
nu hat (MLE)	464.6	nu star (bias corrected)	N/A
MLE Mean (bias corrected)	N/A	MLE Sd (bias corrected)	N/A
		Approximate Chi Square Value (0.05)	N/A
Adjusted Level of Significance	N/A	Adjusted Chi Square Value	N/A
Assuming Gamma Distribution			
95% Approximate Gamma UCL (use when n>=50))	N/A	95% Adjusted Gamma UCL (use when n<50)	N/A
Lognormal GOF Test			
Shapiro Wilk Test Statistic	0.877	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.767	Data appear Lognormal at 5% Significance Level	

Lilliefors Test Statistic	0.324	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.425	Data appear Lognormal at 5% Significance Level	
Data appear Lognormal at 5% Significance Level			
Lognormal Statistics			
Minimum of Logged Data	2.721	Mean of logged Data	2.882
Maximum of Logged Data	2.986	SD of logged Data	0.141
Assuming Lognormal Distribution			
95% H-UCL	24.18	90% Chebyshev (MVUE) UCL	22.35
95% Chebyshev (MVUE) UCL	24.34	97.5% Chebyshev (MVUE) UCL	27.09
99% Chebyshev (MVUE) UCL	32.5		
Nonparametric Distribution Free UCL Statistics			
Data appear to follow a Discernible Distribution at 5% Significance Level			
Nonparametric Distribution Free UCLs			
95% CLT UCL	20.28	95% Jackknife UCL	22.08
95% Standard Bootstrap UCL	N/A	95% Bootstrap-t UCL	N/A
95% Hall's Bootstrap UCL	N/A	95% Percentile Bootstrap UCL	N/A
95% BCA Bootstrap UCL	N/A		
90% Chebyshev(Mean, Sd) UCL	22.19	95% Chebyshev(Mean, Sd) UCL	24.1
97.5% Chebyshev(Mean, Sd) UCL	26.76	99% Chebyshev(Mean, Sd) UCL	31.97
Suggested UCL to Use			
95% Student's-t UCL	22.08		
Recommended UCL exceeds the maximum observation			
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
Recommendations are based upon data size, data distribution, and skewness.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).			
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.			
Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be			
reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.			

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

JOB NAME Grant Mine
SUBJECT ISM Sampling
BY APW
CHK'D ALF
JOB NO. 31-1-20094
DATE 10/22/2019
SHEET 1 of 3

Grant Mine Tillings Impoundment - DU 1

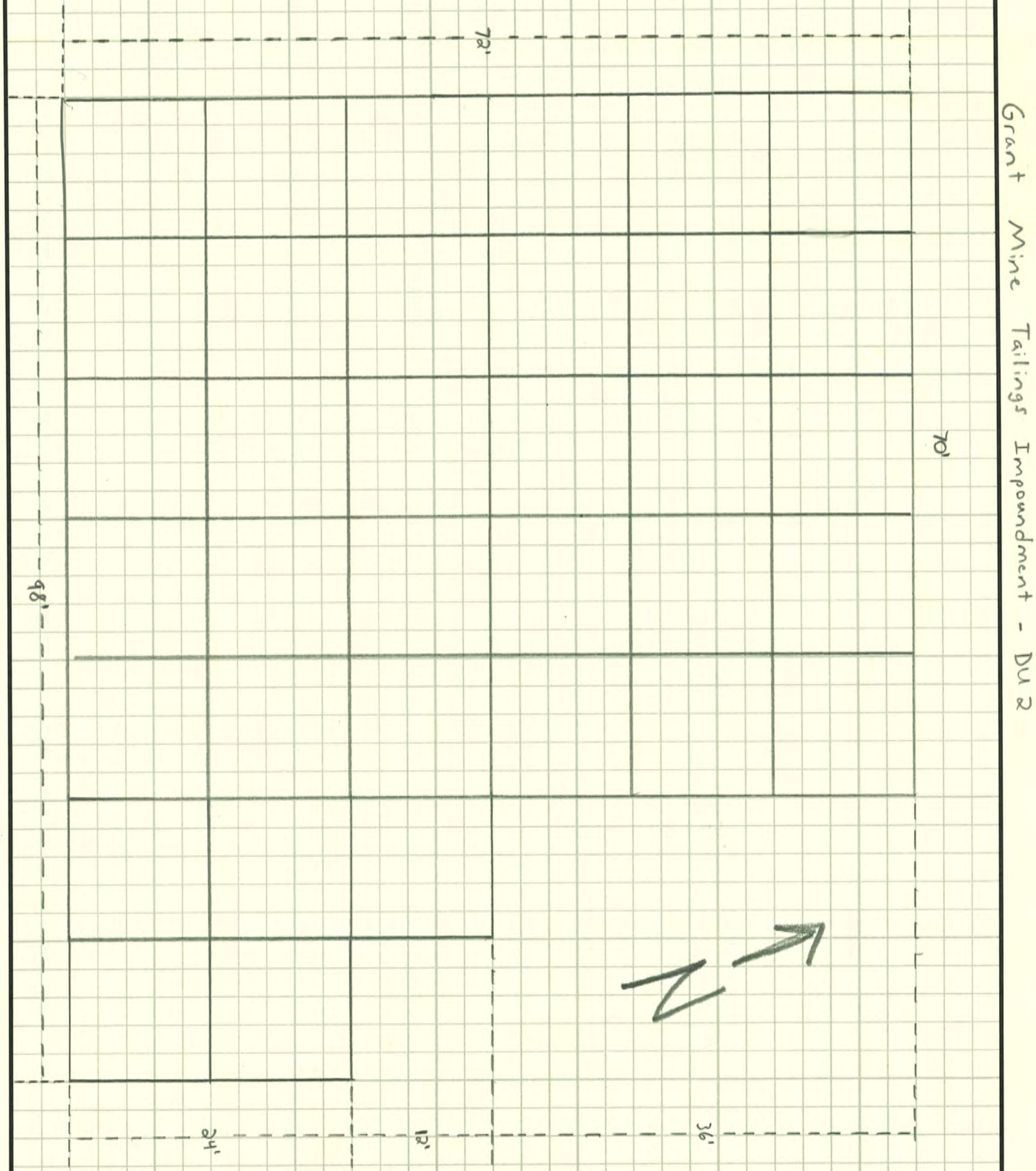


X coordinate: 5
Y coordinate: 10

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

JOB NAME Grant Mine
SUBJECT M.I. Sampling Grids
BY APW
CHK'D ALF
JOB NO. 20094
DATE 10-22-19
SHEET 2 of 3

x = 8
y = 14

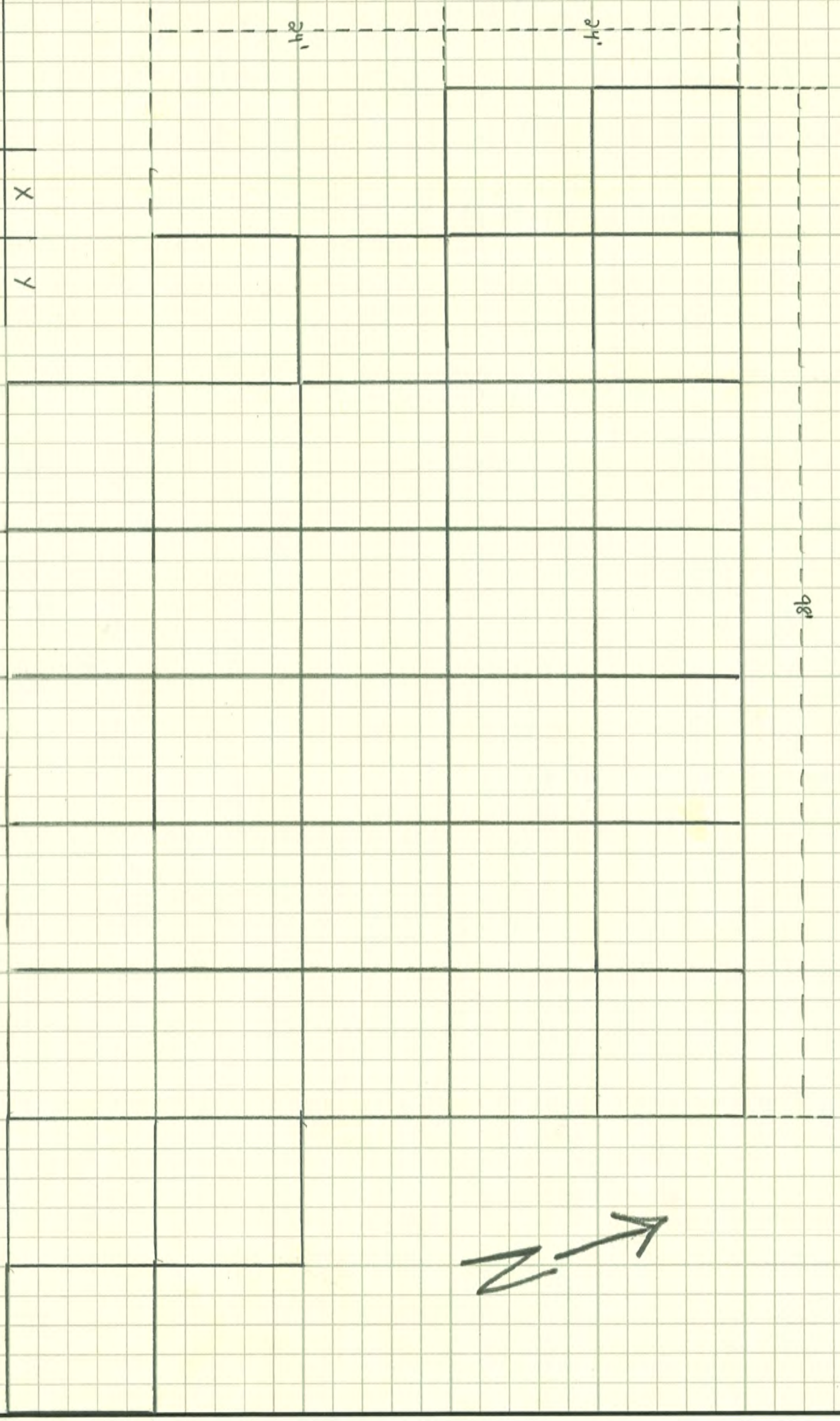


SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

JOB NAME Grant Mine
SUBJECT M.I. Sampling Grid
BY APW
CHK'D ALF
JOB NO. 20094
DATE 10-22-19
SHEET 3 of 3

Grant Mine Tailings Impoundment - DU 3

	X	Y
Replicate A	8	4
Replicate B	13	12
Replicate C	12	6



Laboratory Report of Analysis

To: Shannon & Wilson-Fairbanks
2355 Hill Road
Fairbanks, AK 99709
(907)749-0600

Report Number: **1199895**

Client Project: **20094 Grant Mine**

Dear Andrew Frick,

Enclosed are the results of the analytical services performed under the referenced project for the received samples and associated QC as applicable. The samples are certified to meet the requirements of the National Environmental Laboratory Accreditation Conference Standards. Copies of this report and supporting data will be retained in our files for a period of ten years in the event they are required for future reference. All results are intended to be used in their entirety and SGS is not responsible for use of less than the complete report. Any samples submitted to our laboratory will be retained for a maximum of fourteen (14) days from the date of this report unless other archiving requirements were included in the quote.

If there are any questions about the report or services performed during this project, please call Jennifer at (907) 562-2343. We will be happy to answer any questions or concerns which you may have.

Thank you for using SGS North America Inc. for your analytical services. We look forward to working with you again on any additional analytical needs.

Sincerely,
SGS North America Inc.

Jennifer Dawkins Date
Project Manager
Jennifer.Dawkins@sgs.com

Print Date: 11/12/2019 9:35:46AM

Results via Engage

Case Narrative

SGS Client: Shannon & Wilson-Fairbanks

SGS Project: 1199895

Project Name/Site: 20094 Grant Mine

Refer to sample receipt form for information on sample condition.

1541153MS	**1541154 MS**

6020A - Metals MS recovery for barium and antimony does not meet QC criteria. The post digestion spike was successful.

1541153MSD	**1541155 MSD**

6020A - Metals MSD recovery for barium and antimony does not meet QC criteria. The post digestion spike was successful.

* QC comments may be associated with the field samples found in this report. When applicable, comments will be applied to the associated field samples.

Laboratory Qualifiers

Enclosed are the analytical results associated with the above work order. The results apply to the samples as received. All results are intended to be used in their entirety and SGS is not responsible for use of less than the complete report. This document is issued by the Company under its General Conditions of Service accessible at <http://www.sgs.com/en/Terms-and-Conditions.aspx>. Attention is drawn to the limitation of liability, indenmification and jurisdiction issues defined therein.

Any holder of this document is advised that information contained hereon reflects the Company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents. Any unauthorized alteration, forgery or falsification of the context or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.

SGS maintains a formal Quality Assurance/Quality Control (QA/QC) program. A copy of our Quality Assurance Plan (QAP), which outlines this program, is available at your request. The laboratory certification numbers are AK00971 (DW Chemistry & Microbiology) & 17-021 (CS) for ADEC and 2944.01 for DOD ELAP/ISO17025 (RCRA methods: 1020B, 1311, 3010A, 3050B, 3520C, 3550C, 5030B, 5035A, 6020A, 7470A, 7471B, 8015C, 8021B, 8082A, 8260C, 8270D, 8270D-SIM, 9040C, 9045D, 9056A, 9060A, AK101 and AK102/103). SGS is only certified for the analytes listed on our Drinking Water Certification (DW methods: 200.8, 2130B, 2320B, 2510B, 300.0, 4500-CN-C,E, 4500-H-B, 4500-NO3-F, 4500-P-E and 524.2) and only those analytes will be reported to the State of Alaska for compliance. Except as specifically noted, all statements and data in this report are in conformance to the provisions set forth by the SGS QAP and, when applicable, other regulatory authorities.

The following descriptors or qualifiers may be found in your report:

*	The analyte has exceeded allowable regulatory or control limits.
!	Surrogate out of control limits.
B	Indicates the analyte is found in a blank associated with the sample.
CCV/CVA/CVB	Continuing Calibration Verification
CCCV/CVC/CVCA/CVCB	Closing Continuing Calibration Verification
CL	Control Limit
DF	Analytical Dilution Factor
DL	Detection Limit (i.e., maximum method detection limit)
E	The analyte result is above the calibrated range.
GT	Greater Than
IB	Instrument Blank
ICV	Initial Calibration Verification
J	The quantitation is an estimation.
LCS(D)	Laboratory Control Spike (Duplicate)
LLQC/LLIQC	Low Level Quantitation Check
LOD	Limit of Detection (i.e., 1/2 of the LOQ)
LOQ	Limit of Quantitation (i.e., reporting or practical quantitation limit)
LT	Less Than
MB	Method Blank
MS(D)	Matrix Spike (Duplicate)
ND	Indicates the analyte is not detected.
RPD	Relative Percent Difference
U	Indicates the analyte was analyzed for but not detected.

Note: Sample summaries which include a result for "Total Solids" have already been adjusted for moisture content. All DRO/RRO analyses are integrated per SOP.

Sample Summary

Client Sample ID	Lab Sample ID	Collected	Received	Matrix
GM19-1	1199895001	10/22/2019	10/29/2019	Soil/Solid (dry weight)
GM19-2	1199895002	10/22/2019	10/29/2019	Soil/Solid (dry weight)
GM19-3	1199895003	10/22/2019	10/29/2019	Soil/Solid (dry weight)
GM19-4	1199895004	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-5	1199895005	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-6	1199895006	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-7	1199895007	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-8	1199895008	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-9	1199895009	10/23/2019	10/29/2019	Soil/Solid (dry weight)
GM19-10	1199895010	10/23/2019	10/29/2019	Soil/Solid (dry weight)
19GM-DU3 A	1199895011	10/22/2019	10/29/2019	Soil/Solid (dry weight)
19GM-DU3 B	1199895012	10/22/2019	10/29/2019	Soil/Solid (dry weight)
19GM-DU3 C	1199895013	10/22/2019	10/29/2019	Soil/Solid (dry weight)
19GM-DU2	1199895014	10/23/2019	10/29/2019	Soil/Solid (dry weight)
19GM-DU1	1199895015	10/23/2019	10/29/2019	Soil/Solid (dry weight)

Method	Method Description
SW6020A	Metals by ICP-MS (S)
MI-ITRC ISM (Feb 2012)	MI Sampling/Sieving
SM21 2540G	Percent Solids SM2540G

Detectable Results Summary

Client Sample ID: **GM19-1**
Lab Sample ID: 1199895001

Metals by ICP/MS

Parameter	Result	Units
Arsenic	11.5	mg/Kg
Barium	194	mg/Kg
Cadmium	0.161J	mg/Kg
Chromium	28.6	mg/Kg
Lead	9.46	mg/Kg
Mercury	0.0407J	mg/Kg
Selenium	0.607J	mg/Kg
Silver	0.118J	mg/Kg

Client Sample ID: **GM19-2**
Lab Sample ID: 1199895002

Metals by ICP/MS

Parameter	Result	Units
Arsenic	9.09	mg/Kg
Barium	183	mg/Kg
Cadmium	0.252	mg/Kg
Chromium	31.4	mg/Kg
Lead	9.75	mg/Kg
Mercury	0.0468J	mg/Kg
Selenium	0.518J	mg/Kg
Silver	0.101J	mg/Kg

Client Sample ID: **GM19-3**
Lab Sample ID: 1199895003

Metals by ICP/MS

Parameter	Result	Units
Antimony	0.763J	mg/Kg
Arsenic	110	mg/Kg
Barium	171	mg/Kg
Cadmium	0.177J	mg/Kg
Chromium	28.9	mg/Kg
Lead	15.1	mg/Kg
Mercury	0.0629J	mg/Kg
Selenium	0.740J	mg/Kg
Silver	0.324	mg/Kg

Client Sample ID: **GM19-4**
Lab Sample ID: 1199895004

Metals by ICP/MS

Parameter	Result	Units
Arsenic	50.0	mg/Kg
Barium	152	mg/Kg
Cadmium	0.157J	mg/Kg
Chromium	31.5	mg/Kg
Lead	8.82	mg/Kg
Mercury	0.0721J	mg/Kg
Selenium	0.836J	mg/Kg
Silver	0.150J	mg/Kg

Detectable Results Summary

Client Sample ID: **GM19-5**
Lab Sample ID: 1199895005

Metals by ICP/MS

Parameter	Result	Units
Arsenic	8.22	mg/Kg
Barium	168	mg/Kg
Cadmium	0.188J	mg/Kg
Chromium	28.3	mg/Kg
Lead	9.38	mg/Kg
Mercury	0.0423J	mg/Kg
Selenium	0.544J	mg/Kg
Silver	0.127J	mg/Kg

Client Sample ID: **GM19-6**
Lab Sample ID: 1199895006

Metals by ICP/MS

Parameter	Result	Units
Arsenic	13.9	mg/Kg
Barium	209	mg/Kg
Cadmium	0.205J	mg/Kg
Chromium	28.8	mg/Kg
Lead	9.53	mg/Kg
Mercury	0.0332J	mg/Kg
Selenium	0.696J	mg/Kg
Silver	0.117J	mg/Kg

Client Sample ID: **GM19-7**
Lab Sample ID: 1199895007

Metals by ICP/MS

Parameter	Result	Units
Arsenic	12.3	mg/Kg
Barium	216	mg/Kg
Cadmium	0.217J	mg/Kg
Chromium	30.4	mg/Kg
Lead	9.41	mg/Kg
Mercury	0.0349J	mg/Kg
Selenium	0.527J	mg/Kg
Silver	0.0899J	mg/Kg

Client Sample ID: **GM19-8**
Lab Sample ID: 1199895008

Metals by ICP/MS

Parameter	Result	Units
Arsenic	14.6	mg/Kg
Barium	211	mg/Kg
Cadmium	0.163J	mg/Kg
Chromium	28.7	mg/Kg
Lead	9.94	mg/Kg
Mercury	0.0323J	mg/Kg
Selenium	0.644J	mg/Kg
Silver	0.113J	mg/Kg

Detectable Results Summary

Client Sample ID: **GM19-9**
Lab Sample ID: 1199895009

Metals by ICP/MS

Parameter	Result	Units
Arsenic	14.8	mg/Kg
Barium	186	mg/Kg
Cadmium	0.254	mg/Kg
Chromium	26.8	mg/Kg
Lead	10.4	mg/Kg
Mercury	0.0450J	mg/Kg
Selenium	0.517J	mg/Kg
Silver	0.144J	mg/Kg

Client Sample ID: **GM19-10**
Lab Sample ID: 1199895010

Metals by ICP/MS

Parameter	Result	Units
Arsenic	15.0	mg/Kg
Barium	184	mg/Kg
Cadmium	0.247	mg/Kg
Chromium	25.7	mg/Kg
Lead	10.3	mg/Kg
Mercury	0.0409J	mg/Kg
Selenium	0.464J	mg/Kg
Silver	0.136J	mg/Kg

Client Sample ID: **19GM-DU3 A**
Lab Sample ID: 1199895011

ITRC Incremental Samp Method (2012)
Metals by ICP/MS

Parameter	Result	Units
Multi-Incremental Sub Sampling	0.00	
Arsenic	15.2	mg/Kg
Barium	178	mg/Kg
Cadmium	0.260	mg/Kg
Chromium	26.2	mg/Kg
Lead	11.6	mg/Kg
Mercury	0.0400J	mg/Kg
Selenium	0.741J	mg/Kg
Silver	0.117J	mg/Kg

Client Sample ID: **19GM-DU3 B**
Lab Sample ID: 1199895012

ITRC Incremental Samp Method (2012)
Metals by ICP/MS

Parameter	Result	Units
Multi-Incremental Sub Sampling	0.00	
Arsenic	18.9	mg/Kg
Barium	205	mg/Kg
Cadmium	0.284	mg/Kg
Chromium	26.5	mg/Kg
Lead	11.0	mg/Kg
Mercury	0.0401J	mg/Kg
Selenium	0.694J	mg/Kg
Silver	0.130J	mg/Kg

Detectable Results Summary

Client Sample ID: **19GM-DU3 C**
Lab Sample ID: 1199895013

	Parameter	Result	Units
ITRC Incremental Samp Method (2012)	Multi-Incremental Sub Sampling	0.00	
Metals by ICP/MS	Arsenic	19.8	mg/Kg
	Barium	176	mg/Kg
	Cadmium	0.235	mg/Kg
	Chromium	25.9	mg/Kg
	Lead	9.95	mg/Kg
	Mercury	0.0454J	mg/Kg
	Selenium	0.631J	mg/Kg
	Silver	0.137J	mg/Kg

Client Sample ID: **19GM-DU2**
Lab Sample ID: 1199895014

	Parameter	Result	Units
ITRC Incremental Samp Method (2012)	Multi-Incremental Sub Sampling	0.00	
Metals by ICP/MS	Antimony	0.601J	mg/Kg
	Arsenic	55.1	mg/Kg
	Barium	174	mg/Kg
	Cadmium	0.251	mg/Kg
	Chromium	26.8	mg/Kg
	Lead	14.1	mg/Kg
	Mercury	0.0436J	mg/Kg
	Selenium	0.705J	mg/Kg
	Silver	0.280	mg/Kg

Client Sample ID: **19GM-DU1**
Lab Sample ID: 1199895015

	Parameter	Result	Units
ITRC Incremental Samp Method (2012)	Multi-Incremental Sub Sampling	0.00	
Metals by ICP/MS	Arsenic	13.8	mg/Kg
	Barium	184	mg/Kg
	Cadmium	0.268	mg/Kg
	Chromium	26.8	mg/Kg
	Lead	9.85	mg/Kg
	Mercury	0.0496J	mg/Kg
	Selenium	0.733J	mg/Kg
	Silver	0.115J	mg/Kg

Results of **GM19-1**

Client Sample ID: **GM19-1**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895001
Lab Project ID: 1199895

Collection Date: 10/22/19 14:30
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):83.8
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.570 U	1.14	0.354	mg/Kg	10		11/04/19 19:16
Arsenic	11.5	1.14	0.354	mg/Kg	10		11/04/19 19:16
Barium	194	0.342	0.107	mg/Kg	10		11/04/19 19:16
Cadmium	0.161 J	0.228	0.0707	mg/Kg	10		11/04/19 19:16
Chromium	28.6	0.456	0.148	mg/Kg	10		11/04/19 19:16
Lead	9.46	0.228	0.0707	mg/Kg	10		11/04/19 19:16
Mercury	0.0407 J	0.0912	0.0228	mg/Kg	10		11/04/19 19:16
Selenium	0.607 J	1.14	0.354	mg/Kg	10		11/04/19 19:16
Silver	0.118 J	0.228	0.0707	mg/Kg	10		11/04/19 19:16

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 19:16
Container ID: 1199895001-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.047 g
Prep Extract Vol: 50 mL

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **GM19-2**

Client Sample ID: **GM19-2**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895002
Lab Project ID: 1199895

Collection Date: 10/22/19 14:35
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):82.1
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.580 U	1.16	0.361	mg/Kg	10		11/04/19 19:53
Arsenic	9.09	1.16	0.361	mg/Kg	10		11/04/19 19:53
Barium	183	0.349	0.109	mg/Kg	10		11/04/19 19:53
Cadmium	0.252	0.233	0.0722	mg/Kg	10		11/04/19 19:53
Chromium	31.4	0.466	0.151	mg/Kg	10		11/08/19 18:22
Lead	9.75	0.233	0.0722	mg/Kg	10		11/04/19 19:53
Mercury	0.0468 J	0.0932	0.0233	mg/Kg	10		11/04/19 19:53
Selenium	0.518 J	1.16	0.361	mg/Kg	10		11/04/19 19:53
Silver	0.101 J	0.233	0.0722	mg/Kg	10		11/04/19 19:53

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:22
Container ID: 1199895002-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.046 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 19:53
Container ID: 1199895002-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.046 g
Prep Extract Vol: 50 mL

Results of **GM19-3**

Client Sample ID: **GM19-3**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895003
Lab Project ID: 1199895

Collection Date: 10/22/19 14:40
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):82.5
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.763 J	1.16	0.361	mg/Kg	10		11/04/19 19:58
Arsenic	110	11.6	3.61	mg/Kg	100		11/08/19 18:31
Barium	171	0.349	0.109	mg/Kg	10		11/04/19 19:58
Cadmium	0.177 J	0.233	0.0722	mg/Kg	10		11/04/19 19:58
Chromium	28.9	0.466	0.151	mg/Kg	10		11/08/19 18:27
Lead	15.1	0.233	0.0722	mg/Kg	10		11/04/19 19:58
Mercury	0.0629 J	0.0932	0.0233	mg/Kg	10		11/04/19 19:58
Selenium	0.740 J	1.16	0.361	mg/Kg	10		11/04/19 19:58
Silver	0.324	0.233	0.0722	mg/Kg	10		11/04/19 19:58

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:27
Container ID: 1199895003-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.041 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:31
Container ID: 1199895003-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.041 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 19:58
Container ID: 1199895003-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.041 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **GM19-4**

Client Sample ID: **GM19-4**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895004
Lab Project ID: 1199895

Collection Date: 10/23/19 10:10
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):77.6
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.595 U	1.19	0.370	mg/Kg	10		11/04/19 20:03
Arsenic	50.0	2.99	0.926	mg/Kg	25		11/08/19 18:41
Barium	152	0.358	0.112	mg/Kg	10		11/04/19 20:03
Cadmium	0.157 J	0.239	0.0741	mg/Kg	10		11/04/19 20:03
Chromium	31.5	0.478	0.155	mg/Kg	10		11/08/19 18:36
Lead	8.82	0.239	0.0741	mg/Kg	10		11/04/19 20:03
Mercury	0.0721 J	0.0955	0.0239	mg/Kg	10		11/04/19 20:03
Selenium	0.836 J	1.19	0.370	mg/Kg	10		11/04/19 20:03
Silver	0.150 J	0.239	0.0741	mg/Kg	10		11/04/19 20:03

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:36
Container ID: 1199895004-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.079 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:41
Container ID: 1199895004-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.079 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:03
Container ID: 1199895004-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.079 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **GM19-5**

Client Sample ID: **GM19-5**	Collection Date: 10/23/19 10:15
Client Project ID: **20094 Grant Mine**	Received Date: 10/29/19 09:32
Lab Sample ID: 1199895005	Matrix: Soil/Solid (dry weight)
Lab Project ID: 1199895	Solids (%):82.7
	Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.565 U	1.13	0.350	mg/Kg	10		11/04/19 20:07
Arsenic	8.22	1.13	0.350	mg/Kg	10		11/04/19 20:07
Barium	168	0.338	0.106	mg/Kg	10		11/04/19 20:07
Cadmium	0.188 J	0.226	0.0699	mg/Kg	10		11/04/19 20:07
Chromium	28.3	0.451	0.147	mg/Kg	10		11/08/19 18:46
Lead	9.38	0.226	0.0699	mg/Kg	10		11/04/19 20:07
Mercury	0.0423 J	0.0902	0.0226	mg/Kg	10		11/04/19 20:07
Selenium	0.544 J	1.13	0.350	mg/Kg	10		11/04/19 20:07
Silver	0.127 J	0.226	0.0699	mg/Kg	10		11/04/19 20:07

Batch Information

Analytical Batch: MMS10674	Prep Batch: MXX32947
Analytical Method: SW6020A	Prep Method: SW3050B
Analyst: DMM	Prep Date/Time: 10/30/19 13:05
Analytical Date/Time: 11/08/19 18:46	Prep Initial Wt./Vol.: 1.072 g
Container ID: 1199895005-A	Prep Extract Vol: 50 mL

Analytical Batch: MMS10669	Prep Batch: MXX32947
Analytical Method: SW6020A	Prep Method: SW3050B
Analyst: BMZ	Prep Date/Time: 10/30/19 13:05
Analytical Date/Time: 11/04/19 20:07	Prep Initial Wt./Vol.: 1.072 g
Container ID: 1199895005-A	Prep Extract Vol: 50 mL

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **GM19-6**

Client Sample ID: **GM19-6**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895006
Lab Project ID: 1199895

Collection Date: 10/23/19 10:50
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):79.1
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.575 U	1.15	0.357	mg/Kg	10		11/04/19 20:12
Arsenic	13.9	1.15	0.357	mg/Kg	10		11/04/19 20:12
Barium	209	0.346	0.108	mg/Kg	10		11/04/19 20:12
Cadmium	0.205 J	0.230	0.0714	mg/Kg	10		11/04/19 20:12
Chromium	28.8	0.461	0.150	mg/Kg	10		11/08/19 18:50
Lead	9.53	0.230	0.0714	mg/Kg	10		11/04/19 20:12
Mercury	0.0332 J	0.0922	0.0230	mg/Kg	10		11/04/19 20:12
Selenium	0.696 J	1.15	0.357	mg/Kg	10		11/04/19 20:12
Silver	0.117 J	0.230	0.0714	mg/Kg	10		11/04/19 20:12

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:50
Container ID: 1199895006-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.097 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:12
Container ID: 1199895006-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.097 g
Prep Extract Vol: 50 mL

Results of **GM19-7**

Client Sample ID: **GM19-7**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895007
Lab Project ID: 1199895

Collection Date: 10/23/19 11:00
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):78.6
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.620 U	1.24	0.385	mg/Kg	10		11/04/19 20:17
Arsenic	12.3	1.24	0.385	mg/Kg	10		11/04/19 20:17
Barium	216	0.373	0.117	mg/Kg	10		11/04/19 20:17
Cadmium	0.217 J	0.249	0.0771	mg/Kg	10		11/04/19 20:17
Chromium	30.4	0.497	0.162	mg/Kg	10		11/08/19 18:55
Lead	9.41	0.249	0.0771	mg/Kg	10		11/04/19 20:17
Mercury	0.0349 J	0.0995	0.0249	mg/Kg	10		11/04/19 20:17
Selenium	0.527 J	1.24	0.385	mg/Kg	10		11/04/19 20:17
Silver	0.0899 J	0.249	0.0771	mg/Kg	10		11/04/19 20:17

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 18:55
Container ID: 1199895007-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.023 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:17
Container ID: 1199895007-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.023 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **GM19-8**

Client Sample ID: **GM19-8**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895008
Lab Project ID: 1199895

Collection Date: 10/23/19 11:05
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):85.1
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.575 U	1.15	0.356	mg/Kg	10		11/04/19 20:22
Arsenic	14.6	1.15	0.356	mg/Kg	10		11/04/19 20:22
Barium	211	0.345	0.108	mg/Kg	10		11/04/19 20:22
Cadmium	0.163 J	0.230	0.0712	mg/Kg	10		11/04/19 20:22
Chromium	28.7	0.460	0.149	mg/Kg	10		11/08/19 19:09
Lead	9.94	0.230	0.0712	mg/Kg	10		11/04/19 20:22
Mercury	0.0323 J	0.0919	0.0230	mg/Kg	10		11/04/19 20:22
Selenium	0.644 J	1.15	0.356	mg/Kg	10		11/04/19 20:22
Silver	0.113 J	0.230	0.0712	mg/Kg	10		11/04/19 20:22

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 19:09
Container ID: 1199895008-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.023 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:22
Container ID: 1199895008-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.023 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **GM19-9**

Client Sample ID: **GM19-9**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895009
Lab Project ID: 1199895

Collection Date: 10/23/19 11:08
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):83.5
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.565 U	1.13	0.350	mg/Kg	10		11/04/19 20:26
Arsenic	14.8	1.13	0.350	mg/Kg	10		11/04/19 20:26
Barium	186	0.338	0.106	mg/Kg	10		11/04/19 20:26
Cadmium	0.254	0.226	0.0699	mg/Kg	10		11/04/19 20:26
Chromium	26.8	0.451	0.147	mg/Kg	10		11/08/19 19:14
Lead	10.4	0.226	0.0699	mg/Kg	10		11/04/19 20:26
Mercury	0.0450 J	0.0903	0.0226	mg/Kg	10		11/04/19 20:26
Selenium	0.517 J	1.13	0.350	mg/Kg	10		11/04/19 20:26
Silver	0.144 J	0.226	0.0699	mg/Kg	10		11/04/19 20:26

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 19:14
Container ID: 1199895009-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.061 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:26
Container ID: 1199895009-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.061 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **GM19-10**

Client Sample ID: **GM19-10**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895010
Lab Project ID: 1199895

Collection Date: 10/23/19 10:58
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):83.6
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.545 U	1.09	0.339	mg/Kg	10		11/04/19 20:40
Arsenic	15.0	1.09	0.339	mg/Kg	10		11/04/19 20:40
Barium	184	0.328	0.103	mg/Kg	10		11/04/19 20:40
Cadmium	0.247	0.219	0.0679	mg/Kg	10		11/04/19 20:40
Chromium	25.7	0.438	0.142	mg/Kg	10		11/08/19 19:18
Lead	10.3	0.219	0.0679	mg/Kg	10		11/04/19 20:40
Mercury	0.0409 J	0.0876	0.0219	mg/Kg	10		11/04/19 20:40
Selenium	0.464 J	1.09	0.339	mg/Kg	10		11/04/19 20:40
Silver	0.136 J	0.219	0.0679	mg/Kg	10		11/04/19 20:40

Batch Information

Analytical Batch: MMS10674
Analytical Method: SW6020A
Analyst: DMM
Analytical Date/Time: 11/08/19 19:18
Container ID: 1199895010-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.092 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 20:40
Container ID: 1199895010-A

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/19 13:05
Prep Initial Wt./Vol.: 1.092 g
Prep Extract Vol: 50 mL

J flagging is activated

Results of **19GM-DU3 A**

Client Sample ID: **19GM-DU3 A**	Collection Date: 10/22/19 16:55
Client Project ID: **20094 Grant Mine**	Received Date: 10/29/19 09:32
Lab Sample ID: 1199895011	Matrix: Soil/Solid (dry weight)
Lab Project ID: 1199895	Solids (%):85.3
	Location:

Results by **ITRC Incremental Samp Method (2012)**

Parameter	Date Analyzed
Multi-Incremental Sub Sampling	10/31/19 10:23

Batch Information

Analytical Batch: SPT10926
Analytical Method: MI-ITRC ISM (Feb 2012)
Analyst: M.M
Analytical Date/Time: 10/31/19 10:23
Container ID: 1199895011-A

Results of **19GM-DU3 A**

Client Sample ID: **19GM-DU3 A**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895011
Lab Project ID: 1199895

Collection Date: 10/22/19 16:55
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):85.3
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.565 U	1.13	0.352	mg/Kg	10		11/04/19 22:47
Arsenic	15.2	1.13	0.352	mg/Kg	10		11/04/19 22:47
Barium	178	0.340	0.107	mg/Kg	10		11/04/19 22:47
Cadmium	0.260	0.227	0.0703	mg/Kg	10		11/04/19 22:47
Chromium	26.2	0.454	0.147	mg/Kg	10		11/07/19 21:46
Lead	11.6	0.227	0.0703	mg/Kg	10		11/04/19 22:47
Mercury	0.0400 J	0.0907	0.0227	mg/Kg	10		11/04/19 22:47
Selenium	0.741 J	1.13	0.352	mg/Kg	10		11/04/19 22:47
Silver	0.117 J	0.227	0.0703	mg/Kg	10		11/04/19 22:47

Batch Information

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 21:46
Container ID: 1199895011-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.336 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 22:47
Container ID: 1199895011-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.336 g
Prep Extract Vol: 500 mL

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **19GM-DU3 B**

Client Sample ID: **19GM-DU3 B**	Collection Date: 10/22/19 17:00
Client Project ID: **20094 Grant Mine**	Received Date: 10/29/19 09:32
Lab Sample ID: 1199895012	Matrix: Soil/Solid (dry weight)
Lab Project ID: 1199895	Solids (%):84.2
	Location:

Results by **ITRC Incremental Samp Method (2012)**

Parameter	Date Analyzed
Multi-Incremental Sub Sampling	10/31/19 10:24

Batch Information

Analytical Batch: SPT10926
Analytical Method: MI-ITRC ISM (Feb 2012)
Analyst: M.M
Analytical Date/Time: 10/31/19 10:24
Container ID: 1199895012-A

Results of **19GM-DU3 B**

Client Sample ID: **19GM-DU3 B**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895012
Lab Project ID: 1199895

Collection Date: 10/22/19 17:00
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.2
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.565 U	1.13	0.350	mg/Kg	10		11/04/19 22:52
Arsenic	18.9	1.13	0.350	mg/Kg	10		11/04/19 22:52
Barium	205	0.338	0.106	mg/Kg	10		11/04/19 22:52
Cadmium	0.284	0.226	0.0699	mg/Kg	10		11/04/19 22:52
Chromium	26.5	0.451	0.147	mg/Kg	10		11/07/19 21:51
Lead	11.0	0.226	0.0699	mg/Kg	10		11/04/19 22:52
Mercury	0.0401 J	0.0903	0.0226	mg/Kg	10		11/04/19 22:52
Selenium	0.694 J	1.13	0.350	mg/Kg	10		11/04/19 22:52
Silver	0.130 J	0.226	0.0699	mg/Kg	10		11/04/19 22:52

Batch Information

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 21:51
Container ID: 1199895012-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.532 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 22:52
Container ID: 1199895012-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.532 g
Prep Extract Vol: 500 mL

Results of **19GM-DU3 C**

Client Sample ID: **19GM-DU3 C**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895013
Lab Project ID: 1199895

Collection Date: 10/22/19 17:05
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.3
Location:

Results by **ITRC Incremental Samp Method (2012)**

Parameter	Date Analyzed
Multi-Incremental Sub Sampling	10/31/19 10:24

Batch Information

Analytical Batch: SPT10926
Analytical Method: MI-ITRC ISM (Feb 2012)
Analyst: M.M
Analytical Date/Time: 10/31/19 10:24
Container ID: 1199895013-A

Results of **19GM-DU3 C**

Client Sample ID: **19GM-DU3 C**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895013
Lab Project ID: 1199895

Collection Date: 10/22/19 17:05
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.3
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.565 U	1.13	0.351	mg/Kg	10		11/04/19 22:56
Arsenic	19.8	1.13	0.351	mg/Kg	10		11/04/19 22:56
Barium	176	0.340	0.106	mg/Kg	10		11/04/19 22:56
Cadmium	0.235	0.226	0.0702	mg/Kg	10		11/04/19 22:56
Chromium	25.9	0.453	0.147	mg/Kg	10		11/07/19 21:55
Lead	9.95	0.226	0.0702	mg/Kg	10		11/04/19 22:56
Mercury	0.0454 J	0.0906	0.0226	mg/Kg	10		11/04/19 22:56
Selenium	0.631 J	1.13	0.351	mg/Kg	10		11/04/19 22:56
Silver	0.137 J	0.226	0.0702	mg/Kg	10		11/04/19 22:56

Batch Information

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 21:55
Container ID: 1199895013-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.476 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 22:56
Container ID: 1199895013-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.476 g
Prep Extract Vol: 500 mL

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **19GM-DU2**

Client Sample ID: **19GM-DU2**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895014
Lab Project ID: 1199895

Collection Date: 10/23/19 10:30
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.7
Location:

Results by **ITRC Incremental Samp Method (2012)**

Parameter	Date Analyzed
Multi-Incremental Sub Sampling	10/31/19 10:24

Batch Information

Analytical Batch: SPT10926
Analytical Method: MI-ITRC ISM (Feb 2012)
Analyst: M.M
Analytical Date/Time: 10/31/19 10:24
Container ID: 1199895014-A

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **19GM-DU2**

Client Sample ID: **19GM-DU2**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895014
Lab Project ID: 1199895

Collection Date: 10/23/19 10:30
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.7
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.601 J	1.11	0.345	mg/Kg	10		11/04/19 23:01
Arsenic	55.1	2.78	0.863	mg/Kg	25		11/07/19 22:05
Barium	174	0.334	0.105	mg/Kg	10		11/04/19 23:01
Cadmium	0.251	0.223	0.0690	mg/Kg	10		11/04/19 23:01
Chromium	26.8	0.445	0.145	mg/Kg	10		11/07/19 22:00
Lead	14.1	0.223	0.0690	mg/Kg	10		11/04/19 23:01
Mercury	0.0436 J	0.0891	0.0223	mg/Kg	10		11/04/19 23:01
Selenium	0.705 J	1.11	0.345	mg/Kg	10		11/04/19 23:01
Silver	0.280	0.223	0.0690	mg/Kg	10		11/04/19 23:01

Batch Information

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 22:00
Container ID: 1199895014-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.609 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 22:05
Container ID: 1199895014-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.609 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 23:01
Container ID: 1199895014-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.609 g
Prep Extract Vol: 500 mL

J flagging is activated

Results of **19GM-DU1**

Client Sample ID: **19GM-DU1**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895015
Lab Project ID: 1199895

Collection Date: 10/23/19 12:30
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.7
Location:

Results by **ITRC Incremental Samp Method (2012)**

Parameter	Date Analyzed
Multi-Incremental Sub Sampling	10/31/19 10:24

Batch Information

Analytical Batch: SPT10926
Analytical Method: MI-ITRC ISM (Feb 2012)
Analyst: M.M
Analytical Date/Time: 10/31/19 10:24
Container ID: 1199895015-A

Print Date: 11/12/2019 9:35:54AM

J flagging is activated

Results of **19GM-DU1**

Client Sample ID: **19GM-DU1**
Client Project ID: **20094 Grant Mine**
Lab Sample ID: 1199895015
Lab Project ID: 1199895

Collection Date: 10/23/19 12:30
Received Date: 10/29/19 09:32
Matrix: Soil/Solid (dry weight)
Solids (%):84.7
Location:

Results by **Metals by ICP/MS**

Parameter	Result Qual	LOQ/CL	DL	Units	DF	Allowable Limits	Date Analyzed
Antimony	0.560 U	1.12	0.346	mg/Kg	10		11/04/19 23:06
Arsenic	13.8	1.12	0.346	mg/Kg	10		11/04/19 23:06
Barium	184	0.335	0.105	mg/Kg	10		11/04/19 23:06
Cadmium	0.268	0.224	0.0693	mg/Kg	10		11/04/19 23:06
Chromium	26.8	0.447	0.145	mg/Kg	10		11/07/19 22:09
Lead	9.85	0.224	0.0693	mg/Kg	10		11/04/19 23:06
Mercury	0.0496 J	0.0894	0.0224	mg/Kg	10		11/04/19 23:06
Selenium	0.733 J	1.12	0.346	mg/Kg	10		11/04/19 23:06
Silver	0.115 J	0.224	0.0693	mg/Kg	10		11/04/19 23:06

Batch Information

Analytical Batch: MMS10672
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/07/19 22:09
Container ID: 1199895015-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.564 g
Prep Extract Vol: 500 mL

Analytical Batch: MMS10669
Analytical Method: SW6020A
Analyst: BMZ
Analytical Date/Time: 11/04/19 23:06
Container ID: 1199895015-C

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/19 14:55
Prep Initial Wt./Vol.: 10.564 g
Prep Extract Vol: 500 mL

J flagging is activated

Method Blank

Blank ID: MB for HBN 1801682 [MXX/32947]
Blank Lab ID: 1541150

Matrix: Soil/Solid (dry weight)

QC for Samples:
1199895001, 1199895002, 1199895003, 1199895004, 1199895005, 1199895006, 1199895007, 1199895008, 1199895009, 1199895010

Results by **SW6020A**

Parameter	Results	LOQ/CL	DL	Units
Antimony	0.500U	1.00	0.310	mg/Kg
Arsenic	0.500U	1.00	0.310	mg/Kg
Barium	0.150U	0.300	0.0940	mg/Kg
Cadmium	0.100U	0.200	0.0620	mg/Kg
Chromium	0.200U	0.400	0.130	mg/Kg
Lead	0.100U	0.200	0.0620	mg/Kg
Mercury	0.0400U	0.0800	0.0200	mg/Kg
Selenium	0.500U	1.00	0.310	mg/Kg
Silver	0.100U	0.200	0.0620	mg/Kg

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: BMZ
Analytical Date/Time: 11/4/2019 7:06:55PM

Prep Batch: MXX32947
Prep Method: SW3050B
Prep Date/Time: 10/30/2019 1:05:34PM
Prep Initial Wt./Vol.: 1 g
Prep Extract Vol: 50 mL

Print Date: 11/12/2019 9:35:56AM

Blank Spike Summary

Blank Spike ID: LCS for HBN 1199895 [MXX32947]
Blank Spike Lab ID: 1541151
Date Analyzed: 11/04/2019 19:11

Matrix: Soil/Solid (dry weight)

QC for Samples: 1199895001, 1199895002, 1199895003, 1199895004, 1199895005, 1199895006, 1199895007, 1199895008, 1199895009, 1199895010

Results by **SW6020A**

Blank Spike (mg/Kg)

Parameter	Spike	Result	Rec (%)	CL
Antimony	50	50.4	101	(72-124)
Arsenic	50	53.4	107	(82-118)
Barium	50	52.0	104	(86-116)
Cadmium	5	4.99	100	(84-116)
Chromium	20	22.8	114	(83-119)
Lead	50	52.9	106	(84-118)
Mercury	0.5	0.535	107	(74-126)
Selenium	50	56.5	113	(80-119)
Silver	5	5.46	109	(83-118)

Batch Information

Analytical Batch: **MMS10669**
Analytical Method: **SW6020A**
Instrument: **Perkin Elmer Nexlon P5**
Analyst: **BMZ**

Prep Batch: **MXX32947**
Prep Method: **SW3050B**
Prep Date/Time: **10/30/2019 13:05**
Spike Init Wt./Vol.: 50 mg/Kg   Extract Vol: 50 mL
Dupe Init Wt./Vol.:   Extract Vol:

Print Date: 11/12/2019 9:35:58AM

Matrix Spike Summary

Original Sample ID: 1541153
MS Sample ID: 1541154 MS
MSD Sample ID: 1541155 MSD

Analysis Date: 11/04/2019 19:16
Analysis Date: 11/04/2019 19:20
Analysis Date: 11/04/2019 19:25
Matrix: Solid/Soil (Wet Weight)

QC for Samples: 1199895001, 1199895002, 1199895003, 1199895004, 1199895005, 1199895006, 1199895007, 1199895008, 1199895009, 1199895010

Results by **SW6020A**

		Matrix Spike (mg/Kg)				Spike Duplicate (mg/Kg)						
Parameter	Sample	Spike	Result	Rec (%)		Spike	Result	Rec (%)		CL	RPD (%)	RPD CL
Antimony	0.477U	46.4	17.1	37	*	49.0	20.3	41	*	72-124	16.70	(< 20)
Arsenic	9.63	46.4	60	109		49.0	59.8	102		82-118	0.36	(< 20)
Barium	163	46.4	227	138	*	49.0	230	136	*	86-116	1.33	(< 20)
Cadmium	0.135J	4.64	4.58	96		4.90	4.85	96		84-116	5.62	(< 20)
Chromium	24.0	18.6	44.4	110		19.6	46.7	116		83-119	5.01	(< 20)
Lead	7.92	46.4	55.2	102		49.0	57.3	101		84-118	3.75	(< 20)
Mercury	0.0341J	0.464	.489	98		0.490	0.505	96		74-126	3.22	(< 20)
Selenium	0.509J	46.4	46.5	99		49.0	51.2	104		80-119	9.61	(< 20)
Silver	0.0990J	4.64	4.68	99		4.90	5.03	101		83-118	7.37	(< 20)

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: BMZ
Analytical Date/Time: 11/4/2019 7:20:59PM

Prep Batch: MXX32947
Prep Method: Soils/Solids Digest for Metals by ICP-MS
Prep Date/Time: 10/30/2019 1:05:34PM
Prep Initial Wt./Vol.: 1.08g
Prep Extract Vol: 50.00mL

Bench Spike Summary

Original Sample ID: 1541153
MS Sample ID: 1541156 BND
MSD Sample ID:

Analysis Date: 11/04/2019 19:16
Analysis Date: 11/04/2019 19:30
Analysis Date:
Matrix: Solid/Soil (Wet Weight)

QC for Samples: 1199895001, 1199895002, 1199895003, 1199895004, 1199895005, 1199895006, 1199895007, 1199895008, 1199895009, 1199895010

Results by **SW6020A**

		Matrix Spike (mg/Kg)			Spike Duplicate (mg/Kg)					
Parameter	Sample	Spike	Result	Rec (%)	Spike	Result	Rec (%)	CL	RPD (%)	RPD CL
Antimony	0.477U	119	117	98				80-120		
Barium	163	239	403	101				80-120		

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: BMZ
Analytical Date/Time: 11/4/2019 7:30:23PM

Prep Batch: MXX32947
Prep Method: Soils/Solids Digest for Metals by ICP-MS
Prep Date/Time: 10/30/2019 1:05:34PM
Prep Initial Wt./Vol.: 1.05g
Prep Extract Vol: 50.00mL

Print Date: 11/12/2019 9:35:59AM

Method Blank

Blank ID: MB for HBN 1801735 [MXX/32952]
Blank Lab ID: 1541416

Matrix: Soil/Solid (dry weight)

QC for Samples:
1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SW6020A**

Parameter	Results	LOQ/CL	DL	Units
Antimony	0.500U	1.00	0.310	mg/Kg
Arsenic	0.500U	1.00	0.310	mg/Kg
Barium	0.150U	0.300	0.0940	mg/Kg
Cadmium	0.100U	0.200	0.0620	mg/Kg
Chromium	0.200U	0.400	0.130	mg/Kg
Lead	0.100U	0.200	0.0620	mg/Kg
Mercury	0.0400U	0.0800	0.0200	mg/Kg
Selenium	0.500U	1.00	0.310	mg/Kg
Silver	0.100U	0.200	0.0620	mg/Kg

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: BMZ
Analytical Date/Time: 11/4/2019 9:13:36PM

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/2019 2:55:27PM
Prep Initial Wt./Vol.: 1 g
Prep Extract Vol: 50 mL

Analytical Batch: MMS10675
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: DMM
Analytical Date/Time: 11/9/2019 7:42:46PM

Prep Batch: MXX32952
Prep Method: SW3050B
Prep Date/Time: 10/31/2019 2:55:27PM
Prep Initial Wt./Vol.: 1 g
Prep Extract Vol: 50 mL

Print Date: 11/12/2019 9:36:00AM

Blank Spike Summary

Blank Spike ID: LCS for HBN 1199895 [MXX32952]
Blank Spike Lab ID: 1541417
Date Analyzed: 11/04/2019 21:18

Matrix: Soil/Solid (dry weight)

QC for Samples: 1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SW6020A**

Blank Spike (mg/Kg)

Parameter	Spike	Result	Rec (%)	CL
Antimony	50	48.9	98	(72-124)
Arsenic	50	50.3	101	(82-118)
Barium	50	49.7	99	(86-116)
Cadmium	5	4.88	98	(84-116)
Lead	50	50.2	100	(84-118)
Mercury	0.5	0.515	103	(74-126)
Selenium	50	52.3	105	(80-119)
Silver	5	5.49	110	(83-118)
Chromium	20	21.3	107	(83-119)

Batch Information

Analytical Batch: **MMS10669**
Analytical Method: **SW6020A**
Instrument: **Perkin Elmer Nexlon P5**
Analyst: **BMZ**

Prep Batch: **MXX32952**
Prep Method: **SW3050B**
Prep Date/Time: **10/31/2019 14:55**
Spike Init Wt./Vol.: 50 mg/Kg Extract Vol: 50 mL
Dupe Init Wt./Vol.: Extract Vol:

Analytical Batch: **MMS10675**
Analytical Method: **SW6020A**
Instrument: **Perkin Elmer Nexlon P5**
Analyst: **DMM**

Prep Batch: **MXX32952**
Prep Method: **SW3050B**
Prep Date/Time: **10/31/2019 14:55**
Spike Init Wt./Vol.: 20 mg/Kg Extract Vol: 50 mL
Dupe Init Wt./Vol.: Extract Vol:

Matrix Spike Summary

Original Sample ID: 1541422
MS Sample ID: 1541423 MS
MSD Sample ID: 1541424 MSD

Analysis Date: 11/04/2019 21:37
Analysis Date: 11/04/2019 21:41
Analysis Date: 11/04/2019 21:46
Matrix: Solid/Soil (Wet Weight)

QC for Samples: 1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SW6020A**

		Matrix Spike (mg/Kg)			Spike Duplicate (mg/Kg)					
Parameter	Sample	Spike	Result	Rec (%)	Spike	Result	Rec (%)	CL	RPD (%)	RPD CL
Antimony	0.494U	49.8	28.7	58 *	47.1	27.6	59 *	72-124	3.96	(< 20)
Arsenic	5.37	49.8	58.4	107	47.1	53.9	103	82-118	8.11	(< 20)
Barium	41.7	49.8	96.3	110	47.1	87.9	98	86-116	9.13	(< 20)
Cadmium	0.0674J	4.98	4.95	98	4.71	4.59	96	84-116	7.64	(< 20)
Lead	4.12	49.8	53.8	100	47.1	51.9	102	84-118	3.60	(< 20)
Mercury	0.0658J	0.498	.586	105	0.471	0.555	104	74-126	5.45	(< 20)
Selenium	0.494U	49.8	53.2	107	47.1	49.6	105	80-119	7.10	(< 20)
Silver	0.0990U	4.98	5.36	108	4.71	5.27	112	83-118	1.67	(< 20)
Chromium	29.1	19.9	50.5	108	18.8	44.4	81 *	83-119	13.00	(< 20)

Batch Information

Analytical Batch: MMS10669
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: BMZ
Analytical Date/Time: 11/4/2019 9:41:46PM

Prep Batch: MXX32952
Prep Method: Soils/Solids Digest for Metals by ICP-MS
Prep Date/Time: 10/31/2019 2:55:27PM
Prep Initial Wt./Vol.: 1.00g
Prep Extract Vol: 50.00mL

Analytical Batch: MMS10675
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: DMM
Analytical Date/Time: 11/9/2019 8:10:56PM

Prep Batch: MXX32952
Prep Method: Soils/Solids Digest for Metals by ICP-MS
Prep Date/Time: 10/31/2019 2:55:27PM
Prep Initial Wt./Vol.: 1.00g
Prep Extract Vol: 50.00mL

Print Date: 11/12/2019 9:36:04AM

Bench Spike Summary

Original Sample ID: 1541422
MS Sample ID: 1541425 BND
MSD Sample ID:

Analysis Date: 11/09/2019 20:06
Analysis Date: 11/09/2019 20:20
Analysis Date:
Matrix: Solid/Soil (Wet Weight)

QC for Samples: 1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SW6020A**

		Matrix Spike (mg/Kg)			Spike Duplicate (mg/Kg)					
Parameter	Sample	Spike	Result	Rec (%)	Spike	Result	Rec (%)	CL	RPD (%)	RPD CL
Chromium	29.1	124	155	102				80-120		

Batch Information

Analytical Batch: MMS10675
Analytical Method: SW6020A
Instrument: Perkin Elmer NexIon P5
Analyst: DMM
Analytical Date/Time: 11/9/2019 8:20:19PM

Prep Batch: MXX32952
Prep Method: Soils/Solids Digest for Metals by ICP-MS
Prep Date/Time: 10/31/2019 2:55:27PM
Prep Initial Wt./Vol.: 1.01g
Prep Extract Vol: 50.00mL

Print Date: 11/12/2019 9:36:04AM

Method Blank

Blank ID: MB for HBN 1801666 [SPT/10924]
Blank Lab ID: 1541084

Matrix: Soil/Solid (dry weight)

QC for Samples:
1199895001, 1199895002, 1199895005, 1199895006, 1199895008, 1199895009

Results by **SM21 2540G**

Parameter	Results	LOQ/CL	DL	Units
Total Solids	100			%

Batch Information

Analytical Batch: SPT10924
Analytical Method: SM21 2540G
Instrument:
Analyst: MER
Analytical Date/Time: 10/29/2019 4:21:00PM

Duplicate Sample Summary

Original Sample ID: 1199895002
Duplicate Sample ID: 1541085

Analysis Date: 10/29/2019 16:21
Matrix: Soil/Solid (dry weight)

QC for Samples:

1199895001, 1199895002, 1199895005, 1199895006, 1199895008, 1199895009

Results by **SM21 2540G**

NAME	Original	Duplicate	Units	RPD (%)	RPD CL
Total Solids	82.1	82.3	%	0.26	(< 15)

Batch Information

Analytical Batch: SPT10924
Analytical Method: SM21 2540G
Instrument:
Analyst: MER

Print Date: 11/12/2019 9:36:06AM

Duplicate Sample Summary

Original Sample ID: 1199899001
Duplicate Sample ID: 1541086

Analysis Date: 10/29/2019 16:21
Matrix: Soil/Solid (dry weight)

QC for Samples:

1199895005, 1199895006, 1199895008, 1199895009

Results by **SM21 2540G**

NAME	Original	Duplicate	Units	RPD (%)	RPD CL
Total Solids	95.1	95.3	%	0.23	(< 15)

Batch Information

Analytical Batch: SPT10924
Analytical Method: SM21 2540G
Instrument:
Analyst: MER

Print Date: 11/12/2019 9:36:06AM

Method Blank

Blank ID: MB for HBN 1801712 [SPT/10925]
Blank Lab ID: 1541290

Matrix: Soil/Solid (dry weight)

QC for Samples:
1199895003, 1199895004, 1199895007, 1199895010, 1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SM21 2540G**

Parameter	Results	LOQ/CL	DL	Units
Total Solids	100			%

Batch Information

Analytical Batch: SPT10925
Analytical Method: SM21 2540G
Instrument:
Analyst: MER
Analytical Date/Time: 10/30/2019 3:59:00PM

Duplicate Sample Summary

Original Sample ID: 1196478007
Duplicate Sample ID: 1541291

Analysis Date: 10/30/2019 15:59
Matrix: Soil/Solid (dry weight)

QC for Samples:

1199895003

Results by **SM21 2540G**

NAME	Original	Duplicate	Units	RPD (%)	RPD CL
Total Solids	91.9	92.4	%	0.55	(< 15)

Batch Information

Analytical Batch: SPT10925
Analytical Method: SM21 2540G
Instrument:
Analyst: MER

Print Date: 11/12/2019 9:36:10AM

Duplicate Sample Summary

Original Sample ID: 1199895003
Duplicate Sample ID: 1541292

Analysis Date: 10/30/2019 15:59
Matrix: Soil/Solid (dry weight)

QC for Samples:

1199895003, 1199895004, 1199895007, 1199895010, 1199895011, 1199895012, 1199895013, 1199895014, 1199895015

Results by **SM21 2540G**

NAME	Original	Duplicate	Units	RPD (%)	RPD CL
Total Solids	82.5	84.1	%	1.90	(< 15)

Batch Information

Analytical Batch: SPT10925
Analytical Method: SM21 2540G
Instrument:
Analyst: MER

Print Date: 11/12/2019 9:36:10AM

1199895

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
2355 Hill Road
Fairbanks, AK 99709
(907) 479-0600
www.shannonwilson.com

CHAIN-OF ~~~~CORD

Page 1 of 2
Laboratory SGS
Attn:

profile: 337923

Turn Around Time: ☒ Normal ☐ Rush
Please Specify

Quote No:

J-Flags: ☒ Yes ☐ No

Analytical Methods (include preservative if used)

	Sample Identity	Lab No.	Time	Date Sampled	RCRA Metals 6020 + Antimony							Total Number of Containers	Remarks/Matrix Composition/Grab? Sample Containers
1A	GM19-1		14:30	10-22-19	X							1	Grab Samples
2A	GM19-2		14:35	10-22-19	X							1	
3A	GM19-3		14:40	10-22-19	X							1	
4A	GM19-4		10:10	10-23-19	X							1	
5A	GM19-5		10:15	10-23-19	X							1	
6A	GM19-6		10:50	10-23-19	X							1	
7A	GM19-7		11:00	10-23-19	X							1	
8A	GM19-8		11:05	10-23-19	X							1	
9A	GM19-9		11:08	10-23-19	X							1	
10A	GM19-10		10:58	10-23-19	X							1	

Project Information
Number: 20094
Name: Grant Mine
Contact: MSL
Ongoing Project? Yes ☒ No ☐
Sampler: ALF, APW, RW

Sample Receipt
Total No. of Containers: 15
COC Seals/Intact? Y/N/NA
Received Good Cond./Cold
Temp: 2.7
Delivery Method: Hand

	Reliquished By: 1.	Reliquished By: 2.	Reliquished By: 3.
Signature	Andrew Frick		
Time	13:24	12:30	
Printed Name	Andrew Frick	Castilleja Kuzis	
Date	10-25-19	10/28	
Company	S&W	SGS	

	Received By: 1.	Received By: 2.	Received By: 3.
Signature			
Time	13:21		0937
Printed Name	Castilleja Kuzis		J Shumway
Date	10/24		10/29/19
Company	SGS		SGS

Notes:

Distribution: White - w/shipment - returned to Shannon & Wilson w/ laboratory report
Yellow - w/shipment - for consignee files
Pink - Shannon & Wilson - job file

1F/1B DbI 1.6° No. 411514

1199895

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
2355 Hill Road
Fairbanks, AK 99709
(907) 479-0600
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CHAIN-O ECORD

Page 2 of 2
Laboratory SGS
Attn:

profile: 337923

Turn Around Time: ☒ Normal ☐ Rush
Please Specify

Quote No:

J-Flags: ☒ Yes ☐ No

	Sample Identity	Lab No.	Time	Date Sampled	RCRA Metals + Antimony 6020							Total Number of Containers	Remarks/Matrix Composition/Grab? Sample Containers
⑪ A-D	19GM-DU3 A		16:55	10-22-19	X							1	Multi-Incremental
⑫ A-D	19GM-DU3 B		17:00	|	X							1	Samples
⑬ A-D	19GM-DU3 C		17:05	|	X							1	
⑭ A-D	19GM-DU2		10:30	10-23-19	X							1	
⑮ A-D	19GM-DU1		12:30	10-23-19	X							1	

Project Information
Number: 20094
Name: Grant Mine
Contact: MSL
Ongoing Project? Yes ☒ No ☐
Sampler: ALF

Sample Receipt
Total No. of Containers:
COC Seals/Intact? Y/N/NA
Received Good Cond./Cold
Temp: 2.7
Delivery Method:
See Page 1

Notes:

Reliquished By: 1.	**Reliquished By: 2.**	**Reliquished By: 3.**
Signature: Andrew Fritz Time: 13:24	Signature: Time: 12:30	Signature: Time:
Printed Name: Andrew Fritz Date: 10-24-19	Printed Name: castillejakuzis Date: 10/28	Printed Name: Date:
Company: S&W	Company: SGS	Company:

Received By: 1.	**Received By: 2.**	**Received By: 3.**
Signature: Time: 13:21	Signature: Time:	Signature: Time: 0932
Printed Name: Castilleja Kuzis Date: 10/24	Printed Name: Date:	Printed Name: J Shumway Date: 10/29/19
Company: SGS	Company:	Company: SGS

Distribution: White - w/shipment - returned to Shannon & Wilson w/ laboratory report
Yellow - w/shipment - for consignee files
Pink - Shannon & Wilson - job file

1F/1B 061 1.6° **No.** 411441

e-Sample Receipt Form

SGS Workorder #: **1199895**

Review Criteria	Condition (Yes, No, N/A	Exceptions Noted below
Chain of Custody / Temperature Requirements		N/A Exemption permitted if sampler hand carries/delivers.
Were Custody Seals intact? Note # & location	Yes	1 front 1 back
COC accompanied samples?	Yes	
DOD: Were samples received in COC corresponding coolers?	N/A	

N/A **Exemption permitted if chilled & collected <8 hours ago, or for samples where chilling is not required

Temperature blank compliant* (i.e., 0-6 °C after CF)?	Yes	Cooler ID:	1	@	1.6	°C	Therm. ID:	D61
If samples received without a temperature blank, the "cooler temperature" will be documented instead & "COOLER TEMP" will be noted to the right. "ambient" or "chilled" will be noted if neither is available.		Cooler ID:		@		°C	Therm. ID:	
		Cooler ID:		@		°C	Therm. ID:	
		Cooler ID:		@		°C	Therm. ID:	
		Cooler ID:		@		°C	Therm. ID:	

**If >6°C, were samples collected <8 hours ago?*	N/A	
If <0°C, were sample containers ice free?	N/A	
Note: Identify containers received at non-compliant temperature . Use form FS-0029 if more space is needed.		
Holding Time / Documentation / Sample Condition Requirements		Note: Refer to form F-083 "Sample Guide" for specific holding times.
Were samples received within holding time?	Yes	
Do samples **match COC**** (i.e.,sample IDs,dates/times collected)? **Note: If times differ <1hr, record details & login per COC. ***Note: If sample information on containers differs from COC, SGS will default to COC information	Yes	
Were analytical requests clear? (i.e., method is specified for analyses with multiple option for analysis (Ex: BTEX, Metals)	Yes	
		N/A ***Exemption permitted for metals (e.g,200.8/6020A).
Were proper containers (type/mass/volume/preservative***)used?	Yes	
Volatile / LL-Hg Requirements		
Were Trip Blanks (i.e., VOAs, LL-Hg) in cooler with samples?	N/A	
Were all water VOA vials free of headspace (i.e., bubbles ≤ 6mm)?	N/A	
Were all soil VOAs field extracted with MeOH+BFB?	N/A	

Note to Client: Any "No", answer above indicates non-compliance with standard procedures and may impact data quality.

Additional notes (if applicable):

e-Sample Receipt Form FBK

SGS Workorder #:	**1199895**	1199895

Review Criteria	Condition (Yes, No, N/A	Exceptions Noted below
Chain of Custody / Temperature Requirements		Yes Exemption permitted if sampler hand carries/delivers.
Were Custody Seals intact? Note # & location	N/A	
COC accompanied samples?	Yes	
DOD: Were samples received in COC corresponding coolers?	N/A	
☐ **Exemption permitted if chilled & collected <8 hours ago, or for samples where chilling is not required		
Temperature blank compliant* (i.e., 0-6 °C after CF)?	Yes	Cooler ID: 1 @ 2.7 °C Therm. ID: 65 Cooler ID: @ °C Therm. ID: Cooler ID: @ °C Therm. ID: Cooler ID: @ °C Therm. ID:
If samples received without a temperature blank, the "cooler temperature" will be documented instead & "COOLER TEMP" will be noted to the right. "ambient" or "chilled" will be noted if neither is available.		
If >6°C, were samples collected <8 hours ago?		
If <0°C, were sample containers ice free?		
Note: Identify containers received at non-compliant temperature . Use form FS-0029 if more space is needed.		
Holding Time / Documentation / Sample Condition Requirements		Note: Refer to form F-083 "Sample Guide" for specific holding times.
Do samples **match COC**** (i.e.,sample IDs,dates/times collected)?	N/C	
**Note: If times differ <1hr, record details & login per COC.		
***Note: If sample information on containers differs from COC, SGS will default to COC information		
Were samples in good condition (no leaks/cracks/breakage)?	Yes	
Were analytical requests clear? (i.e., method is specified for analyses with multiple option for analysis (Ex: BTEX, Metals)	Yes	
Were Trip Blanks (i.e., VOAs, LL-Hg) in cooler with samples?	N/A	
Were all water VOA vials free of headspace (i.e., bubbles ≤ 6mm)?	N/A	
Were all soil VOAs field extracted with MeOH+BFB?	N/A	
For Rush/Short Hold Time, was RUSH/Short HT email sent?	N/A	

Note to Client: Any "No", answer above indicates non-compliance with standard procedures and may impact data quality.

Additional notes (if applicable):

SGS Profile #	**337923**	337923

Sample Containers and Preservatives

Container Id	Preservative	Container Condition	Container Id	Preservative	Container Condition
1199895001-A	No Preservative Required	OK			
1199895002-A	No Preservative Required	OK			
1199895003-A	No Preservative Required	OK			
1199895004-A	No Preservative Required	OK			
1199895005-A	No Preservative Required	OK			
1199895006-A	No Preservative Required	OK			
1199895007-A	No Preservative Required	OK			
1199895008-A	No Preservative Required	OK			
1199895009-A	No Preservative Required	OK			
1199895010-A	No Preservative Required	OK			
1199895011-A	No Preservative Required	OK			
1199895011-B	No Preservative Required	OK			
1199895011-C	No Preservative Required	OK			
1199895011-D	No Preservative Required	OK			
1199895012-A	No Preservative Required	OK			
1199895012-B	No Preservative Required	OK			
1199895012-C	No Preservative Required	OK			
1199895012-D	No Preservative Required	OK			
1199895013-A	No Preservative Required	OK			
1199895013-B	No Preservative Required	OK			
1199895013-C	No Preservative Required	OK			
1199895013-D	No Preservative Required	OK			
1199895014-A	No Preservative Required	OK			
1199895014-B	No Preservative Required	OK			
1199895014-C	No Preservative Required	OK			
1199895014-D	No Preservative Required	OK			
1199895015-A	No Preservative Required	OK			
1199895015-B	No Preservative Required	OK			
1199895015-C	No Preservative Required	OK			
1199895015-D	No Preservative Required	OK			

Container Condition Glossary

Containers for bacteriological, low level mercury and VOA vials are not opened prior to analysis and will be assigned condition code OK unless evidence indicates than an inappropriate container was submitted.

OK - The container was received at an acceptable pH for the analysis requested.
BU - The container was received with headspace greater than 6mm.
DM - The container was received damaged.
FR - The container was received frozen and not usable for Bacteria or BOD analyses.
IC - The container provided for microbiology analysis was not a laboratory-supplied, pre-sterilized container and therefore was not suitable for analysis.
NC- The container provided was not preserved or was under-preserved. The method does not allow for additional preservative added after collection.
PA - The container was received outside of the acceptable pH for the analysis requested. Preservative was added upon receipt and the container is now at the correct pH. See the Sample Receipt Form for details on the amount and lot # of the preservative added.
PH - The container was received outside of the acceptable pH for the analysis requested. Preservative was added upon receipt, but was insufficient to bring the container to the correct pH for the analysis requested. See the Sample Receipt Form for details on the amount and lot # of the preservative added.
QN - Insufficient sample quantity provided.

Laboratory Data Review Checklist

Completed By:

Ashley Jaramillo

Title:

Chemist

Date:

November 21, 2019

CS Report Name:

20094 Grant Mine

Report Date:

November 12, 2019

Consultant Firm:

Shannon & Wilson, Inc.

Laboratory Name:

SGS North America, Inc.

Laboratory Report Number:

1199895

ADEC File Number:

100.38.182

Hazard Identification Number:

731

1199895

1. Laboratory

   a. Did an ADEC CS approved laboratory receive and perform all of the submitted sample analyses?

      ● Yes ○ No Comments:

      Analyses were performed by the SGS laboratory in Anchorage, AK.

   b. If the samples were transferred to another “network” laboratory or sub-contracted to an alternate laboratory, was the laboratory performing the analyses ADEC CS approved?

      ○ Yes ● No Comments:

      Not applicable, no samples were transferred or subcontracted to an alternate laboratory.

2. Chain of Custody (CoC)

   a. CoC information completed, signed, and dated (including released/received by)?

      ● Yes ○ No Comments:

   b. Correct Analyses requested?

      ● Yes ○ No Comments:

3. Laboratory Sample Receipt Documentation

   a. Sample/cooler temperature documented and within range at receipt (0° to 6° C)?

      ● Yes ○ No Comments:

   b. Sample preservation acceptable – acidified waters, Methanol preserved VOC soil (GRO, BTEX, Volatile Chlorinated Solvents, etc.)?

      ● Yes ○ No Comments:

   c. Sample condition documented – broken, leaking (Methanol), zero headspace (VOC vials)?

      ● Yes ○ No Comments:

      The laboratory noted that samples were received in good condition.

d. If there were any discrepancies, were they documented? For example, incorrect sample containers/preservation, sample temperature outside of acceptable range, insufficient or missing samples, etc.?

○ Yes ● No Comments:

Not applicable, no discrepancies were noted by the laboratory during sample login.

e. Data quality or usability affected?

Comments:

The data quality and usability were not affected.

4. Case Narrative

a. Present and understandable?

● Yes ○ No Comments:

b. Discrepancies, errors, or QC failures identified by the lab?

○ Yes ● No Comments:

Metals MS/MSD recoveries for barium and antimony do not meet QC criteria. The post digestion spike was successful. See section 6.b.iii for discussion.

c. Were all corrective actions documented?

● Yes ○ No Comments:

See above.

d. What is the effect on data quality/usability according to the case narrative?

Comments:

Case narrative does not discuss effect on data quality, it only discusses discrepancies and what was done in light of them. Any notable data quality issues mentioned in the case narrative are discussed above in 4b or elsewhere within this ADEC checklist.

5. Samples Results

a. Correct analyses performed/reported as requested on COC?

● Yes ○ No Comments:

b. All applicable holding times met?

● Yes ○ No Comments:

c. All soils reported on a dry weight basis?

● Yes ○ No Comments:

d. Are the reported LOQs less than the Cleanup Level or the minimum required detection level for the project?

● Yes ○ No Comments:

e. Data quality or usability affected?

○ Yes ● No Comments:

See above.

6. <u>QC Samples</u>

a. Method Blank

i. One method blank reported per matrix, analysis and 20 samples?

● Yes ○ No Comments:

ii. All method blank results less than limit of quantitation (LOQ)?

● Yes ○ No Comments:

iii. If above LOQ, what samples are affected?

Comments:

N/A; see above.

iv. Do the affected sample(s) have data flags? If so, are the data flags clearly defined?

○ Yes ● No Comments:

N/A; see above.

v. Data quality or usability affected?

Comments:

No; see above.

b. Laboratory Control Sample/Duplicate (LCS/LCSD)

i. Organics – One LCS/LCSD reported per matrix, analysis and 20 samples? (LCS/LCSD required per AK methods, LCS required per SW846)

○ Yes ● No Comments:

N/A; organics were not analyzed.

ii. Metals/Inorganics – one LCS and one sample duplicate reported per matrix, analysis and 20 samples?

● Yes ○ No Comments:

An LCS and a MS/MSD were reported metals analysis.

iii. Accuracy – All percent recoveries (%R) reported and within method or laboratory limits? And project specified DQOs, if applicable. (AK Petroleum methods: AK101 60%-120%, AK102 75%-125%, AK103 60%-120%; all other analyses see the laboratory QC pages)

○ Yes ● No Comments:

The MS and/or MSD recovery for barium, antimony, and chromium did not meet laboratory QC criteria. However, the parent sample used for the MS/MSD analyses was not a project sample. Therefore, data quality/usability not affected.

iv. Precision – All relative percent differences (RPD) reported and less than method or laboratory limits? And project specified DQOs, if applicable. RPD reported from LCS/LCSD, MS/MSD, and or sample/sample duplicate. (AK Petroleum methods 20%; all other analyses see the laboratory QC pages)

● Yes ○ No Comments:

v. If %R or RPD is outside of acceptable limits, what samples are affected?

Comments:

N/A; The parent sample for the MS and MSD recovery failures were not associated with the samples collected for this project. In addition, post digestion spikes for these MS and MSD samples were with laboratory QC criteria. Project samples are not affected by these QC failures.

vi. Do the affected sample(s) have data flags? If so, are the data flags clearly defined?

○ Yes ● No Comments:

See above.

vii. Data quality or usability affected? (Use comment box to explain.)

Comments:

No; see above.

c. Surrogates – Organics Only

i. Are surrogate recoveries reported for organic analyses – field, QC and laboratory samples?

○ Yes ● No Comments:

N/A; organics were not analyzed.

ii. Accuracy – All percent recoveries (%R) reported and within method or laboratory limits? And project specified DQOs, if applicable. (AK Petroleum methods 50-150 %R; all other analyses see the laboratory report pages)

○ Yes ● No Comments:

N/A; organics were not analyzed.

iii. Do the sample results with failed surrogate recoveries have data flags? If so, are the data flags clearly defined?

○ Yes ● No Comments:

N/A; organics were not analyzed.

iv. Data quality or usability affected?

Comments:

No; see above.

d. Trip blank – Volatile analyses only (GRO, BTEX, Volatile Chlorinated Solvents, etc.): <u>Water and Soil</u>

i. One trip blank reported per matrix, analysis and for each cooler containing volatile samples?
(If not, enter explanation below.)

○ Yes ● No Comments:

N/A; volatiles were not analyzed.

ii. Is the cooler used to transport the trip blank and VOA samples clearly indicated on the COC? (If not, a comment explaining why must be entered below)

● Yes ○ No Comments:

N/A; volatiles were not analyzed.

iii. All results less than LOQ?

● Yes ○ No Comments:

N/A; volatiles were not analyzed.

iv. If above LOQ, what samples are affected?

Comments:

None; see above.

v. Data quality or usability affected?

Comments:

No; see above.

e. Field Duplicate

i. One field duplicate submitted per matrix, analysis and 10 project samples?

● Yes ○ No Comments:

The samples submitted with this work order contain a replicate ISM sample. The results of the three replicates are used to calculate a relative standard deviation (RSD) to assess the overall representativeness of the data. The formula used to calculate $RSD(\%) = \frac{Standard\ Deviation}{Arithmetic\ Mean\ of\ Target\ Analyte} \times 100$

ii. Submitted blind to lab?

● Yes ○ No Comments:

The ISM replicate samples 19GM-DU3 *A*, *B*, *C* were submitted with this work order.

iii. Precision – All relative percent differences (RPD) less than specified DQOs? (Recommended: 30% water, 50% soil)

$$\text{RPD (\%) = Absolute value of: } \frac{(R_1 - R_2)}{((R_1 + R_2)/2)} \times 100$$

Where R_1 = Sample Concentration
R_2 = Field Duplicate Concentration

● Yes ○ No Comments:

The RSD calculated for the ISM replicates *A*, *B*, and *C* of the sample *19GM-DU3* were within the recommended DQO of 30% for all analytes, were calculable.

iv. Data quality or usability affected? (Use the comment box to explain why or why not.)

Comments:

No, see above.

f. Decontamination or Equipment Blank (If not applicable, a comment stating why must be entered below).

○ Yes ○ No ● Not Applicable

Samples were collected with disposable equipment.

i. All results less than LOQ?

○ Yes ● No Comments:

N/A; an equipment blank was not submitted.

ii. If above LOQ, what samples are affected?

Comments:

N/A; an equipment blank was not submitted.

iii. Data quality or usability affected?

Comments:

No; see above.

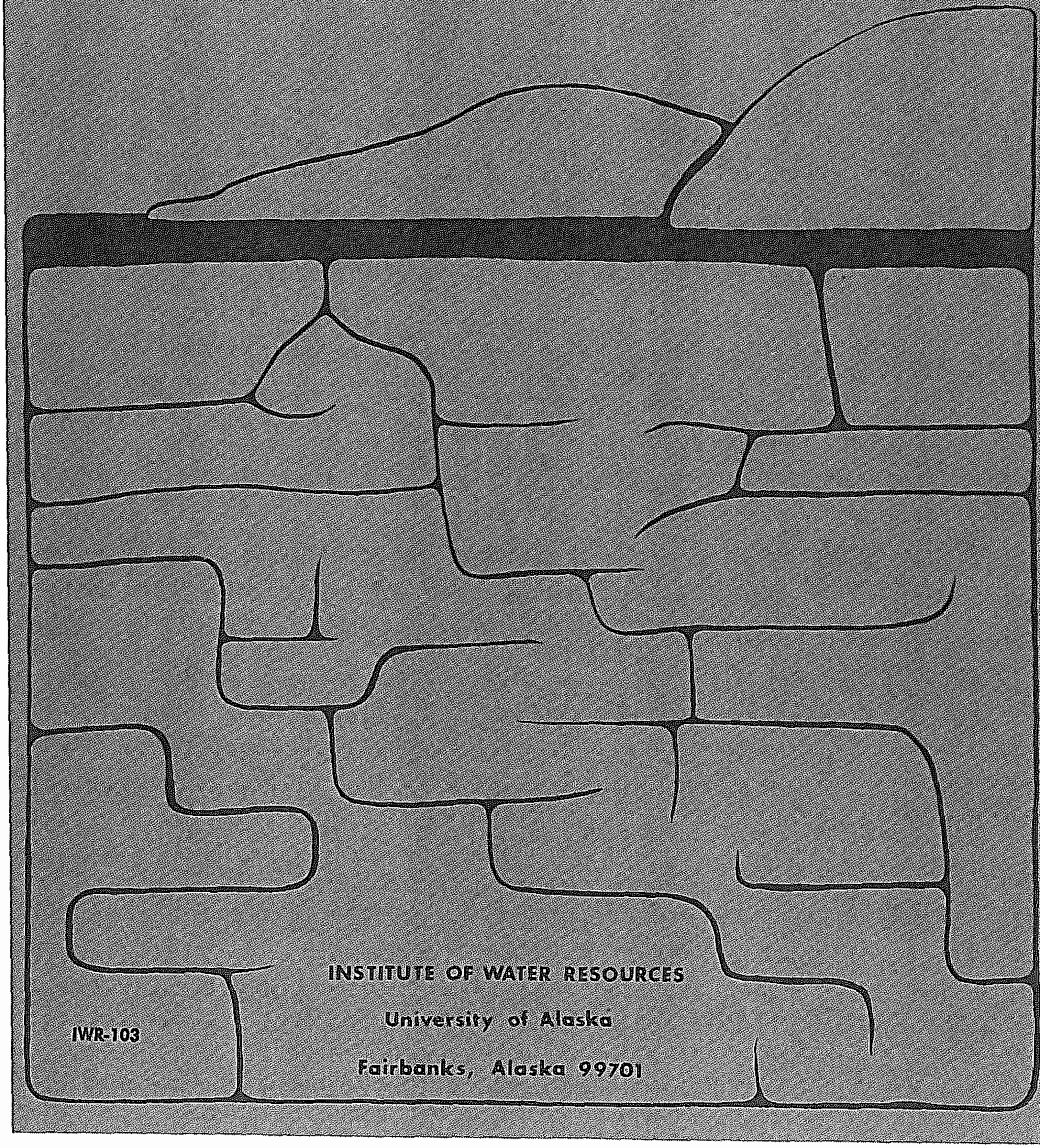
7. Other Data Flags/Qualifiers (ACOE, AFCEE, Lab Specific, etc.)

a. Defined and appropriate?

○ Yes ● No Comments:

Additional data flags or qualifiers are not required.

ARSENIC IN THE WATER, SOIL BEDROCK AND PLANTS OF THE ESTER DOME AREA OF ALASKA



IWR-103

INSTITUTE OF WATER RESOURCES

University of Alaska

Fairbanks, Alaska 99701

ARSENIC IN THE WATER, SOIL, BEDROCK AND PLANTS OF THE ESTER DOME AREA OF ALASKA

Arsenic in the water, soil, bedrock adn plants of the Ester Dome area of Alaska

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Report IWR-103 June 1982

ABSTRACT

Concentrations of arsenic as large as 10 ppm (200 times the safe limit for drinking water) occur in the groundwater of a mineralized residential area near Fairbanks. Bedrock of the area contains 750 ppm As, primarily as arsenopyrite and scorodite. The oxygen-poor groundwater is enriched in As(III) and ferrous iron while the surface waters are iron free and contain less than 50 ppb As(V). Arsenic is removed from the water by coprecipitation with ferric hydroxide. Some iron-rich stream sediments contain as much as 1,400 ppm arsenic.

The distribution of arsenic in the groundwater is controlled by the distribution of arsenic in the bedrock. The arsenic content of the B soil horizon over mineralized veins is about 150 ppm, while that over barren rock is 30 ppm. The vegetation over the veins is not significantly enriched in arsenic.

Lettuce, radishes and tomatoes grown with arsenic-rich water (5 ppm) contain 16, 8 and 1 ppm As, respectively; these amounts are significantly greater than plants not treated with arsenic.

Preliminary studies by state and federal health agencies show no detrimental effects on the health of persons drinking these arsenic-rich waters.

ACKNOWLEDGMENTS

We thank the Jerry Swartz family and the James Barefoot family for their cooperation in this study. We also thank Swan Drilling for its cooperation in permitting us to log wells while they were being drilled. The work upon which this publication is based was supported in part by funds provided by the Office of Water Research and Technology (Project B-037-ALAS, Agreement No. 14-34-0001-8056), U.S. Department of the Interior, Washington, D.C., as authorized by the Water Research and Development Act of 1978.

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AN INTRODUCTION TO THE ARSENIC PROBLEM

GENERAL

Arsenic (As) is a rare element with an average concentration in crustal rocks of about 5 parts per million (ppm = 1 mg/kg). Its abundance in various terrestrial materials is shown in Table 1 (Whiteacre and Pearse, 1974).

TABLE 1: ARSENIC CONCENTRATION IN VARIOUS ROCKS.

Material	As (ppm)
Igneous rocks	1.5
Sedimentary rocks	
Shales	13
Sandstones	1
Limestones and dolomites	1
Pelagic clays	11
Coal	25
Metamorphic rocks	0.4-18

Arsenic occurs in more than 100 minerals, but it is a major constituent in only a few of these. Arsenic is present naturally in soils at concentrations ranging from 1 to 100 ppm (Whiteacre and Pearse, 1974; Shacklette and Connors, 1975), with an average concentration of about 5-10 ppm.

In waters free from arsenic pollution, the arsenic concentration is about one part per billion (ppb = 0.001 mg/kg). In waters contaminated by natural or man-made sources of arsenic, the arsenic concentration can range as high as hundreds to several thousands of parts per million (National Academy of Sciences, 1977).

Arsenic is a common, naturally occurring, trace constituent in plants. The concentrations of arsenic in plants depend upon the kind of plant and the quantity of arsenic to which the plant was exposed. On the average, the arsenic content of plants varies from less than 0.01 ppm to about 5 ppm (dry-weight basis), with some plants containing as much as 94 ppm (National Academy of Sciences, 1977).

Arsenic is present in animals and man. Marine fishes may contain up to 10 ppm, while mollusks and some crustaceans contain as much as 128 ppm. Freshwater fishes usually contain less than 1 ppm, although values may reach 3 ppm. Domestic animals and man generally contain less than 0.3 ppm on a wet-weight basis. The total human-body content of arsenic is between 3 and 4 mg, and tends to increase with age (National Academy of Sciences, 1977).

Arsenic is widely used in insecticides, herbicides, dessicants, wood preservatives, feed additives, drugs, war gases and riot-control agents, and in various metallurgical applications. As a result, man contributes to the quantity and distribution of arsenic in the environment. The general cycle of arsenic shown in Figure 1 summarizes the different sources of arsenic and the transfer processes.

Arsenic has long been used as a pharmaceutical but a specific nutritional role of inorganic arsenic has only recently been revealed. A curious feature of arsenic biochemistry is the ability of arsenic to counteract partially the ill effects of another toxic element, selenium. Suffice it to say that the biochemistry of arsenic is complex and differs with different organisms (National Academy of Sciences, 1977).

The toxicological effects on humans from drinking arsenic-rich water is particularly relevant to the present study in which arsenic concentrations ranging from 400 to 21,000 ppb (0.4 to 21 ppm) have been found. Such concentrations, comparable to those in the waters of Ester Dome (near Fairbanks, Alaska) have been encountered elsewhere in the world and their toxicological effects documented. For example, acute and subacute arsenic intoxication occurred in Minnesota from drinking well waters contaminated by pesticides containing 11 to 21 ppm As. In Antefogasta, Chile, skin pigmentation changes and squamous cell carcinoma resulted from long-term consumption of well waters containing around 580 ppb arsenic. Similarly in Taiwan, peripheral vascular disease and skin carcinoma resulted from long-term ingestion of well water containing from 400 to 600 ppb arsenic (Harrington et al., 1978).

Although similar concentrations of arsenic are present in some well waters of the hillside areas around Fairbanks, no clinical abnormalities

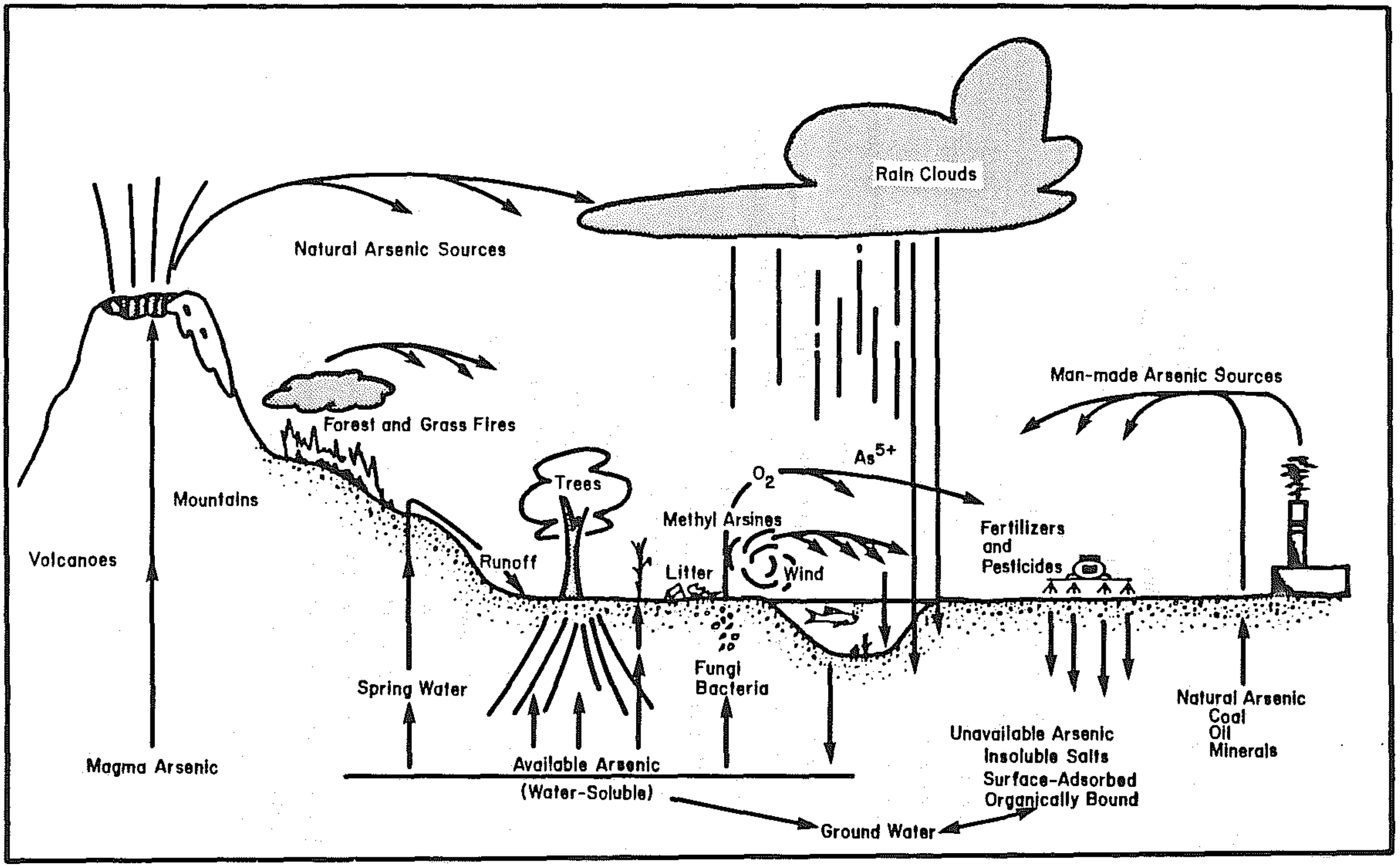

Figure 1. The general arsenic cycle (adapted from National Academy of Sciences, 1977).

in the human population drinking these waters have been found. Harrington et al. suggest that "higher concentrations or longer times of exposure are required to produce overt clinical effects in a well-nourished U.S. population."

A number of studies bearing on different aspects of arsenic in the environment have been published recently. The list of references at the end of this section is not complete but serves as an introduction to the extensive literature on arsenic.

PREVIOUS WORK

The earliest work on arsenic in waters of the Fairbanks area began in 1974 as an outgrowth of a joint University of Alaska and U.S. Geological Survey Heavy-Metals Project carried out from 1967-1970 (see, for example, Stevens et al., 1969). This project studied the gold mineralization in the Fairbanks District, where gold is accompanied by arsenic mineralization in soils and bedrock. The extent of arsenic enrichment in the area revealed by the study led one of us (DBH) to postulate that arsenic may be present in water of the Fairbanks area.

As a result, a study was begun (Wilson and Hawkins, 1978) to investigate arsenic concentrations in the surface and groundwaters of the Cleary Summit -- Pedro Dome area near Fairbanks. This study showed that surface waters and particularly stream sediments of certain streams were enriched in arsenic. A limited number of wells were sampled and analyzed for arsenic, three of which showed arsenic concentrations slightly in excess of 50 ppb -- the U.S. Public Health Service (USPHS) recommended concentration limit for arsenic in domestic waters.

A subsequent study of the waters of the Ester Dome area was undertaken by Wilcox (Johnson et al., 1978). This area has gold-arsenic mineralization and also is a developing residential area where the water supply is drawn from domestic wells. She showed that concentrations of arsenic as large as 3 ppm were present in domestic well waters. State and federal health authorities were notified, resulting in an extensive water-testing program (Johnson et al., 1978). As a result, a number of domestic wells in the Ester Dome area and other hillside residential areas around Fairbanks were found to contain arsenic in excess of the USPHS concentration limits.

These findings sparked a joint investigation by state and federal health authorities (Harrington et al., 1978). This study showed that persons drinking arsenic-enriched waters were themselves enriched in arsenic. No detrimental effects to the population were evident but, because the effects of chronic exposure to small concentrations of arsenic are not well known, a subsequent study by the Federal Center for Disease Control and the University of Boston's Medical School was undertaken in the summer of 1978. In this study, numerous people were examined for possible neurological damage resulting from ingesting arsenic. The results of this study are being evaluated.

Since 1976, geological and geochemical studies have been continued by the Institute of Water Resources and the Geology-Geophysics Program, at the University of Alaska. A Student-Initiated National Science Foundation grant was obtained by Burton et al. (1978) to investigate arsenic in soils, plants and waters of the Ester Dome area and, in particular, to examine the effects of mining activities on the arsenic concentrations of surface waters and groundwaters. Burton et al. suggested that lode-gold mining activities may contribute to the arsenic burden of streams draining the area where mining is being carried out. They also studied the uptake of arsenic by various plants native to the region. They concluded that Labrador tea (*Ledum* spp.) took up arsenic from the soil and that the arsenic content of the ash from this plant might be indicative of arsenic-bearing mineral assemblages in the bedrock.

THIS STUDY

The present study attempts to answer questions of geological and geochemical nature that were raised as a result of preceding work.

- What are the sources of arsenic in the waters of the Ester Dome area?
- What governs the behavior of arsenic in the groundwater?
- Why are there such strong, lateral concentration gradients present in the groundwater?

- What processes govern the behavior of arsenic in the surface waters?
- Can areas of probable arsenic contamination of the groundwater be predicted on the basis of geology?
- Does native vegetation become enriched in arsenic as a result of growing in arsenic-rich soil?
- Do garden vegetables become enriched in arsenic as a result of being irrigated with arsenic-rich water?
- Are there methods that can be used by homeowners to remove arsenic from their water supplies?

This study is divided into two segments: the geologic aspects of arsenic in the Ester Dome area; and the geochemistry of arsenic.

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See also National Academy of Sciences (1977) under General.

GEOLOGY AND LODE DEPOSITS OF ESTER DOME

INTRODUCTION

To understand the geology of a small area such as Ester Dome, it is necessary to see how the geologic features of the small area fit into the general geologic fabric of a much larger region. This section presents an overview of the regional geology of the Yukon-Tanana Uplands before focussing on the geology of Ester Dome. This permits an interpretation of the geology of Ester Dome that is compatible with the geology of the surrounding region.

REGIONAL GEOLOGY

Petrology and Structure of the Crystalline Basement Rocks

The Yukon-Tanana Uplands are underlain by crystalline rocks of the Yukon-Tanana Complex (Foster et al., 1973). The oldest rocks in the complex are schists and gneisses which were formerly known as the Birch Creek Schist Formation (Spurr, 1898). Previously, this sequence of metamorphic rocks was believed to be of Precambrian age (Mertie, 1937), but recent work has shown that the Yukon-Tanana metamorphic terrane is composed of at least two sequences of metamorphic rocks, which include parental rocks of differing ages.

The metamorphics have been intruded by granitic rocks ranging in composition from granodiorite to granite. Some of these masses, including the Charley River and Mt. Harper plutons are of batholithic dimensions. The schists and gneisses have also been intruded by small mafic and ultramafic plutons, including diorite, gabbro, hornblendite, and periodotite.

Outcrop patterns of the metamorphic rocks in the Fairbanks and Big Delta districts form several northeast-trending belts (Figure 2). One belt of highly deformed greenschist-facies rocks characterized by slate and calc-phyllite is traceable through the central part of the Fairbanks district. To the southeast, a zone of cataclastic rocks separates two amphibolite-facies schist-terranes. The amphibolite-facies rocks include biotite schists and various gneisses. The fabrics indicate that

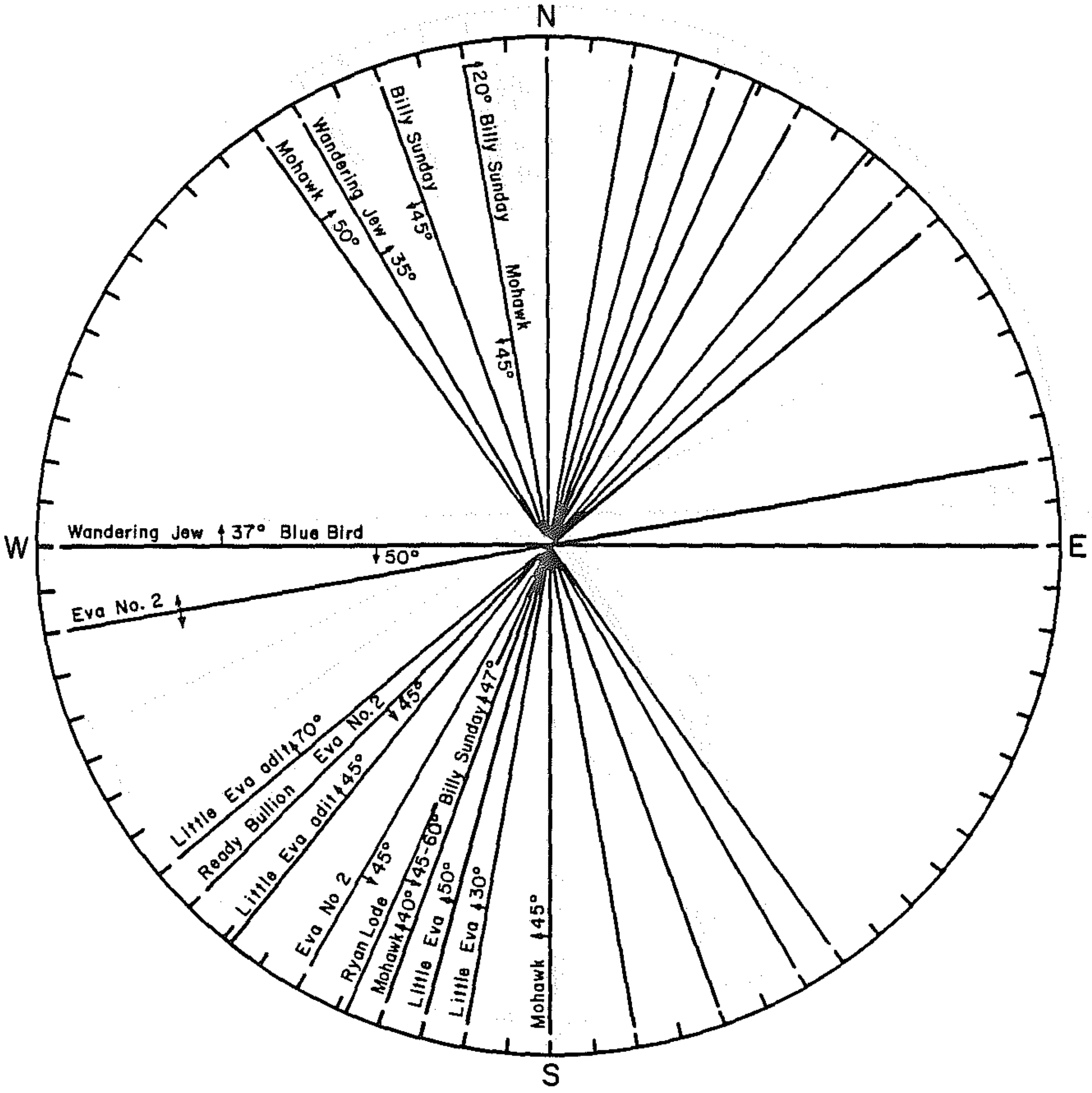

Figure 2A. Orientation of veins in the Ester Dome area (adapted from Hill, 1933).

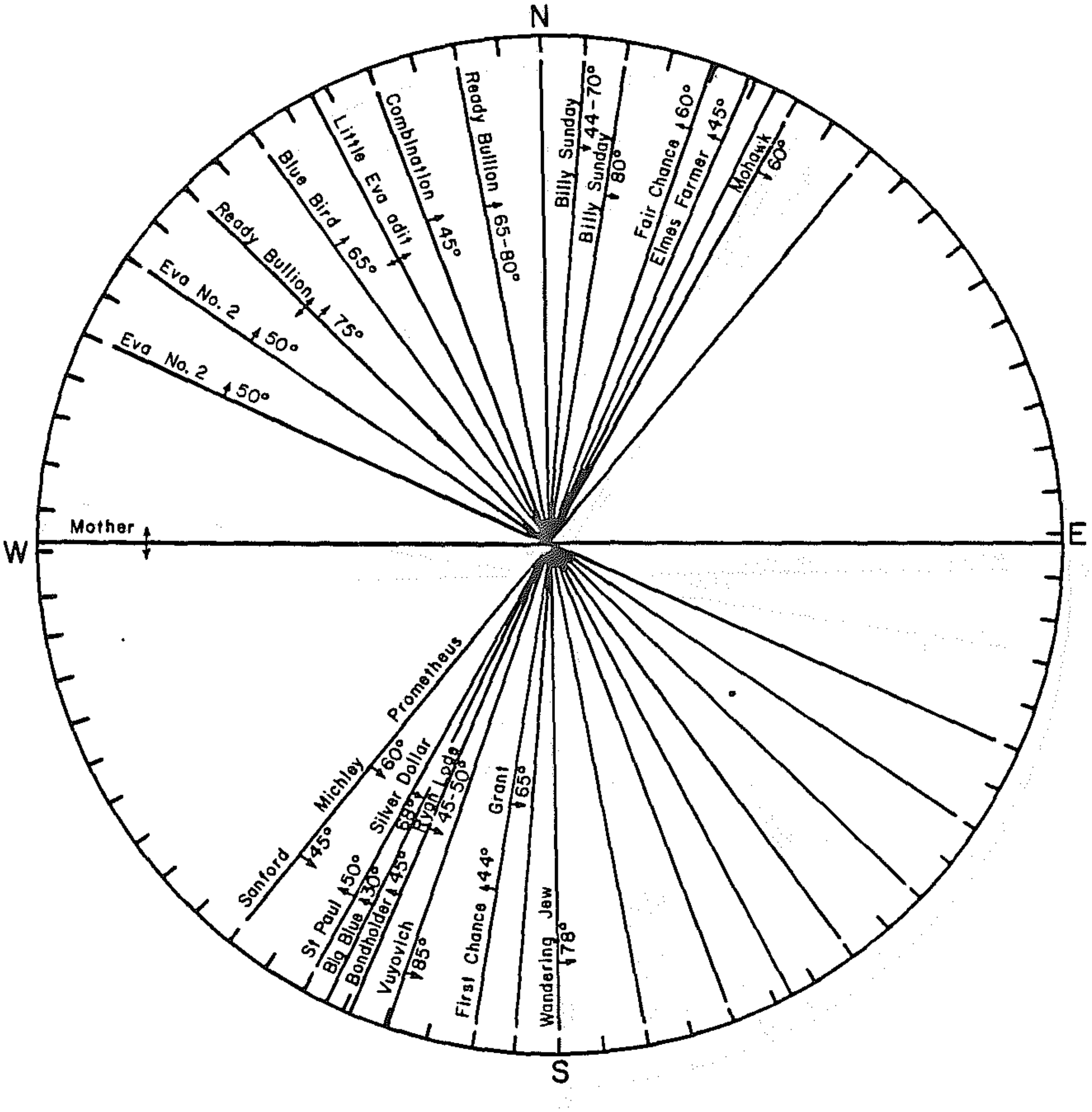

Figure 2B. Orientation of faults in the Ester Dome area (adapted from Hill, 1933).

these rocks have a polymetamorphic history, and that amphibolite-facies metamorphism was followed by a retrograde event that resulted in the formation of assemblages belonging to the greenschist facies in some areas.

The north margin of the greenschist-facies belt grades into mica schists transitional between greenschist and epidot-amphibolite facies. In this zone of metamorphic rocks (Figure 2), Prindle (1973) discovered an eclogite-bearing terrane about 15 mi (24 km) north of Fairbanks. Recent studies of these rocks by Forbes et al. (1968), and Swainbank and Forbes (1975), indicate that younger pelitic schists and subordinate greenschists have been thrust over the older and more highly deformed eclogitic rocks.

The thrust zone, where exposed along the Elliott Highway, is defined by coarse-grained garnetiferous calc-mylonites, which appear to be cataclastically deformed, and by retrograded calc-silicate rocks. Eclogitic rocks intercalated with calcium-magnesium schists are characterized by the assemblage clinopyroxene-garnet-carbonate-sphene (with or without quartz). The structural style is isoclinal-overturned, with northwesterly trending fold axes. This is a trend which is discordant to the northeasterly trending fold axes of the schists that compose the upper plate. The northwesterly trending folds of the lower plate were subsequently refolded into open synclines and anticlines along the younger northeasterly trend.

Metamorphic and Intrusive History

To date, none of the potassium-argon (K-Ar) dating done on metamorphic rocks from the Uplands has produced a valid Precambrian crystallization age. Hornblende K-Ar data indicate an initial cooling age of 180-190 million years for amphibolite facies rocks from the Fairbanks, Fortymile, Delta and Eagle quadrangles. This earlier apparent age has been perturbed in some areas by a younger thermal event which is reflected in potassium-argon mica ages ranging between 90 and 120 million years.

The later thermal event is probably related to the widespread emplacement of granitic plutons during this same time period.

The eclogite-bearing schist terrane, which is exposed as a structural window north of Fairbanks, has yielded an amphibole potassium-argon age of 470 ± 35 million years (MY).

Based on radiometric age data and the above evidence, the metamorphic terranes of the Yukon-Tanana Complex were derived from parental rocks ranging in age from late Precambrian to late Paleozoic.

MESOZOIC SEDIMENTARY AND VOLCANIC ROCKS

Sedimentary Rocks

Fossiliferous Mesozoic sedimentary rocks have not been found in the southeastern part of the Yukon-Tanana Uplands, although a re-entrant of Cretaceous argillaceous sediments has been mapped in the Livengood District, northwest of Fairbanks.

Volcanic Rocks

Small areas of tholeiitic basaltic rocks, including pillow basalts, subaerial flows and breccias occur in the Fairbanks District. These rocks are characteristically preserved in downthrown fault blocks. Preliminary potassium-argon age determinations indicate that these basalts are of late Cretaceous age. Silicified mata-sequoia trunks and branches have been discovered in a fossil soil zone between the schists and the overlying basalts, supporting an early Cretaceous age for the basalts.

Basalt also occurs as cross-cutting dikes throughout the Uplands. Based on compositional similarities to those in the Fairbanks District and minimal alteration, they are probably of late Cretaceous or early Tertiary age.

TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

Sedimentary Rocks

Tertiary sediments including siltstones, sandstones and conglomerates occur as small, isolated outcrop areas in the Yukon-Tanana Uplands. All of the known occurrences are of continental origin, and some of the preserved sections contain coal measures and/or basal basalts. The lithology and stratigraphy of these sections are similar to that of the coal-bearing Tertiary on the north flank of the Alaska Range.

Volcanic Rocks

A large Tertiary volcanic field dominated by felsic volcanic rocks including welded tuffs has been mapped in the Tanacross Quadrangle by Foster (1970). The volcanic suite is similar to that of the Tertiary volcanic fields of the Great Basin, or the circum-Pacific island arcs. Possible caldera structures have also been described by Foster (1970).

GLACIAL HISTORY

Although there is fragmentary evidence which suggests that glaciation in interior Alaska may have been initiated in late Miocene or Pliocene time, moraines and outwash of the Delta (Illinoian) Glaciation mark the onset of glaciation in the northeastern part of the Alaska Range (Pewe and Holmes, 1964; Holmes and Foster, 1968). Delta Glaciation, following the Sangamon interglacial interval, was followed by the Donnelly (Wisconsin) Glaciation.

Both Illinoian and Wisconsin glaciations have left a record in the northeastern Alaska Range and the Yukon-Tanana Uplands. Glaciation in the Uplands was restricted to local alpine glacial systems which developed in the higher hills, and included relatively small distributary valley glaciers; however, valley glaciers descending the north slope of the Alaska Range reached the flood plains of the Tanana, Delta and Tok rivers, as documented by moraines and glacio-fluvial deposits which have been identified and mapped by Pewe and Holmes (1964), and others.

Glacial advances were accompanied by a great increase in the amount of suspended sediment brought into the master streams by tributaries descending the north slope of the Alaska Range. As a result, the Tanana, Delta and Tok rivers aggraded their channels, causing lateral migration and meandering across the valley floor at a rate which was too rapid for the development of vegetation on the valley floor. Therefore, southerly winds were able to pick up a large quantity of silt from the floodplains, and deposit it in the uplands to the north as "loess."

Alluvial and Colluvial Deposits

During Holocene time (beginning 10,000 years ago), tributary streams in the uplands have initiated a new cycle of downcutting. The master streams are no longer overladen with glacial debris, and geodetic measurements indicate that the Tanana Valley is subsiding, and that the Alaska Range is undergoing relative uplift. Under these conditions, glacial deposits are being reworked by the master streams in the floodplains, and colluvial deposits are developing in the uplands.

Permafrost

During Wisconsin time, the $0^{\circ}C$ isotherm may have reached depths down to 1,200 ft in the Yukon-Tanana District. During the last two or three thousand years, a warming trend has initiated a long-term thawing cycle. Currently, the permafrost table is deepest on north-facing slopes, and in alluvial fill covered by vegetation in steep-walled valleys. Broad valleys, floored by floodplain deposits are underlain by discontinuous permafrost. South-facing slopes are generally free of permafrost.

THE GEOLOGY AND STRUCTURE OF ESTER DOME

Crystalline Basement Rocks

Ester Dome is underlain by metamorphic and igneous rocks of the Yukon-Tanana Complex, including micaceous quartzites, quartz-mica schists (with and without garnet), calc-schists and subordinate greenschists, amphibolites and impure marbles. The metamorphic rocks have been intruded by dikes and small plutons of biotite-granodiorite-quartz monzonite. However, there is no proved association between these particular intrusives and mineralization on Ester Dome.

Structure of the Crystalline Basement Rocks

Structural measurements including the attitudes of bedding, foliation, fold axes and mineral lineations indicate that the metamorphic rocks of Ester Dome have been deformed into a structural high with the geometry of an asymmetric anticlinorium (Figure 3).

Divergent plunge patterns of small fold axes, with an apex near the topographic summit of Ester Dome, suggest that the structure may actually be an asymmetric dome. Additional evidence for a domal structure is offered by the break in continuity of both rock type and structural axes, between Ester Dome and the hills northeast of the Goldstream Valley. An alternate explanation could be supplied by offset due to faulting along the trace of the valley, or a combination of doming and faulting.

The amphibolites, coarse-grained garnet-mica schists and marbles that are exposed in the Murphy Dome road cuts (on the southwest slope of Goldstream Valley), have not been found in outcrop or in the subsurface mine workings on Ester Dome. However, this sequence of rocks does occur along the crest of Chena Ridge, south of the Ester-Cripple Creek Valley.

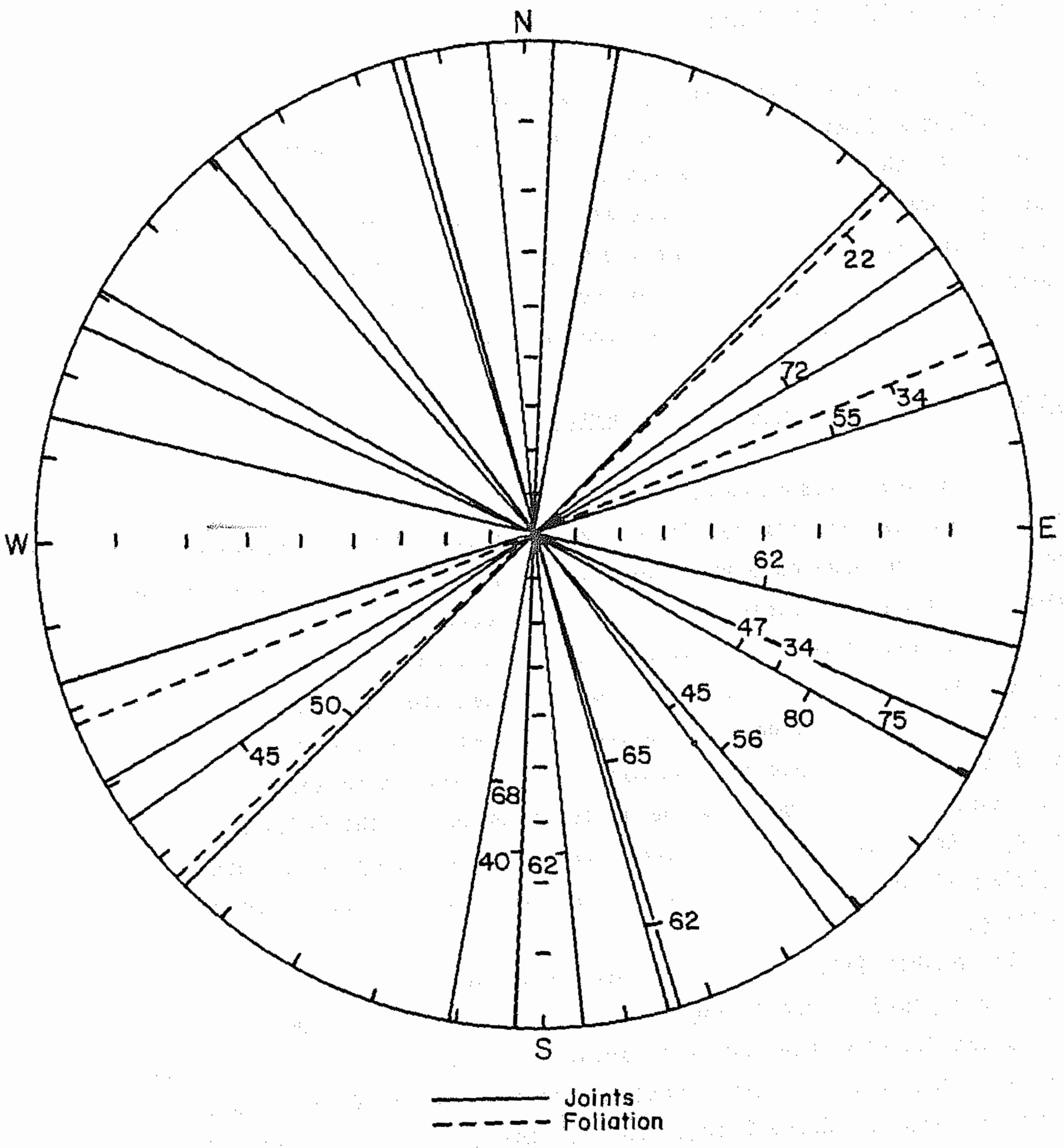

Figure 3. Orientation of joints and the attitude of the foliation of host micaceous quartzites on the southeastern flank of Ester Dome.

Surficial Deposits

The valleys descending the flanks of Ester Dome contain alluvial sands and gravels deposited by ancestral streams which were responsible for valley downcutting during Quaternary time. Most of the steep valley sides are underlain by colluvium which interfingers with the alluvial sands and gravels on the valley floors.

Wind-blown silt (loess) blankets the older colluvial and alluvial deposits, and it is mixed with organic material in the valley fill. Valley fill is perennially frozen on all exposures around the Dome. The loess blanket is thicker on the south slopes, and much thinner on the north (lee) flank of the Dome.

Surficial deposits on south-facing ridges are usually thawed, but loess and colluvium on north exposures are perennially frozen.

Groundwater Geology

The loess blanket that overlies bedrock, colluvium and alluvium is relatively impermeable. Therefore, water wells driven into the upper slopes of Ester Dome obtain water from fracture systems in bedrock, as porosity is practically nil in the highly recrystallized metamorphic rocks. A few producing wells may obtain water from colluvial fans on valley sides, but the dominant aquifer at the higher elevations is fractured bedrock. Fracture systems are more highly developed in the more competent and brittle rock units (e.g. quartzites) rather than the more highly schistose rock types (e.g. mica schists).

In recent years, dwellings have been constructed on placer tailings in the Ester-Cripple and Sheep Creek valleys, and water is also being obtained from wells driven down to the contact zone between the base of the tailings and underlying bedrock.

Artesian systems are unknown in any of the above settings, and it is reasonable to conclude that groundwater recharge is dependent on the downward percolation of water from local rain and snowmelt into the aquifers. Currently, we do not have hard data on the recharge rate and draw-down characteristics of these aquifers.

MINERALIZED ZONES AND VEIN SYSTEMS

Lode Classification and Distribution

The gold-bearing quartz lodes of Ester Dome are similar to those that occur elsewhere in the Fairbanks gold belt, which extends northeast from Ester Dome to Pedro Dome and the Cleary Summit area. Although contact metasomatic deposits are known to occur around the margins of the quartz monzonite plutons on Gilmore Dome and Pedro Dome, and fissure sulfide veins were encountered in the Busty Belle adit on Pedro Dome, lode deposits in the Fairbanks gold belt are dominantly fissure-controlled or fault-controlled metalliferous quartz veins in micaceous quartzites and quartz-mica schists. Recent work also suggests that strata-bound sulfide concentrations also occur in the Pedro Dome -- Cleary Summit area, which were formerly interpreted as replacement deposits (P. Metz, personal communication). The existence of this type of deposit may be relevant to the arsenic problem, and the implications are discussed in more detail in a later section.

Although the lode deposits appear to be spatially related to granitic stocks and dikes in the Pedro Dome -- Cleary Summit area, this association is not obvious on Ester Dome, unless the plutons are undetected in the subsurface.

Mineralogy of the Lodes

Sandvik (1967), progressing beyond the earlier work of Hill (1936), determined that the "introduction of vein minerals took place in four phases, each preceded by tectonic activity which prepared the ground for the passage of hydrothermal solutions." Sandvik's proposed sequence of mineralization is shown in Table 2.

TABLE 2: SEQUENCE OF MINERALIZATION IN FAIRBANKS DISTRICT GOLD-BEARING LODES, AS PROPOSED BY SANDVIK (1967).

Phase 1 - Quartz (barren of metallic minerals)

Phase 2 - Quartz, loellingite, arsenopyrite, pyrite, and gold

Phase 3 - Quartz, pyrite, gold, sphalerite, chalcopyrite, freibergite, jamesonite, galena, boulangerite, robinsonite, zinkenite, and stibnite

Phase 4 - Quartz and stibnite

Following Lindgren's depth-temperature classification, Phases 1 and 2 are high-temperature mesothermal, Phase 3 is low-temperature mesothermal, and Phase 4 is epithermal.

High grade (bonanza) gold-quartz lodes on Ester Dome are usually associated with arsenopyrite ($FeAsS$) and/or loellingite ($FeAs_2$), pyrite (FeS_2) and one or more of the sulfosalts such as jamesonite ($Pb_4FeSb_6S_{14}$), freibergite ($(Cu, Fe, Ag)(_{12}Sb_4S_{13})$), boulangerite ($5PbS \cdot 2Sb_2S_3$), robisonite ($7PbS \cdot 6Sb_2S_3$) and zinkenite ($PbS \cdot Sb_2S_3$). Stibnite ($Sb_2S_3$) is also associated with gold-quartz lodes, but it usually occurs as lens-shaped masses along the hanging or foot walls of the lodes, and it appears to represent the latest phase of mineralization. Galena (PbS), sphalerite (ZnS) and chalcopyrite ($CuFeS_2$) have also been reported in Ester Dome lode assemblages, but they are relatively rare.

Stibnite-quartz lodes also occur on Ester Dome; they contain little gold and accessory sulfosalts. These lodes (e.g. McQueen Mine; Stibnite Lode Mine) are highly brecciated and sheared, and appear to have been deposited along fault or shear zones.

Arsenic Content of Stibnite and Secondary Alteration Products

Sandvik (1964), in his investigation of the trace metal content of stibnite in the Fairbanks District, found that Pb, As, Bi, Ag and Cu are frequently present in relatively high total concentrations (up to 3,000 ppm). Stibnite from the Ester Dome lodes contains an average of

1,900 ppm arsenic, and is the probable source of scorodite ($FeAsO_4 \cdot 2H_2O$), a secondary arsenic mineral which also occurs as an alteration product of arsenopyrite ($FeAsS$) and loellingite ($FeAs_2$). Stibnite in some lode deposits is almost completely replaced by secondary minerals including cervantite (Sb_2O_4), stibiconite ($Sb_3O_6 \cdot OH$), senarmontite (Sb_2O_3), bermesite (Sb_2S_2) and scorodite.

STRUCTURAL CONTROL OF MINERALIZED LODES

Distribution and Orientation of Lodes

As previously noted by earlier workers, most of the Ester Dome lodes are located on the southeast flank of the Dome. The most intensive concentration of lodes defines a northeast-trending mineralized zone extending from the divide between Moose and Ready Bullion Creeks to the hills forming the Happy Creek watershed (see Map 1). The lodes in this belt have a dominant northeasterly strike, dipping to both the northwest and southeast.

A second trend of mineralized lodes is characterized by northerly and northwesterly trending vein systems, which can be traced from the Eva Creek area over the west ridge of Ester Dome and down into the headwaters of Nugget Creek. Northerly and northwesterly trending fractures and fault zones seem to have favored stibnite deposition, and appear to have formed subsequent to the northeasterly trending fractures.

Large-Scale Structural Controls

The lodes of the northeasterly trending Ester-Happy zone have been emplaced on the southwest and descending limb of an asymmetric anticlinorium (Figure 3). Although a local reversal occurs around a major fold axis, layering and foliation strike consistently to the northeast, and the dip is dominantly to the southeast.

There is a rather consistent discordance between the strike of minor fold axes and the dip of foliation, indicating that the episode which produced the northeasterly trending structures was preceded by an earlier deformation producing folds around more westerly trending axes. Mineralization appears to have followed the more recent deformation.

The lodes of the Ester-Happy zone (including the Ryan Lode system) are dominated by northeasterly trending veins, which parallel the strike, but are usually discordant to the dip of layering and foliation.

Large-scale structural controls of the northwesterly trending Eva Creek -- Nugget Creek zone are more elusive, since the lodes appear to transect various bedrock attitudes, and the terrane appears to be dominated by northwesterly rather than northeasterly trending fractures and faults.

Fracture, Joint and Fault Control

Hill (1933) was the first to investigate the possible correlation between faults and lode orientation on Ester Dome. Figure 2, taken from Hill, shows an apparent correlation between fault and vein orientation.

However, Figure 3 (a diagram which plots the orientations of unmineralized and open joints, and the strike and dip of foliation of the host quartzites and micaceous quartzites) presents a strong case for joint control of lode orientation. The diagram clearly defines a strike-joint set, and cross joints that are both normal and inclined to the northeasterly strike of foliation and fold axes. In fact, the joint orientation diagram reaffirms the validity of the "strain ellipsoid," including the presence of tensional joints in a zone approximately 45¼ degrees to the fold axes.

The lodes of the Eva-Nugget trend appear to be related to tensional joints, while some of the lodes along the Ester-Happy zone may be strike joint and/or fault controlled.

The joint system illustrated in Figure 3 shows that the more competent rock units are pervasively fractured and that such units in thawed terranes will have excellent fracture permeability, which will accelerate the down-dip movement of groundwater. Highly schistose units will have lower down-dip permeability (Figure 4).

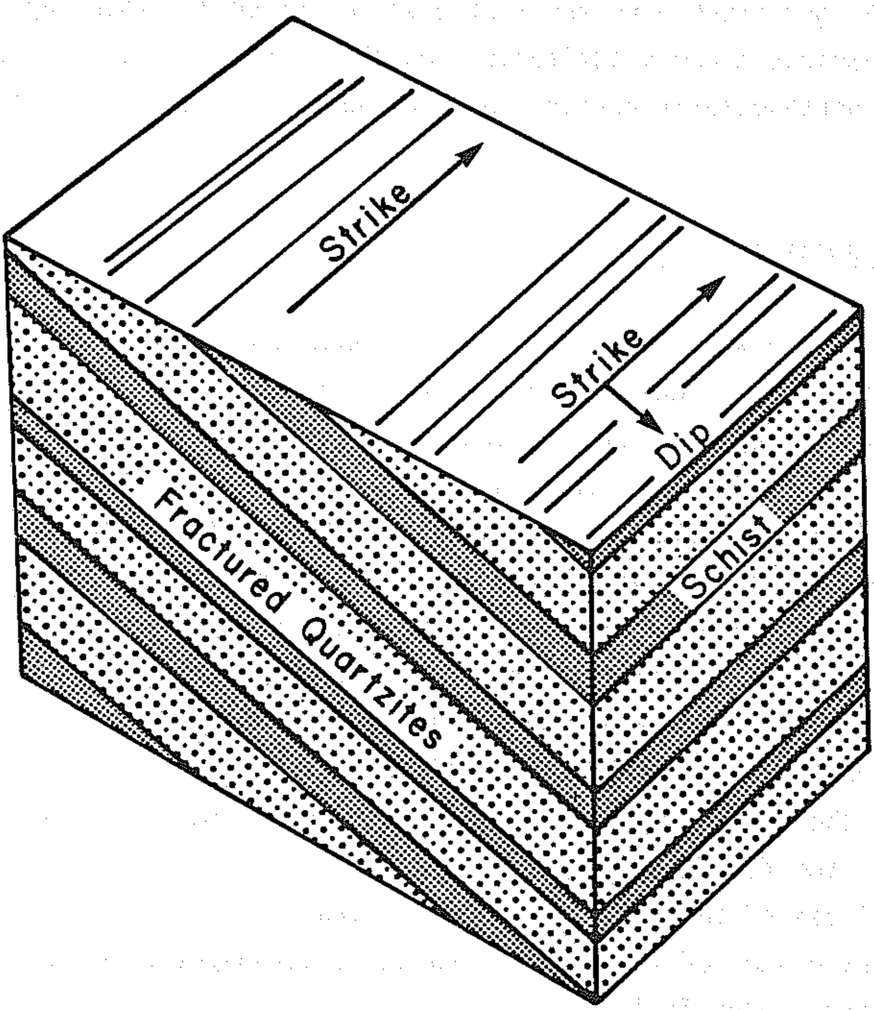

Figure 4. Idealized block diagram illustrating down-dip fracture permeability controlled by joint sets.

ARSENIC CONCENTRATIONS IN LODES AND HOST ROCKS

Lode and Auger Sample Concentrations

Map 2 identifies Ester Dome lode deposits and outcrop and auger samples that contain anomalous concentrations of arsenic-bearing mineral phases, including stibnite (Sandvik, 1967). The map patterns clearly show that over 90 percent of all of the known lode deposits on the southeastern slope of Ester Dome contain arsenic-bearing mineral phases, and that many grab and subsurface auger samples from the extension of the Ester-Happy zone (taken from ridge traverses and the Ester Dome road; Stevens et al., 1969) produce anomalous gold and covariant arsenic values (Table 3).

The covariant arsenic/gold anomalies documented in Table 3 and plotted in Map 2, show that the Ester-Happy lode zone is signalled by an arsenic-gold signature that can be traced to the northeast beyond the recognized occurrence of mineralized lodes.

Influence of Arsenic-bearing Lodes and Host Rocks on Groundwater

The maps and data discussed above clearly show that the Ester-Happy lode zone is enriched in arsenic-bearing mineral phases, and that the surrounding host rocks carry anomalous concentrations of arsenic. This very wide zone of metallic enrichment, which includes lodes and intercalated mineralized schists and micaceous quartzites, carries highly anomalous concentrations of arsenic. Considering the down-dip structural setting (see Figure 4), and the well-developed fracture permeability of the more competent rock units, waters moving through this zone could be expected to develop high concentrations of arsenic mitigated by chemical constraints including water temperature, Eh and pH.

TABLE 3: ARSENIC AND GOLD ASSAYS OF SURFACE (GRAB) AND DOWNHOLE SAMPLES TAKEN FROM ESTER DOME (ONLY ANOMALOUS ANALYSES ARE INCLUDED).

Sample No.	Sample Interval (ft)	Arsenic (ppm)	Gold (ppm)
ESTER DOME ROAD			
27A	3-6	1,430	<0.05
	6-9	1,050	<0.02
	9-10	950	<0.05
32A	3-6	1,150	0.11
	6-11	--	<0.02
	>11	950	0.11
42A	2.5-3.5	2,250	0.77
	3.5-4.0	1,900	0.17
46A	1.5-7	2,150	0.21
49A	2.5-4.5	1,150	0.60
	4.5-10	940	0.12
	10-14	1,050	0.33
	14-16	1,600	1.35
86A	2-6	3,170	2.80
	6-7	4,500	0.08
90A	4-5.5	1,050	<0.08
	5.5-7.5	1,140	0.25
	7.5-9	--	0.15
	9-13	940	0.15
	13-15.5	945	<0.02
	15.5-17	--	<0.02
	17-19	--	0.11
	19-23	1,230	0.14
	23-24.5	--	0.23
	24.5-27	--	<0.02
	27-29	--	<0.02
95	Surface	3,250	0.15
97A	2-5.5	1,030	0.07
101A	4-14	1,700	0.35
	10-14	2,050	0.22
107	Surface	1,750	0.045
108	"	1,730	<0.02
109	"	2,060	<0.02
112	"	1,830	0.60
113A West	Surface-2.5	1,400	0.26
	2.5-4	840	0.03
113A East	0-2.5	1,550	0.21
	2.5-5	1,350	0.26
118	Surface	1,575	<0.02
130	Surface	1,380	0.11
142A	3	1,820	0.23
144	Surface	500	0.89
157A	11-12.5	940	0.35
166A	Surface	1,050	<0.05
168A	42-50	1,240	0.09
172A	30-32	1,430	<0.02
176A	48-49	1,350	<0.02
HENDERSON ROAD			
1A	18-23	1,270	0.20
	23-25	1,175	0.12
7A	15-17	1,200	0.14
10A	10-13	1,160	0.08
GRAB SAMPLES FROM ESTER DOME OUTCROPS			
ED9-1-1	Surface	940	0.06
ED9-1-3	"	1,150	0.64
ED9-1-4	"	1,220	0.11
ED9-1-6	"	970	0.20
ED9-1-12	"	960	0.20
ED9-1-17	"	800	<0.02
ED9-1-21	"	2,620	1.46
ED9-1-22	"	2,560	162.0

a. From Stevens et al. (1969).

b. Emission spectrography. Detection limit: 500 ppm. Mean value estimated assuming samples with arsenic values less than the detection limit contained 250 ppm As.

c. Emission spectrography. Values reported only for those samples with arsenic values greater than 500 ppm.

d. X-ray fluorescence analysis of well cuttings. See Appendix D for a description of the analytical method. Analytical detection limit: 40 ppm.

e. Metamorphic rocks, unspecified.

GEOCHEMISTRY OF ARSENIC

ARSENIC IN SURFACE WATERS AND STREAM SEDIMENTS

Several streams on the eastern side of Ester Dome were sampled during August 1978. Sample localities are shown in Map 2 and the arsenic content of surface-water and stream-sediment samples are given in Table 4.

Data for pH, temperature, dissolved oxygen and specific conductance were obtained with a HORIBA Water Quality Meter, the probe of which was immersed in the flowing stream at the sample locality. The arsenic concentration of the water was determine by atomic absorption spectrometry (see Appendix A for method) following filtration through a 0.45 μ Millipore filter and acidification of the sample in the field. The arsenic content of the sediment samples was determined by x-ray fluorescence analysis of the total sample (see Appendix A).

A stepwise multiple-regression analysis (BMDP-2R; Dixon & Brown, 1977) was performed on the data of Table 4 to determine if the arsenic content of the stream water was related to the other variables measured. Sample 21 (from a seep draining a mineralized vein) was not included in this analysis because this is an exotic sample, not typical of the surface waters as a whole.

Based on multiple regression analysis, there was no significant relationship among the arsenic content of stream water, the arsenic content of the bottom sediments, pH, dissolved-oxygen content and specific conductance of the stream water.

Wilson and Hawkins (1978) observed a significant positive correlation between the arsenic content of stream water and that of the bottom sediments. The lack of agreement between these two studies may stem from the fact that Wilson and Hawkins studied streams which were very muddy while those of the present study were clear. Also -- and perhaps more important -- because of the heavy suspended sediment load, Wilson and Hawkins were unable to filter the samples in the field. Their samples were acidified and then filtered in the laboratory. This treatment led to some enrichment in arsenic of the waters by leaching from the suspended sediments, as was discussed by them.

TABLE 4: ARSENIC CONCENTRATION IN BOTTOM SEDIMENTS AND WATERS OF ESTER DOME.

	Water						Sediment
Sample	Date	pH	Temp. °C	D.O.	Sp. Cond.	As (ppb)	As (ppm)
Nugget Cr. 1	7/25/78	6.7	1.8	13.1	47	<10	123
Nugget Cr. 2a	7/25/78	6.8	4.9	11.5	93	<10	147
Nugget Cr. 2b	7/25/78	6.7	6.3	8.4	192	---	888
Ready Ballion Cr. 8	7/25/78	7.3	10.0	12.9	81	14	876
Ready Ballion Cr. 9	7/25/78	7.5	3.6	13.1	47	14	1,304
Ready Ballion Cr. 11	7/25/78	7.2	17.9	9.2	440	20.37	1,451
Sheep Creek 12	7/27/78	6.5	4.9	11.5	64	<10	350
Sheep Creek 13	7/27/78	6.1	8.1	10.3	157	30	695
Eva Creek 15	8/8/78	6.6	9.1	11.6	208	57	<40
Eva Creek 16	8/8/78	6.6	7.9	9.9	202	74	363
Eva Spring at Clipper Mine 17	8/8/78	6.4	5.9	5.1	47	<10	228
Eva Creek 18	8/8/78	6.5	8.4	3.2	62	38	1,172
Eva Creek 19	8/8/78	6.6	3.6	10.6	85	42	570
Eva Creek 20	8/8/78	6.7	10.6	8.2	47	10	260
Eva Creek 20a	8/8/78	6.8	10.6	9.7	44	---	---
Eva Seep 21	8/8/78	8.7	23.2	10.3	85	229	1,723
Mill Stream 22	8/8/78	8.7	dry	dry	dry	dry	1,120
West Mill Pond 23	8/8/78	7.2	26.5	8.8	32	45	1,389
East Mill Pond 24	8/8/78	6.3	23.9	6.6	67	127	---

In clear streams, even those draining heavily mineralized areas, the arsenic concentration of the stream water is about 50 ppb. For those streams with a large suspended-sediment load, the arsenic concentration can be estimated roughly by the regression equation of Wilson and Hawkins

$$\log As_{(ppb)}\text{water} = 0.352 \log As_{(ppm)}\text{sediment} + 0.992.$$

The data in Map 2 suggest that arsenic analysis of stream-sediment samples might be useful in geochemical exploration for arsenic-bearing mineral assemblages (e.g., certain types of gold deposits). Care must be taken in interpreting the results of such a study because the scavenging effect of the iron oxides produces many false anomalies. For example, samples 2A and 2B (Nugget Creek) were taken about 3 feet apart, but one is iron-oxide rich and contains 888 ppm As, while the other is normal sediment and contains 147 ppm As. Similarly, samples 12 and 13 from Sheep Creek contain 695 ppm As (iron rich) versus 350 ppm As (iron poor), respectively.

These samples serve as good examples of the self-cleansing property of surface waters as a result of sorption of dissolved arsenic on iron oxides and hydroxides. This process is shown schematically in Figures 5 and 6.

Note that the surface waters draining the mineralized area of Ester Dome and in contact with sediment having 570 ppm As contain about 50 ppb As. The groundwaters draining the same area contain 5 ppm arsenic (100 times as much arsenic as in the surface water). This indicates that the coprecipitation and sorption process responsible for the removal of arsenic from surface waters is largely inoperative in the poorly oxygenated groundwater.

From Map 2 it is evident that the arsenic content of the stream sediments increases toward the headwaters of Eva and Ready Bullion creeks, an area of widespread arsenic mineralization. Several lode-gold mines are located in this area. No discernible effect on the arsenic content of the streams can be exclusively attributed to the mines. However, the arsenic-enriched sediments of the settling ponds by the mill (samples 22, 23, 24) are clearly the result of arsenic-enriched

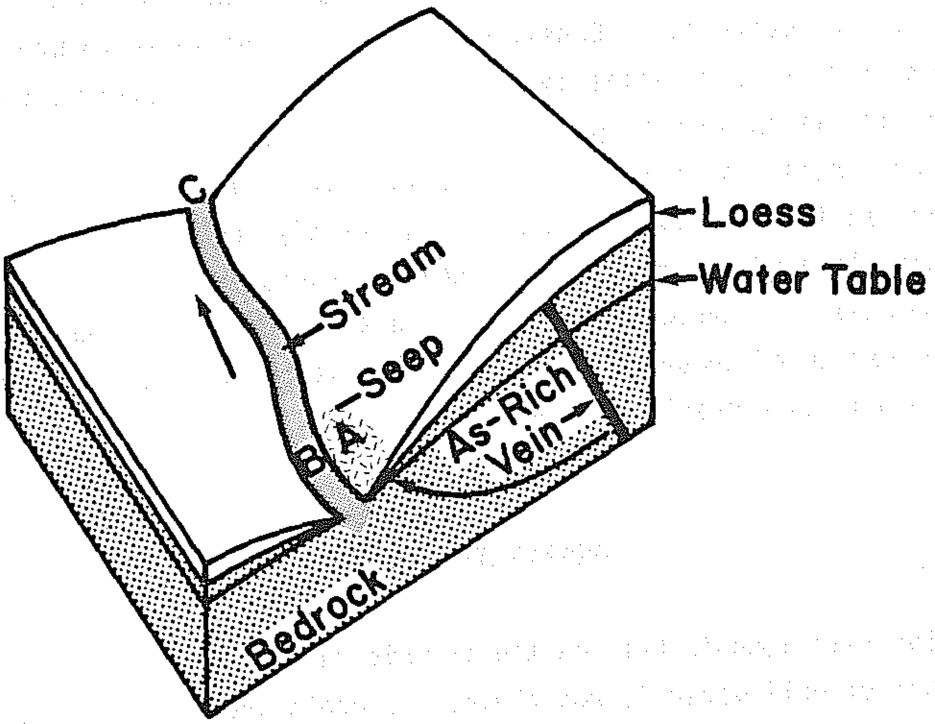

Figure 5. Idealized cross section of stream on Ester Dome showing the relation of arsenic-bearing vein to groundwater and surface water.

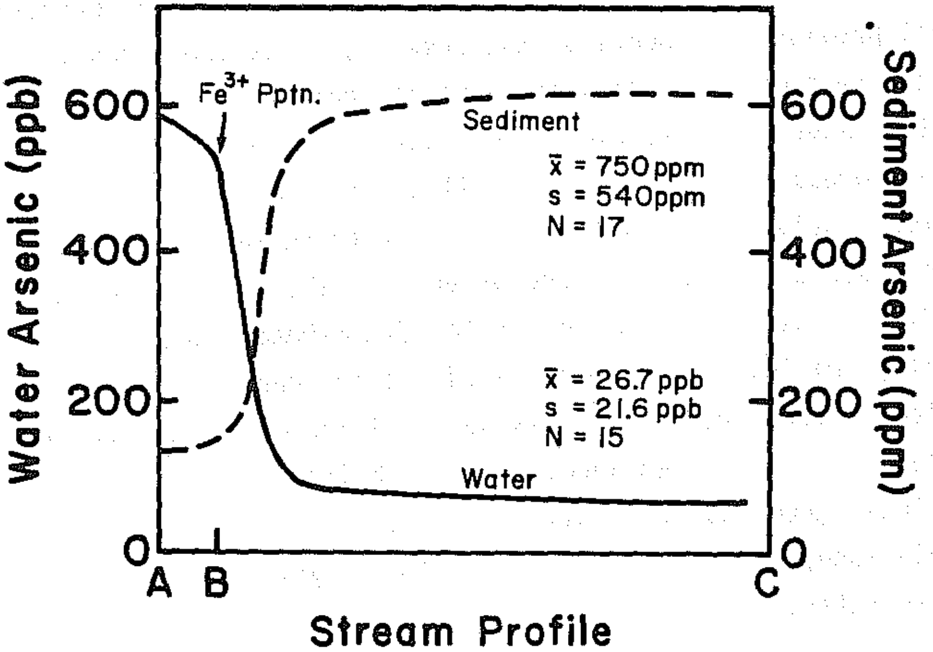

Figure 6. Arsenic concentration in stream and groundwater at localities A, B, and C (see Figure 5). Note the removal of arsenic by coprecipitation on ferric hydroxide.

mill tailings. Streams could be adversely affected if subsequent mining and milling activities produce waste and tailings piles of arsenic-enriched materials. Consideration must be given to reduce the impact of these activities on the surface and, particularly, the groundwaters if extensive mining develops in the future.

We stress that stream sediments contain by far the greatest quantity of arsenic in a stream. Placer mining greatly increases the suspended-sediment load of a stream and thereby increases the quantity of arsenic transported. If these sediments are settled, the dissolved arsenic concentration of these streams will be about 50 ppb, assuming no changes in pH occur as a result of the placer mining.

GROUNDWATER STUDIES

The relationship between the arsenic content of the country rock and that of well water is not clear. We don't know whether arsenic-rich well waters obtain their arsenic from sulfide-bearing veins somewhat distant from the wells in question, or whether the arsenic-contaminated wells penetrate arsenic-rich rocks, which are the source of arsenic in the well water. In other words, do the rocks immediately penetrated by the well provide the source of the arsenic, or is the arsenic source distant from the well? Does the distant source produce a zone of contaminated water which is then intercepted by a well?

To address these questions, well-cuttings and water from various wells were analyzed for arsenic to see if there was a relationship between arsenic in the rocks and arsenic in the water. Six wells were studied, only two of which were in the Ester-Dome area. These wells were being drilled in the upland subdivisions during the summer of 1978 by various homeowners. Few wells were drilled on Ester Dome because homeowners were concerned about the possibility of arsenic contamination of the local groundwater. They therefore chose not to spend the considerable money needed to drill wells that might produce arsenic-contaminated water.

With the cooperation of the various well drillers in the area, cuttings from 6 wells were sampled at various depth intervals. The number of intervals sampled and the distance between intervals depended upon the total depth of the well. Depth intervals usually ranged from 10 to 25 feet and cuttings from 6 to about 12 intervals were sampled. Special attention was paid to sample the rocks immediately above and below the water table, and to obtain at least several samples of cuttings from below the water table. A water sample was taken from each well. The sample was filtered through a 0.45 μ Millipore filter, acidified with 8 M nitric acid, and returned to the laboratory for analysis. Water from Brown's, Dean's and Gibson's wells were resampled in November 1979. The data are summarized in Table 5.

The results for Gibson's well are striking in that all rocks are rich in arsenic. The arsenic content of the rocks seems to be affected by the water table; samples above the water table contain more arsenic (mean value 1,200 ppm) than do those below the water table (mean value 400 ppm). The groundwater flowing through these rocks is much enriched in arsenic (850 ppb). These results are shown schematically in Figure 7.

The rocks in Brown's well (below the water table) contained an average of 200 ppm arsenic, yet the arsenic content of the water was less than 10 ppb. A resampling and reanalysis yielded results consistent with the initial values.

TABLE 5: AVERAGE CONCENTRATION OF ARSENIC IN ROCKS BELOW THE WATER TABLE AND IN THE GROUNDWATER FOR DIFFERENT WELLS.

Well	Average As in Rock (ppm)	Average As in Water (ppb)
Brown	100	<10
Dean	<40	<10
Gilbert	<40	<10
Koppelins	<40	<10
Maddocks	40	24
Gibbson	407	728

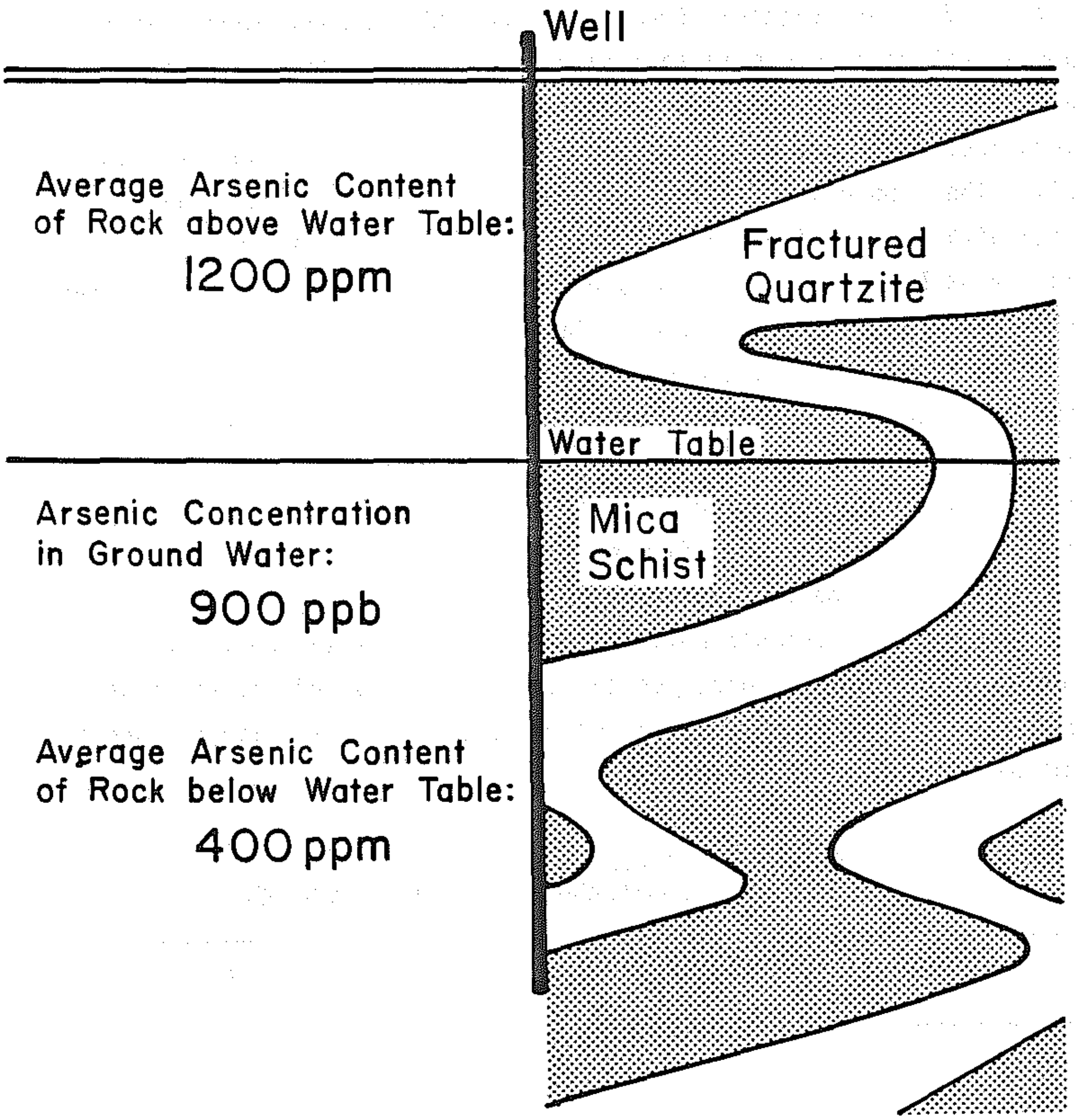

Figure 7. Schematic representation of the arsenic content of rocks and groundwater.

The data of Table 5 -- particularly the data for Gibson's well -- suggest that, in some instances, the arsenic in the water is being derived from the rocks in the immediate vicinity.

The data from Gibson's well suggest that, for large concentrations of arsenic to occur in the groundwater, there must also be heavy arsenic enrichment in all the rocks in the groundwater zone intercepted by the well.

The presence of a few arsenic-rich zones in the rocks at depth may, depending upon permeability, contribute arsenic-rich water to the well. The overall arsenic concentration in the well depends upon the arsenic concentration of the rocks, the number of horizons penetrated, and the amount of water flowing through the arsenic-rich zones relative to the amount of water flowing through arsenic-free zones. The zonal nature of arsenic contamination in the groundwater has been confirmed elsewhere in the Fairbanks area by the U.S. Geological Survey (Dorothy Wilcox, personal communication). The USGS investigators were able to seal off a zone of arsenic-rich water by means of hydraulic packers, and to pump water of low arsenic concentrations from the remaining zone. Unfortunately, this is not an economically feasible method for home owners to obtain good drinking water. A further problem (because of the erratic vertical distribution of arsenic-rich horizons) is that, upon deepening a well to obtain greater yield, a zone of arsenic-rich rocks and water may be intercepted, resulting in arsenic-rich water in a previously uncontaminated well.

ARSENIC LEACHING EXPERIMENT

To determine if arsenic could be contributed to groundwater by leaching arsenic-rich rocks, the following experiment was performed. We placed 1.0 g of well cuttings (-2 mesh, Gibson well) into 30 ml centrifuge tubes with 25 ml of distilled water (pH 6.3). Nitrogen was bubbled through the solution in half the tubes for 2 minutes to dispel air. All the tubes were covered with Parafilm, capped, and then agitated on a mixing wheel for one week at room temperature. At the end of one week, the pH of the solutions was measured and the solutions were filtered through 0.45 μ Millipore filters and analyzed for arsenic. The results of this experiment are shown in Table 6A. The quantities of arsenic leached in the nitrogen-saturated solutions were indistinguishable from those leached in the air-saturated solutions. Therefore, all results with the same final pH were pooled.

The average final pH values, the average arsenic values and values of arsenic predicted to be in equilibrium with $FeAsO_4$ based on Wagemann's calculations (1978) at the different pH values are shown in Table 6B. The concentrations calculated by Wagemann are for $FeAsO_4$ in a "typical freshwater." Because of the difference in ionic strength of the "freshwater" and the distilled water used in this experiment, concentrations calculated for this system should be somewhat lower than the calculated values in Table 6B.

Several features are evident in Tables 6A and 6B. Significant quantities of arsenic can be quickly leached from the country rock by distilled water. Furthermore, the arsenic concentration in solution follows a pH dependency like that for $FeAsO_4$. This suggests that the source of the arsenic in the rock is probably scorodite ($FeAsO_4 \cdot 2H_2O$) or possibly arsenic-bearing iron oxide. These results suggest that for well waters in the area, $FeAsO_4$ or a similar compound is the major component from which the groundwaters derive their arsenic concentrations. The arsenic concentration can be expected to vary as a function of the pH and E_h of the groundwater, with higher arsenic concentrations favored at low pH and E_h. This implies that, as either pH or E_h is increased, arsenic should be removed from solution first by coprecipitation on ferric hydroxide or by enhanced sorption on ferric-oxide coatings. Looking futher at the process of coprecipitation by $Fe(OH)_3$ and arsenic in an oxidizing environment, Figure 8 shows the decrease in total dissolved arsenic (TDA) of a groundwater sample originally containing 1 ppm arsenic, followed by standing undisturbed for 550 hours. It can be seen that coprecipitation in an oxidizing environment is capable of reducing arsenic concentrations from greater than 1 ppm to the U.S. Public Health Service drinking-water level of 50 ppb.

TABLE 6A: ARSENIC CONCENTRATIONS AND pH OF SOLUTIONS IN CONTACT WITH CUTTINGS FROM GIBSON'S WELL.

Sample Depth (ft)	As in Rock (ppm)	As in Solution (ppb)		Final pH
		N_2 Saturated	Air Saturated	
96	1,304	388, 295	245, 433	6.3, 6.2, 6.3, 6.3
121	1,451	144	535, 192	6.3, 6.6, 6.7
125 (Water Table)	1,730	172	228	7.3, 7.3
146	653	72, 84	70	7.7, 7.9, 7.9
171	876	74, 140	92, 74	8.1, 8.1, 8.2, 8.2

TABLE 6B: COMPARISON OF OBSERVED ARSENIC CONCENTRATIONS (TABLE 6A) WITH THOSE EXPECTED FOR EQUILIBRIUM WITH SCORODITE (WAGEMANN, 1978).

Final pH	Average As Concentration in Solution (ppb)	Total Dissolved As in Equilibrium with $FeAsO_4$ at Different pH Values[a]
6.4	320	>860
7.3	200	>200
8.0	90	60

[a] From Wagemann (1978, p. 141).

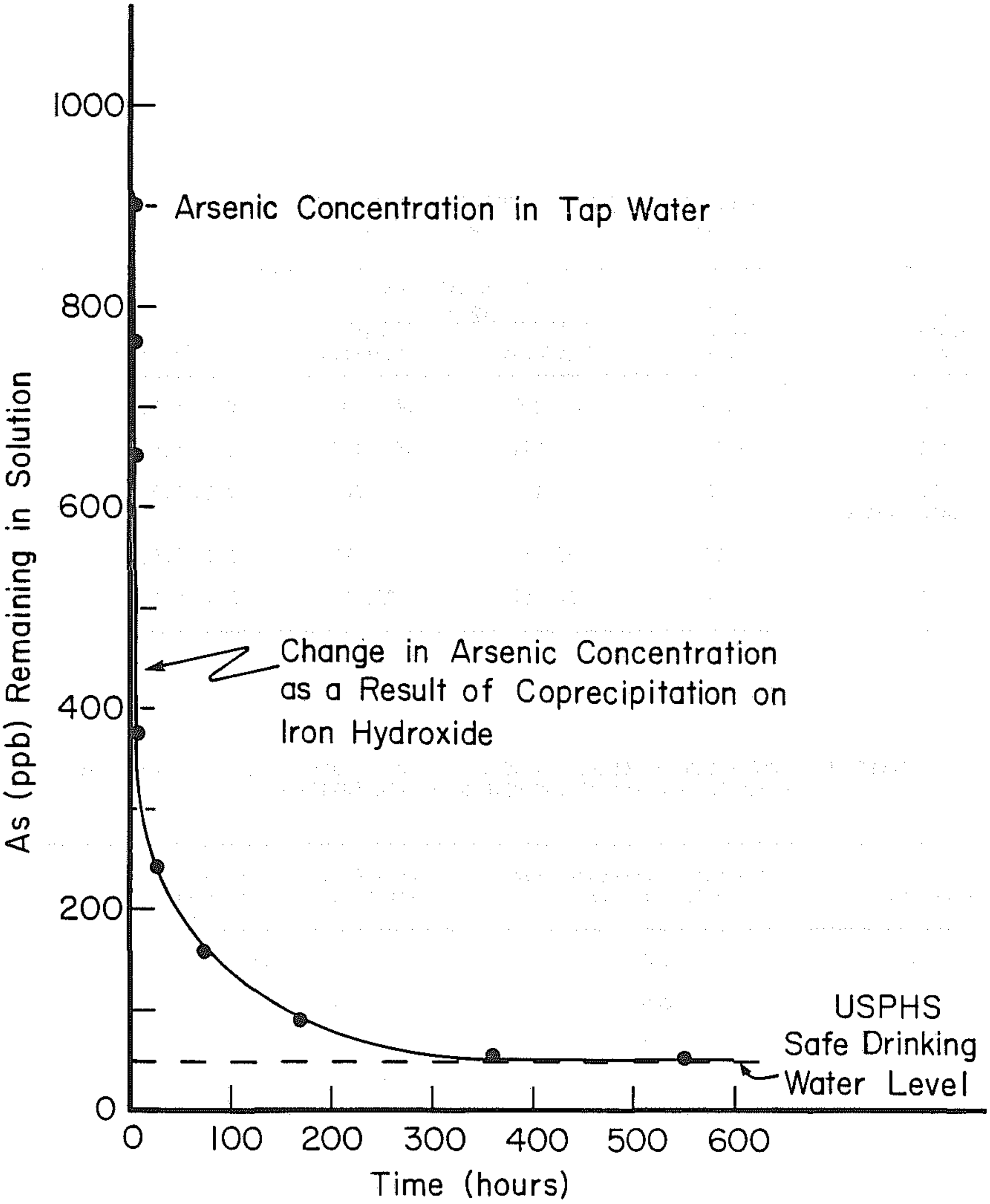

Figure 8. Arsenic concentration versus time in a domestic water sample.

This particular sample was from a residence equipped with a homemade iron-removal system. The sample was from freshly pumped water before the water passed to the iron-removal system.

Samples of water that had passed through the iron remover were also analyzed. These showed a behavior consistent with coprecipitation on ferric hydroxide. The first sample was of milk prepared by mixing dried milk with tap water. This sample contained 160 ppb As (the same as that of the tap water). A sample of coffee made by means of an electric percolator was analyzed and found to contain 60 ppb As. The reduced arsenic concentration in the coffee results from aging; boiling reduces the concentration by flocculating ferric hydroxide, and the ferric hydroxide is removed by filtration through the coffee grounds. In other words, this process is a homely example of the classic Group III iron-separation scheme of qualitative analysis, and results in a decrease of both iron and arsenic in the water.

It is interesting to note that the final arsenic concentration achieved upon precipitation of the ferric hydroxide is close to that of the surface waters of Ester Dome.

ARSENIC SORPTION

To test the effect of sorption in oxidizing and reducing environments, the following experiment was performed. Duplicate samples weighing 0.25 g each of Fe_2O_3-coated quartz sand (Gent, 1977) (-35 to +60 mesh) and Fe-stained micaceous quartzite (Ester Dome) (-35 + 60 mesh) were placed in 30 ml thick-walled, screw-cap culture tubes. Then 25.0 ml of 1.0 ppm As standard solution in distilled H_2O was added to each tube, and the pH was adjusted to 5.5, 6.5, or 7.5 with NaOH and HNO_3. Nitrogen was bubbled through half the solutions for 2 minutes. The tubes were covered with Parafilm, capped, and placed on a mixing wheel for 24 hours. The solutions were the filtered through 0.45 μ Millipore filters, and the pH of the solutions measured. The pH values of all solutions changed, with the final average pH = 7.1 ± 0.45.

The design for this experiment is shown in Table 7A; in effect, this was a modified partly replicated 2^3 factorial design. Analysis of the design showed that pH variations were not significantly different over the final pH range. Therefore, the data were pooled over the duplicates and the 3 pH values originally studied. Blanks were run to test the sorption of arsenic on glass or glass plus acid-washed quartz under nitrogen or air. The values in Table 7B are the observed arsenic concentrations (ppb) remaining in solution at the end of the experiment.

TABLE 7A: ARSENIC SORPTION EXPERIMENT.

	Quartz + Fe_2O_3		Schist	
pH	Air	N_2	Air	N_2
5.5	52	206	246	547
6.5	60	---	185	487
7.5	77	267	280	469

TABLE 7B: CONTROLS FOR ARSENIC SORPTION EXPERIMENT.

	Quartz & Glass Tube	Glass Tube	
N_2	750	796	
Air	964	848	$\bar{x}$ = 840 ± 140 ppb

With a coefficient of variation of 0.17, the above values for the blanks are indistinguishable statistically from each other, and the mean value is not significantly different from the original concentration. There may be a tendency for some sorption, (circa 15 percent) to occur on the vessel walls, but this cannot be shown statistically by the above data. As a consequence, no attempt was made to adjust the values of arsenic remaining in solution in contact with the schist or Fe_2O_3-coated quartz for sorption on the vessel walls.

It is evident from Table 7A that arsenic removal is enhanced under oxidizing, iron-rich conditions.

ARSENIC SPECIATION

The conditions under which the different inorganic arsenic species are stable are summarized in the Eh-pH diagram (Figure 9), which also shows stability relations of some common iron species as well. Knowledge of the ionic state of arsenic in groundwater is important both in terms of understanding the chemical behavior of arsenic in groundwater and coping with the greater toxicity of As(III) relative to As(V). Unfortunately, the data in Table 8 do not answer the question of arsenic speciation unequivocally. Because of analytical difficulties, we were able to determine only total arsenic (As_T) concentrations on samples A, B, and C of Table 8. Maynard (1979) determined As(III) but not As(V) using polarographic methods. We could not determine As(V) by difference between these two values because the error in the individual determinations was too large. It seems, however, because of the good agreement between the As-total and As(III) values, that most of the arsenic is present in these samples in the As(III) state.

The data of Harrington et al. (1978; samples 1-5) show a wide range in the As(V) to As(III) ratio from 30/1 for sample 1, 1.5/1 for sample 2, and from 2/1 to 3.5/1 for the remaining samples. These data support our observations that most of the arsenic is present in the As(III) state. The samples analyzed by Harrington et al. were shipped to a laboratory in the conterminous United States for analysis. It is possible that because of the time elapsed between collection of the sample and analysis that some oxidation of the arsenic to the As(V) state occurred in spite of the precautions taken to minimize such oxidation. As a result, the relatively large concentrations of As(V) in some of the samples may be an artifact of the sample treatment. The data of Harrington et al. suggest that little arsenic occurs as an organic complex. This result is also speculative in that oxidation of the sample could destroy arseno-organic complexes prior to analysis.

These limited data suggest that most of the arsenic is present in the groundwater as As(III), and that As(V) and organic arsenic complexes are much less abundant. This conclusion is supported by Bottomley's

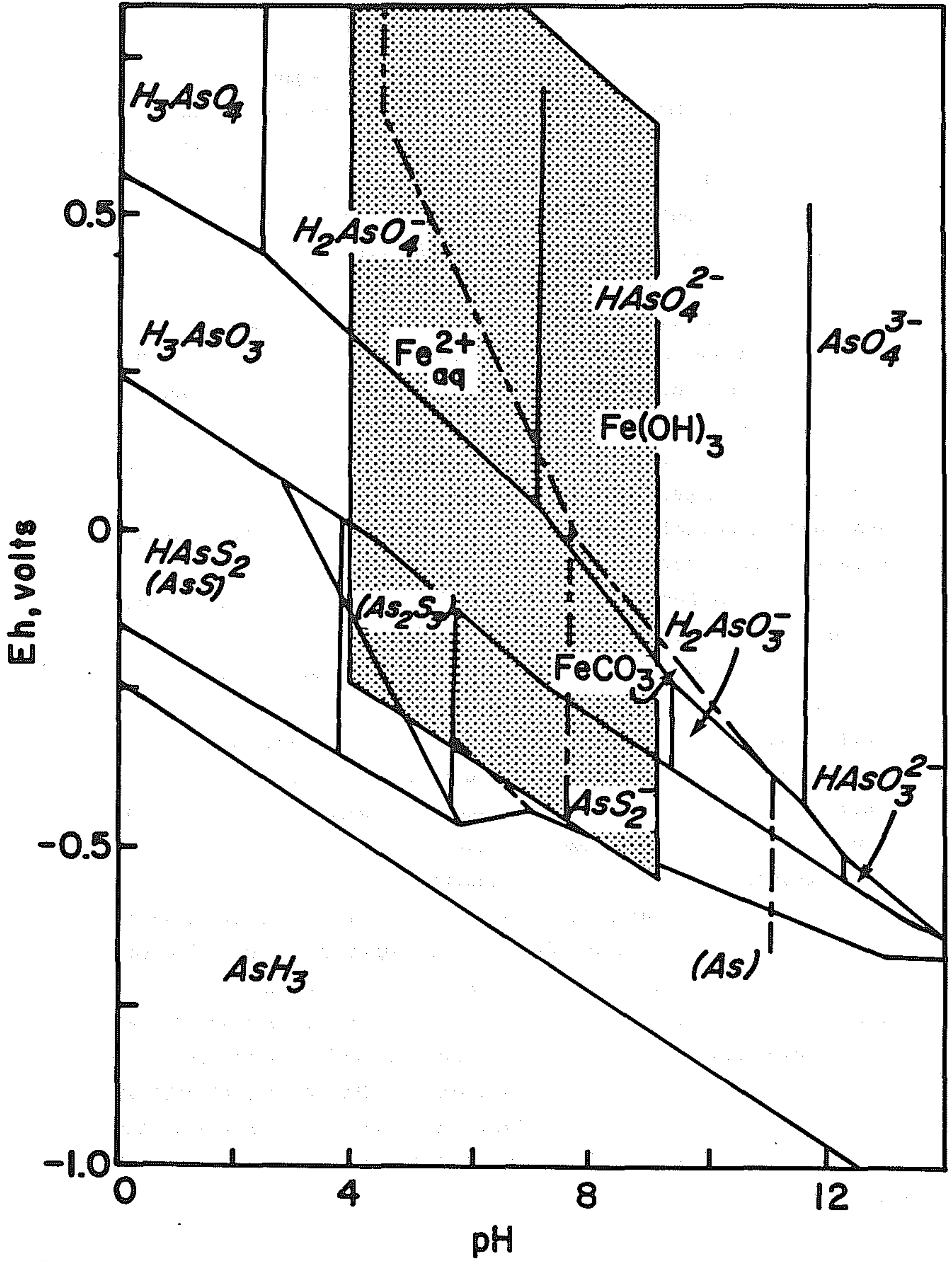

Figure 9. E_h versus pH diagram, showing various arsenic ionic species and iron minerals (adapted from Wilson and Hawkins, 1978).

(1979) observation of arsenic in well waters of Nova Scotia. We stress that precise determination of relative quantities of different species of arsenic in groundwaters of the area remains to be done.

No data are available on the distribution of the different arsenic species in the surface waters of the Fairbanks area. Braman and Foreback (1973), in their studies of surface waters in Florida containing less than 5 ppb As, showed that about 40 percent of the arsenic was present as As(V), about 25 percent as As(III) and the remainder was present as methylarsonic and dimethyl arsonic acid. Presumably, most of the arsenic in the surface waters of the Fairbanks area is present as As(V).

TABLE 8: CONCENTRATION OF ARSENIC IN DIFFERENT IONIC STATES IN GROUNDWATERS OF FAIRBANKS AREA, EXPRESSED AS PARTS PER BILLION.

Sample	As(Total)	As(III)	As(V)	MA[d]	DMAA[e]
A	<10[a]	9.67[b]	---	---	---
B	<10[a]	16.5[b]	---	---	---
C	851[a]	854[b]	---	---	---
1	---	35[c]	1,065[c]	<1	<1
2	---	1,140[c]	1,780[c]	<1	<1
3	---	1,170[c]	2,470[c]	<1	<1
4	---	90[c]	330[c]	<1	<1
5	---	110[c]	410[c]	<1	<1

[a] Determined by atomic absorption spectrometry.

[b] D. Maynard, (personal communication), determined by differential pulse polarography.

[c] Harrington et al. (1978), determined by differential pulse polarography.

[d] Methylansinic acid.

[e] Dimethylarsinic acid.

WATER-TREATMENT METHODS FOR REMOVING ARSENIC

Methods exist for large-scale removal of arsenic from domestic water supplies. Several of these are discussed by Whiteacre and Pearse (1974). A method using activated alumina for the removal of arsenic and fluoride from drinking water has been developed by the Alcoa Company (see Commerce Bus. Daily, 4-18-78) under the auspices of the U.S. Environmental Protection Agency. Several of these units are being evaluated in Alaska for arsenic removal (Wm. Morgan, personal communication), but we have no information on their performance.

Until arsenic-removal systems suitable for single residences are available, homeowners with arsenic-contaminated and iron-contaminated waters may alleviate the problem through the use of a properly functioning iron-removal system (for example, see Casper, 1975). The arsenic concentration of the treated water should be carefully monitored, and the water should not be consumed if the arsenic concentration exceeds 50 ppb.

SOIL AND VEGETATION STUDIES

Burton et al. (1978) investigated the arsenic content of different types of vegetation on Ester Dome. Their results are shown in Appendix C. Their work suggested that Labrador tea (*Ledum* spp.) might be useful in geochemical exploration because the plant was ubiquitous, and because its arsenic content seemed to vary in response to changes in the arsenic content of the soil on which it was growing. Results of their geochemical sampling across the Ryan Lode are shown in Figures C1-C4.

We examined further the arsenic content of Labrador tea and its usefulness in biogeochemical prospecting for arsenic and related minerals. We analyzed different soil horizons as well as Labrador tea at various sample sites. Our results are shown in Tables 8A, 8B, and 8C and in Figures 10A, 10B, and 10C.

Our results, particularly for samples from the Ridge traverse (Table 8B and Figure 10C) show that arsenic concentrations vary in the different samples of Labrador tea, and the A_0- and A-soil horizons. The agreement between our analytical results and those obtained by neutron activation analysis indicate that the arsenic enrichment in the Labrador tea samples is real.

The relationship between the arsenic content of the Labrador tea and that of the different soil horizons is not clear. Our data for the Ryan-Lode traverse show little response in these sample media to the

TABLE 8A: ARSENIC IN SOILS AND VEGETATION: RYAN LODE TRAVERSE (VALUES IN PPM).[a]

	Soil Horizon			Vegetation
Locality	A_0	A_1	B	Labrador Tea
1	5.9	25	33	2.5
2	10	16	25	<2.0
3	6.9	24	24	2.1
4	7.9	31	33	<2.0
5	7.9	35	28	<2.0
6	10	32	24	---
7	10	20	25	<2.0
8	22	23	27	<2.0
9	93	31	25	<2.0
10	28	28	29	<2.0
11	25	24	151	2.1
12	6.9	22	26	<2.0
13	7.9	30	33	<2.0
14	7.9	18	34	<2.0

[a] Analytical precision for values reported under A_0, A_1 and Labrador Tea, in Table 8A, 8B, 8C. Error range at 2 standard deviations.

For	x <2.0	Error	± ∞
"	2.0< x <3.0	"	± 1.0x to ± 0.8x
	3.0< x <5.0	"	± 0.8x to ± 0.5x
"	5.0< x <10	"	± 0.5x to ± 0.3x
"	10< x <20	"	± 0.3x to ± 0.2x
"	20< x <50	"	± 0.2x to ± 0.17x
"	50< x	"	± 0.17x

TABLE 8B: ARSENIC IN SOILS AND VEGETATION.

Locality	Soil Horizon A_0	A_1	B	Vegetation Labrador Tea	
1	18	35	33	<2.0	
2	16	26	29	<2.0	
3	70	110	52	3.8	4.91[a]
4	22	80	36	<2.0	1.15[a]
5	5.0	19	49	<2.0	
6	2.4	20	48	2.3	
7	<2.0	3.9	67	3.4	
8	3.8	3.0	148	<2.0	
9	2.8	11	60	<2.0	
10	3.5	18	32	<2.0	
11	3.4	24	18	---	
12	<2.0	15	23	---	
13	5.9	14	21	---	
14	4.9	14	19	<2.0	

[a] Neutron activation analysis results.

TABLE 8C: ARSENIC IN LABRADOR TEA NEAR STREAM SAMPLE LOCALITIES (ALL VALUES IN PPM).

Locality	A_s
Nugget Creek 1	<2.0
Nugget Creek 4	<2.0
Nugget Creek 5	<2.0
Nugget Creek 6	<2.0
Nugget Creek 7	<2.0
Eva Creek 14	<2.0
Eva Creek 15	2.9
Eva Creek 16	<2.0
Eva Creek 17	<2.0
Eva Creek 19	<2.0
Ready Bullion Creek 9	<2.0
Gilbert Weil Creek 4	<2.0

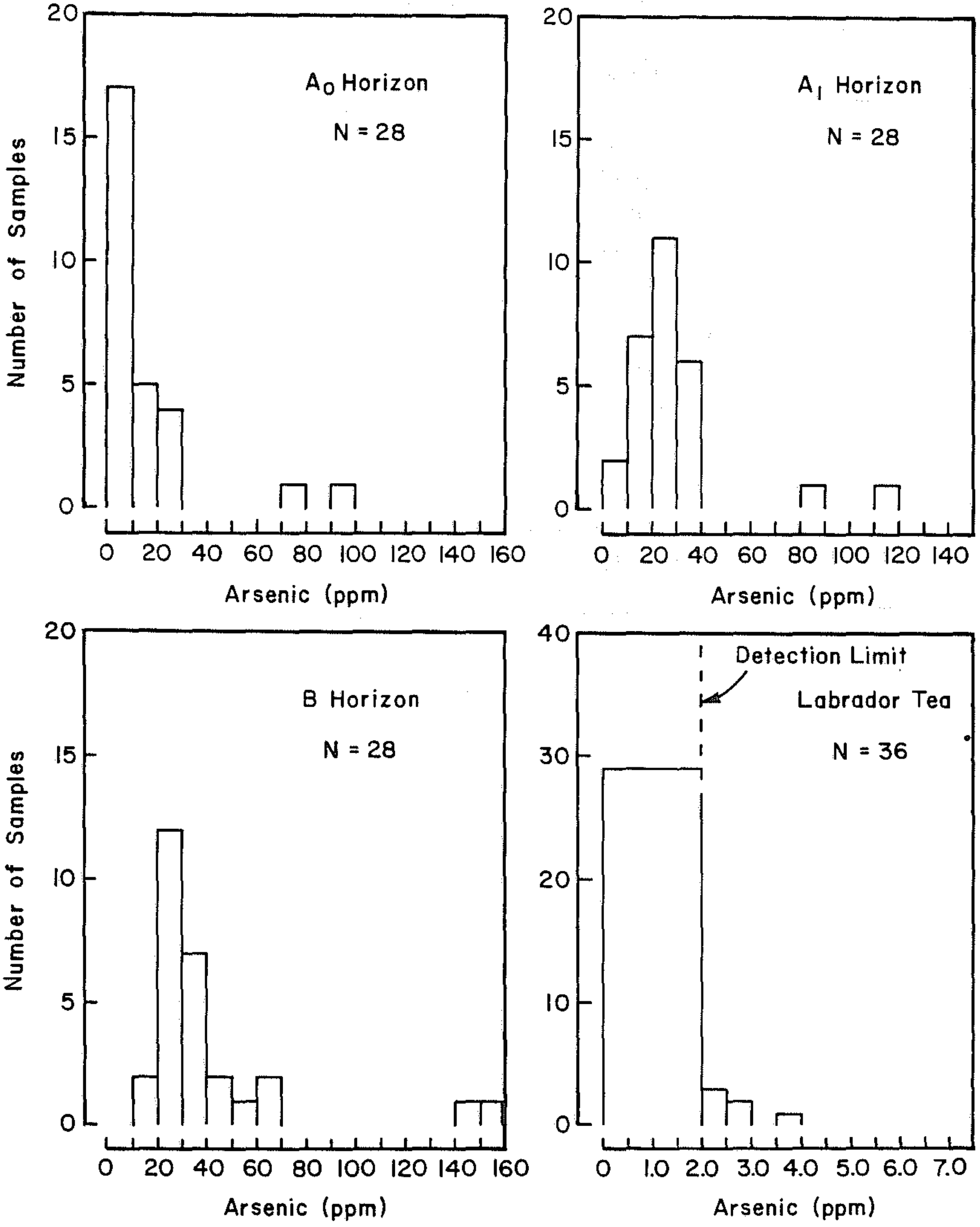

Figure 10A. Arsenic content in soil horizons and vegetation from Ryan Lode traverse.

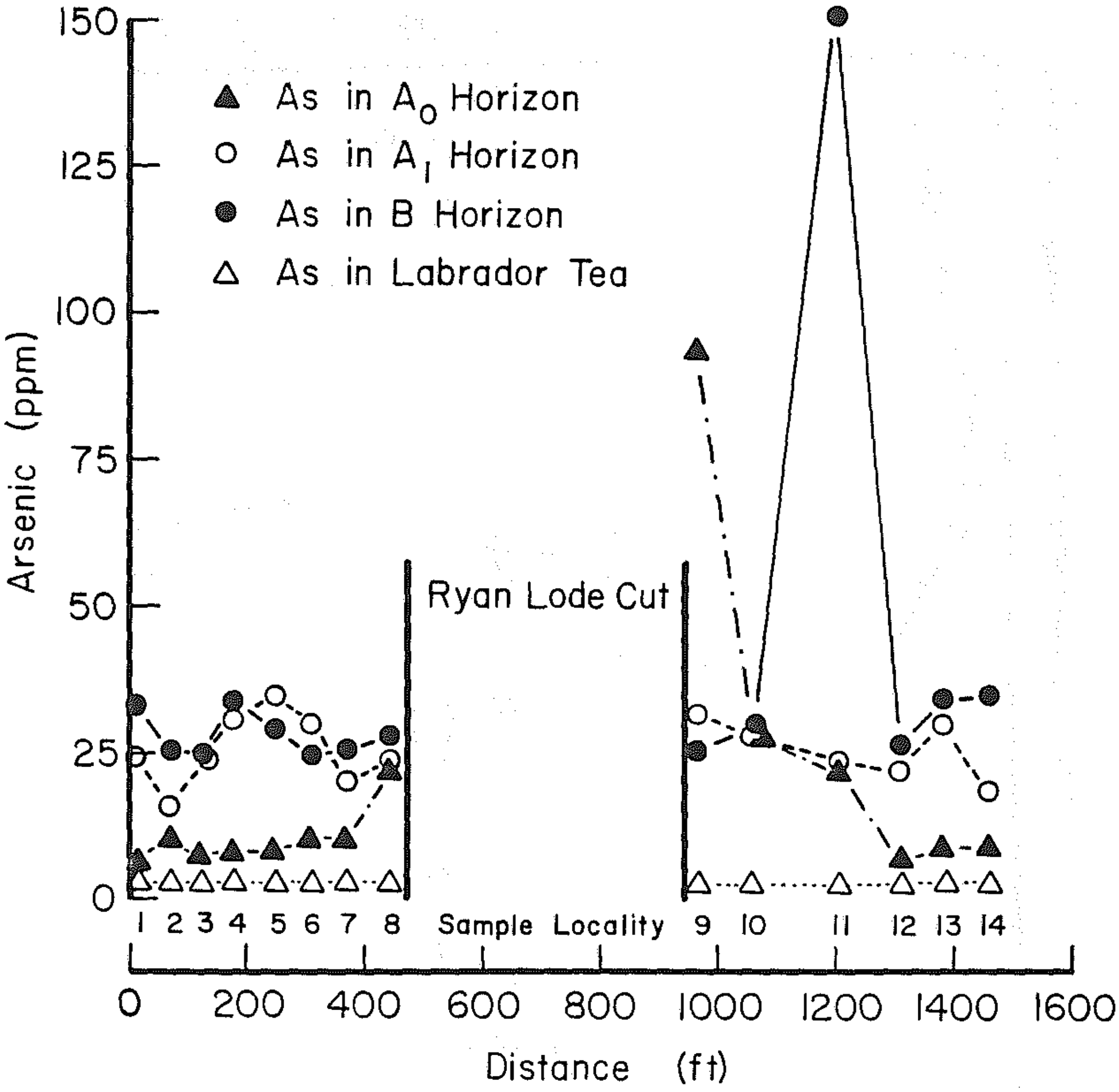

Figure 10B. Arsenic in samples from Ryan Lode traverse.

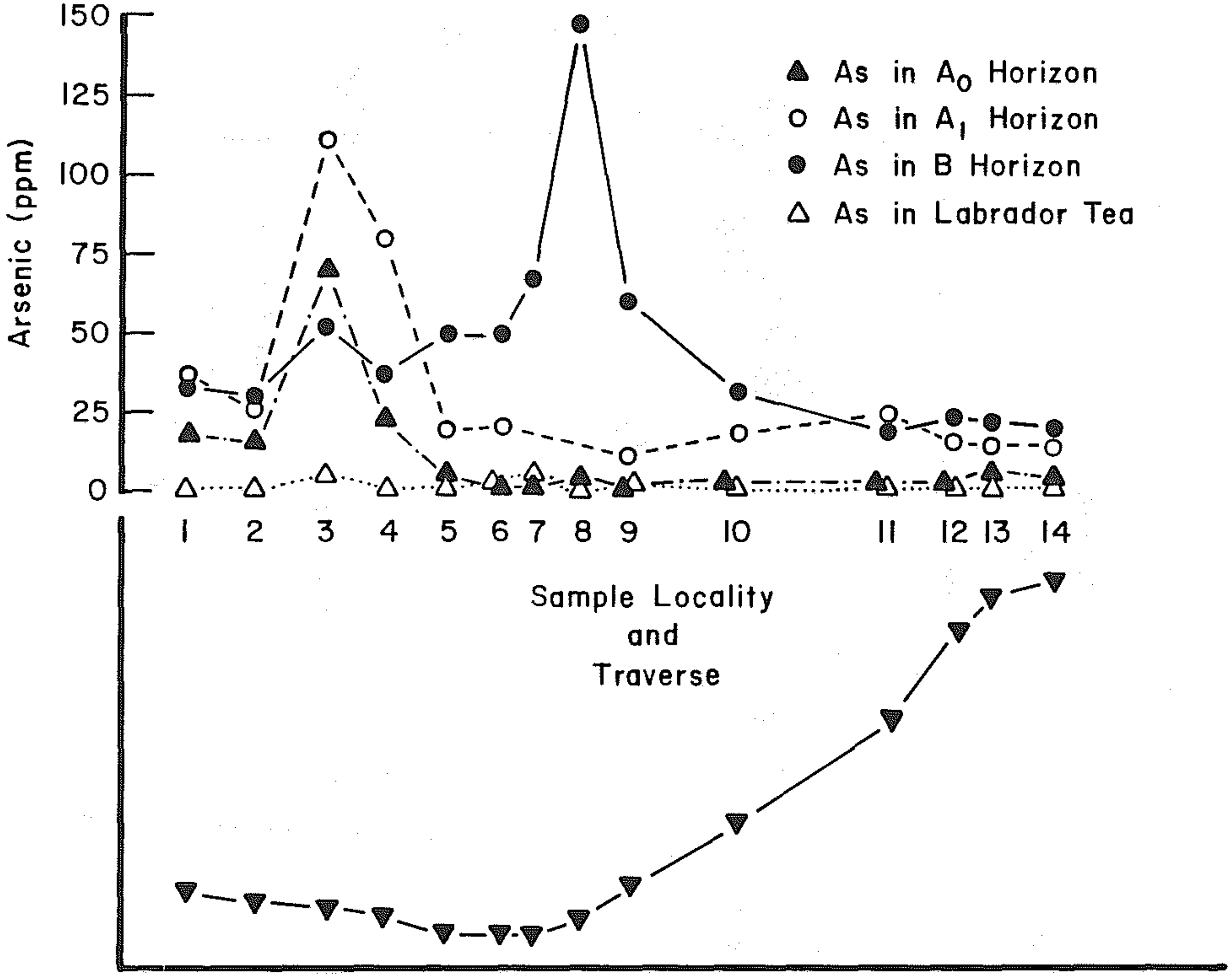

Figure 10C. Arsenic in samples from ridge traverse.

presence of arsenic mineralization. The single high value for arsenic in the A_0-horizon sample from locality 8 may be a result of contamination by arsenic-rich dust from the stripped mineralized zone adjacent to this locality. Samples from localities 1 through 4 of the Ridge traverse may be contaminated by dust from the Ester Dome road.

Arsenic enrichment in the B-horizon samples from both the Ryan-Lode and Ridge traverses is statistically significant (α 0.05) and chances of contamination are slight. Arsenic should be enriched in the B-horizon because iron oxides accumulate in this zone. The affinity of iron oxides for arsenic should then lead to enrichment of this horizon in arsenic. The anomalously high values of arsenic in some of the B-horizon samples probably reflect arsenic mineralization in the bedrock. A comparison of these arsenic values with gold values obtained by Stevens et al. (1969) along the same (Ridge) traverse supports this interpretation. Of particular interest are the analytical results for samples 7, 8, and 9 of the Ridge traverse, which suggest a mineralized zone beyond and approximately parallel to the Ryan Lode.

We are unable to reproduce the arsenic values obtained by Burton et al. in vegetation samples taken across the Ryan Lode. We agree with them that arsenic is taken up from the soil by Labrador tea, but our results suggest that this enrichment is slight. It seems that for this reason, and due to ease of analysis, that sampling and analysis of the B-soil horizon is a more effective geochemical prospecting method to delineate arsenic mineralization than is vegetation sampling.

With regard to using plants for geochemical prospecting, Horler et al. (1980) present data on detecting arsenic-rich areas by remote-sensing methods. Their results show a highly significant negative correlation (>99 percent between the soil arsenic concentration and the 1.65 μm reflectance for oak trees growing in arsenic-rich soils). Other investigators have shown that plants under stress are most evident in the fall or in the spring immediately after snowmelt. These results suggest that a remote-sensing investigation using this spectral region might be useful in delineating arsenic-rich areas in the Fairbanks region.

GREENHOUSE STUDIES

Various common garden vegetables were grown under greenhouse conditions to test the extent to which garden vegetables become enriched in arsenic when grown with arsenic-containing water. Six plants each of tomatoes (Tuckcross 533), cucumbers (LaReine), lettuce (Ostinata), and radishes (Burpee White) were grown. Three of each set were treated with arsenic-containing well water (Ester Dome area, 3.5 ppm As) and three were treated with water containing no arsenic. The tomatoes and cucumbers potted in 2 gallon nursery cans (1 plant per can) received 500 to 1,000 ml of water every 2 to 3 days per plant.

At the end of the experiment, the plants were harvested and the fruit, leaves and roots were dried and ground. The air-dried plant material was then analyzed for arsenic following the method described in Appendix A. Because of possible arsenic contamination from the analytic reagents and the possible loss of arsenic through volatilization during the ashing process, we checked our results using neutron activation analysis on selected samples of dried plant material. The results of both types of arsenic analysis are summarized in Table 9 and given in greater detail in Appendix B.

The soils in which the plants were grown were also analyzed and the results of these analyses are presented in Table 9.

The data of Table 9 clearly show that soils treated with arsenic-rich water are enriched in arsenic. The tomatoes received about twice as much water as did the other plants because of the longer growing period required. The soils in which the tomatoes were grown contained correspondingly more arsenic. Clearly then, the more arsenic-containing water added to the soil, the more arsenic there is in the soil. The water used in this study contained much iron, which precipitated in the jug upon standing, carrying down the arsenic. Such arsenic-rich iron precipitate becomes concentrated in the top part of the soil, where it sorbs arsenic from solution in subsequent waterings. As a result, the soil (particularly the top part, as can be seen in Table 9) becomes increasingly rich in arsenic with continued watering.

TABLE 9A: ARSENIC IN GREENHOUSE VEGETABLES EXPRESSED IN PPM.[a]

Plants	Without Arsenic Roots or Fruit	Without Arsenic Stems & Leaves	With 3.5 ppm Arsenic Roots or Fruit	With 3.5 ppm Arsenic Stems & Leaves
Tomato	<2 ppm	<2	<2	2.9
Cucumber	<2	2.8	<2	4.8
Lettuce	--	2.9	--	12
Radish	<2	<2	4.8	14

[a] Experiments were done in triplicate. Analysis was by atomic absorption spectrometry and neutron activation. Natural arsenic-containing well water was used.

TABLE 9B: ARSENIC IN GREENHOUSE SOIL EXPRESSED IN PPM.

Soil	Top Half	Bottom Half	Total (ppm)	Liters Water Used
Untreated	--	--	14.8	--
Treated				
Tomato	200	41.7	122	52
Cucumber	47.2	27.8	38.5	15
Lettuce	36.7	28.7	32.7	20
Radish	45.3	31.0	38.2	23

The fruit of tomatoes and cucumbers grown with arsenic-rich water are only slightly enriched in arsenic relative to the untreated plants. Tomato leaves and particularly cucumber leaves of the arsenic-treated plants contain more arsenic than do those of the untreated plants. The arsenic-treated lettuce and radishes showed significant arsenic enrichment compared with the untreated plants. The leaves of radishes are enriched in arsenic compared to the roots of the same plants. It appears from our data that for the different plants studied, the leaves tend to be richer in arsenic than do the roots or fruit. Furthermore, it appears that radishes and lettuce have higher arsenic concentrations than do tomatoes and cucumbers, even though the tomatoes in particular received a larger quantity of arsenic.

The results of our atomic absorption analysis are in reasonable agreement with those obtained by neutron activation analysis. Our data (Tables 9A and 9B) are comparable to similar data from other studies (Table 10).

The arsenic enrichment of the top, compared with the bottom, part of the soil suggests a possible explanation for why the lettuce and radishes contained more arsenic than did the tomatoes and cucumbers.

The lettuce and radishes are shallow rooted and thus grow in the top arsenic-rich zone, whereas the tomatoes and cucumbers are deeper rooted and draw water and nutrients from the lower arsenic-poor zone. Differences in the arsenic content of the water reaching the roots of the plants, as well as differences in the arsenic-assimilative behavior of the different plant types, may also contribute to the observed differences in arsenic content among the plants studied.

The tendency for arsenic to accumulate in the top part of soil treated with arsenic-rich water may be cause for concern among gardeners with long-established garden plots. The following calculation is an attempt to estimate (for the worst possible case) the quantity of arsenic that might be obtained by eating vegetables grown on such arsenic-rich plots. Assume a tilling depth of 1 foot and a 10-year period of watering the soil with water containing 5 ppm arsenic. Using the soil from the tomatoes as an example, 125 ppm arsenic accumulates in one

TABLE 10: ARSENIC CONCENTRATIONS IN GREEN VEGETABLES GROWN WITH AND WITHOUT ADDITION OF VARIOUS ARSENIC COMPOUNDS.

Vegetable	Without arsenic (ppm dry wt.)		With arsenic (ppm dry wt.)		
	Root or Fruit	Stem & Leaves	Root or Fruit	Stem & Leaves	Arsenic[a] Treatment
Tomato	0.01-2.95	<.2	0.68-39.5	334	4S
Tomato	0.08-0.09	6.75	trace-0.09	11.4	1S
Tomato	trace	--	3.75-145	---	3N
Tomato	trace	--	trace-18.1	---	4N
Cucumber	0.02-2.4	--	0.2	---	1S
Lettuce	---	0.01-3.78	---	0.0-2.1	3P
Lettuce	---	--	---	0.08-0.32	1S
Radish	0.01-2.02	--	trace	---	SP
Radish	---	--	0.02-0.22	---	1S

a Treatment codes, 1 = lead arsenate, 2 = calcium arsenate, 3 = sodium arsenate, 4 = sodium arsenite, N = nutrient solution, S = soil, SP = smelter pollution.

year. If the arsenic content is linearly additive, then in 10 years there might be 1,250 ppm arsenic (as a ferric arsenate compound) in the soil. This value is comparable to that found in stream sediments of the area. If the arsenic content of the vegetables is proportional to the arsenic content of the soil in which they are grown, then a person could possibly ingest 625 μg arsenic by eating one normal serving of lettuce per day (see calculation in Appendix B). In comparison, the average daily water intake of an adult is about 1,000 ml. The quantity of arsenic ingested from such lettuce is then comparable to that obtained from drinking a normal daily quantity of water containing 625 ppb (μg/L) arsenic.

It is not known if such high arsenic concentrations in lettuce can result from growing lettuce on soil watered for prolonged periods with arsenic-rich waters. The data of Table 10 show that concentrations as large as this have been found in vegetables and that the resultant concentration in the plant appears to depend upon the form in which the arsenic is added.

As a result, the possibility exists that eating vegetables grown in gardens watered with arsenic-rich water can provide quantities of arsenic comparable to those obtained from drinking arsenic-rich waters. In other words, the arsenic dose received by eating such vegetables may not be insignificant in comparison to that from drinking arsenic-rich water.

We have no data on the actual arsenic content of garden vegetables, or of garden soils in the Ester Dome area. Such data should be obtained.

SUMMARY

This study was undertaken as a result of an earlier study in which arsenic concentrations as large as 10 parts per million (ppm) were found in domestic water supplies of the area. This earlier study triggered an intensive study by various state and federal agencies to evaluate the threat to human health posed by these arsenic-rich waters.

From a health standpoint, 70 mg arsenic has proven to be toxic to humans, while arsenic in low concentrations (less than 1 ppm) appears to be a carcinogen. The U.S. Public Health Service (USPHS) recommended guide limit for arsenic in potable water supplies is 10 parts per billion (ppb). An arsenic level above 50 ppb constitutes grounds for rejecting the water as a public water supply.

From the work of the various health agencies in the Fairbanks area, it was found that people drinking arsenic-rich waters are themselves enriched in arsenic. It is not known at this time if such arsenic-enrichment affects the health of the individuals involved. It was also found that the arsenic contamination of the groundwaters of the Fairbanks area was more extensive than first thought. The Ester Dome area has a high proportion of wells containing large concentrations of arsenic.

Our previous work and subsequent studies by the U.S. Geological Survey and the Alaska Department of Environmental Conservation suggest that arsenic-containing wells in the area are confined to the hillside residential subdivisions where water is obtained from bedrock aquifers. The arsenic concentrations in these areas show large horizontal concentration gradients, so that while one well might have 5 ppm arsenic, another well 100 yards away might contain only 50 ppb arsenic. The waters from these areas are used for domestic purposes as well as for irrigating vegetable gardens.

OBJECTIVES

1. To determine the geological and geochemical factors affecting the distribution of arsenic in the waters of the Ester Dome area.

2. To evaluate the arsenic content of plants grown on arsenic-rich soils or with arsenic-rich water.

RESULTS AND CONCLUSIONS

Geologic mapping of the Ester Dome area has more clearly defined the previously recognized mineralized region there. A very wide zone of metallic enrichment exists which includes lodes and interlayered mineralized schists and micaceous quartzites typified by high concentrations of arsenic. For example, rocks from this zone contain an average of 750 ppm arsenic, which is about 100 times higher than the arsenic content of average unmineralized metamorphic rocks. The arsenic-rich zone is situated on the southeastern flank of Ester Dome and the rocks in this zone have a predominantly southeasterly dip. The structural dip and the well-developed fractures in the more competent rock units provide channels for the down-dip movement of arsenic-rich waters. As a result of this geologic setting, it is not surprising that many of the domestic wells with the highest concentrations of arsenic are situated on the southeast flank of Ester Dome, down dip from the arsenic-bearing mineralized zone.

Analyses of well cuttings from domestic wells show that some wells are drilled through rocks enriched in arsenic. These rocks serve as an immediate source of arsenic to the groundwater flowing into the well. The primary source of arsenic in the waters of the area is the arsenic-bearing sulfide mineralization in the mineralized zone. However, equilibration of the groundwater with the iron-arsenate mineral, scorodite, seems to be the main factor governing the concentration of arsenic in the groundwater. None of the cuttings from these arsenic-rich wells contained arsenic sulfides visible under the microscope. The cuttings did have arsenic-containing iron oxides coating veinlets and fissures. Laboratory experiments showed that arsenic in concentrations comparable to those found in groundwater (500 ppb) could be obtained from these cuttings by leaching the rock chips in distilled water under oxygen-poor conditions at pH values near 6.5. Such solutions are rich in arsenic and iron, and oxygen poor.

A similar situation obtains in the groundwaters of the area where it appears that most of the arsenic in the groundwater is present in the reduced (As III) rather than oxidized (As V) form. When these waters are aerated, arsenic is coprecipitated with ferric hydroxide. Also, arsenic is removed by sorption (especially under oxidizing conditions) on previously precipitated ferric hydroxides and oxides. This process is operative in the surface waters of the area and is the means whereby the arsenic concentration of the surface waters is naturally reduced.

Stream sediments in the area tend to be enriched in arsenic particularly in or near the mineralized zone. This suggest that arsenic analysis of stream sediments might be useful in geochemical prospecting for sulfide and accompanying gold mineralization in the area. Our earlier work showed a significant correlation between the arsenic content of the bottom sediments and the dissolved arsenic concentration in the stream water. This relationship was especially evident in streams containing large amounts of suspended sediments, such as would result from placer mining. It was suggested that removal of the suspended sediments would significantly reduce the dissolved arsenic concentration.

Results from the present study on samples taken under conditions in which the suspended-solids content was low showed no relation between the arsenic content of the bottom sediments and the dissolved arsenic concentration. Furthermore, the arsenic concentrations were all less than 100 ppb, even for those samples in which the bottom sediments contained as much as 1,400 ppm arsenic. This tends to confirm our earlier observations that, although placer mining contributes arsenic to stream waters through the sediment burden produced, the dissolved arsenic concentration is brought to near or below the USPHS concentration guide limits when these sediments are removed.

Garden vegetables, grown under greenhouse conditions using water containing 3 ppm arsenic tend to be enriched in arsenic relative to those vegetables grown with arsenic-free water. The leaves of lettuce and radishes grown with arsenic-rich water contained 12-24 ppm arsenic per gram of dry plant, whereas the leaves plants treated with arsenic-free water contained less than 2 ppm arsenic. (Two ppm was the analytical detection limit using atomic absorption spectrometry. These results of vegetation analysis were confirmed by neutron activation analysis of selected samples.) Radish roots of arsenic-treated plants contained 5 ppm arsenic, whereas the roots of untreated plants contained less than 2 ppm. Fruits of tomatoes and cucumbers grown with arsenic-rich waters were not significantly enriched in arsenic relative to the untreated plants. Because the soil becomes enriched in arsenic upon prolonged watering with arsenic-rich water, and because the arsenic content of the plants may increase with increasing arsenic content of the soil, the quantity of arsenic a person might ingest by eating garden vegetables grown with arsenic-rich water may not be insignificant relative to that obtained by drinking the water. Further study of this seems warranted.

In an earlier and related study, students of the Geology-Geophysics Program of the University of Alaska obtained results suggesting that alder and Labrador tea growing in arsenic-rich soils were enriched in arsenic. Our study showed only a slight increase in the arsenic content of Labrador tea growing in heavily mineralized areas. Furthermore, there was no clear-cut relationship between the slight enrichment found and location of mineralized veins. This suggests that the vegetation studied does not become particularly enriched in arsenic and that biogeochemical prospecting using these plants may not be very successful. Similarly, there was a tendency toward slight arsenic enrichment in the organic-rich A_0 and A-soil horizons. The B-soil horizon, on the other hand, showed significant arsenic enrichment that seemed to parallel known arsenic mineralization. This suggests that the B horizon might be much more useful as a sampling medium in geochemical prospecting for arsenic and accompanying gold mineralization.

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APPENDIX A

ANALYTICAL METHODS

Water

The procedure used here is the same as that used by Wilson and Hawkins (1978) which was modified from Fernandez and Manning (1971). The instrument used was a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer equipped with an HGA-2600 graphite furnace.

Twenty-five microliters (25 μL) of filtered and acidified water sample was transferred to the furnace by means of a pipette. Next, 25 μL of an aqueous 0.1 percent $Ni(NO_3)_2 \cdot 6H_2O$ solution was added to reduce volatility of the arsenic during the drying and charring stages. Instrumental conditions for the spectrophotometer were the same as those listed for arsenic in the Perkin-Elmer manual. The furnace settings were as follows:

dry	115°C	60 seconds
char	1,200°C	30 seconds
atomize	2,500°C	15 seconds
gas	argon	300 cm^3/minute

Standards containing 10, 20, 30, 50 and 100 ppb arsenic were prepared by serial dilution with 0.2 m HNO_3 of a 1,000 ppm arsenic standard solution. Standards and samples were analyzed in triplicate under the above instrumental conditions. The quantity of arsenic in the sample was obtained from a standard curve. Because of the number of arsenic analyses performed and the fact that the standard curve changed somewhat during the lifetime of a graphite tube, the arsenic standard curve was fit by means of a computer program. This program (called ASSTD; written by D. Hawkins) constructs a least-squares fit to the arsenic-standard curve data and calculates the concentration of arsenic in the samples giving a mean value plus or minus 2 standard deviations. The estimated precision of the analysis was obtained by taking into account both the variance of the standard curve data and that for the samples. A copy of the program can be obtained from us on request.

Vegetation Analysis

The method used was slightly modified from that of Ward (1975) for the dry ignition of vegetation prior to the arsenic determination. This method is similar to that used by Burton et al. (1978) which was based on the method of Friend, Smith and Wishart (1977).

Following Ward:

1. Weigh 2.0 g of ground, air-dried vegetation into an evaporating dish and wet with a small amount of ethanol.
2. Add 10 ml of magnesium oxide-magnesium nitrate-nickelous nitrate slurry and mix well.
3. Place dish on a hot steam bath and dry.
4. Transfer dish to preheated muffle furnace and ignite vegetation at 550-600°C for 2 to 4 hours.
5. Remove dish from the muffle furnace, cool, moisten ash with a minimum amount of water and cover dish with a cover glass. Add about 15 ml of 6 M HCl.
6. Heat dish and contents on water bath until sample dissolves.
7. Filter the hot acid solution through Whatman 41 filter paper into 100 ml volumetric flask. Rinse dish and filter with several portions of hot distilled, arsenic-free water until filtrate volume is about 60 ml. Cool the flask to room temperature and dilute the flask to volume with water.
8. Analyze using atomic absorption spectrometry following the method described above. It is not necessary to add additional nickelous nitrate.

The furnace settings as follows:

dry	115°C	2 minutes
char	1,200°C	1 minute
atomize	2,500°C	15 seconds

Magnesium oxide-magnesium nitrate-nickelous nitrate slurry:

Suspend 37.5 g magnesium oxide, 52.5 g magnesium nitrate hexahydrate and 24.8 g nickelous nitrate hexahydrate in enough arsenic-free water to make 500 ml of solution. Shake slurry vigorously before using.

This solution serves as an ashing aid with the nickel acting to reduce the volatility of arsenic both during ashing and during analysis.

Soils

In this method, arsenic bound with iron oxides dissolves, but only partial dissolution of arsenic-bearing sulfides is achieved.

1. Weigh 1.0 g of -100 mesh air-dried soil into a 125 ml beaker.
2. Add 50 ml of 1.0 N HCl. Cover beaker with a watch glass, place beaker on hot plate at medium heat and boil gently for 1 hour.
3. Filter the hot acid solution through Whatman 41 filter paper into a 100 ml volumetric flask, washing the cover glass, beaker and filter several times with hot, arsenic-free water until the filtrate has a volume of about 60 ml.
4. Cool the flask to room temperature and dilute to volume with arsenic-free water.
5. Analyze for arsenic following the procedure used for the water analysis.

Rocks and Sediments

The rocks (well cuttings) and stream sediments were analyzed by x-ray fluorescence. Because iron is the only abundant element affecting the K_α spectra in the sample, standards were prepared by serial addition of As_2O_3 to finely ground mixtures of quartz and Fe_2O_3. The iron content of the standards were 10 percent by weight, which is about equal to the sum of Fe_2O_3, FeO, MgO and MnO in the samples (quartz-mica schists). The standards were mixed for three minutes in a Pitchford blender. Next, 1.50 g of the standard was mixed with 3.0 g stearic acid, and this was mixed for 1 minute in the blender. A pellet was prepared from this mixture by pressing in a pellet press for 20 seconds at 20,000 psi. The standards ranged from 0 to 5,000 ppm arsenic.

W X-ray tube	
40 Kv	
20 mA	
Air path	
LiF Crystal	
Arsenic K_α, 33.98° $2\,\theta$	
Pulse Height Analysis	
Scintillation detector	950 v
Base level	17.6 v
Window width	28.0 v
Counting time	50 seconds

Three 50-second counts were taken at 33.0, 33.98 and 35.0 degrees to determine background and peak intensities. The background at 33.98 degrees was estimated by interpolation from the background at 33.0 and 35.0 degrees. A standard curve of net counts per 50 seconds versus arsenic concentration was prepared over the range 0 to 5,000 ppm. Under these conditions, the detection limit was 40 ppm arsenic.

APPENDIX B

ARSENIC CONTENT OF GREENHOUSE SAMPLES

CALCULATION OF POSSIBLE ARSENIC CONCENTRATION OF LETTUCE GROWN ON ARSENIC-RICH SOILS.

Assumptions:

1. As content of soils increases with long-term exposure to arsenic-rich waters, achieving a value of 1,250 ppm (like that observed for rocks and sediments of Ester Dome).

2. The As content of lettuce is directly proportional to the As content of the soil on which it is grown. A probable ratio for As/g dried plant to As/g soil is 0.1 (see Table B1).

3. Lettuce contains 90% water by weight.

4. Average serving of lettuce weighs 50 g (Marguerite Stetson, personal communication).

Calculations:

From Assumptions 1 and 2, we find

$$1{,}250 \, \frac{\mu\text{g As}}{\text{g soil}} \times \frac{0.1 \, \mu\text{g As/g dry lettuce}}{1 \, \mu\text{g As/g soil}}$$

$= 125 \, \mu\text{g}$ As/g dried lettuce.

From Assumption 3, 10 g of wet lettuce corresponding to a dry weight of 1 g.

Thus a person could ingest 125 μg As/10 g wet lettuce.

If the average lettuce serving/person is 50 g (Assumption 4), then an average daily serving of wet lettuce would yield 625 μg As.

TABLE B1: ARSENIC CONTENT OF GREENHOUSE SAMPLES.

Plant	As(AA)	As(NAA)	Soil (-100 mesh) Ave. As(mg/g)		Total Added As (mg)
			Top Half	Bottom Half	
Lettuce Leaves	<2	≤1.7	14.8	14.8	0.0
" "	3.8		"	"	"
" "	3.4		"	"	"
" "	17	16.4	36	29	70,000
" "	4.4		"	"	"
" "	14		"	"	"
Radish Leaves	<2		14.8	14.8	0.0
" "	<2		"	"	"
" "	<2		"	"	"
" "	2.1		45	30	80,500
" "	17		"	"	"
" "	23		"	"	"
" Roots	<2	≤0.60	14.8	14.8	0.0
" "	<2		"	"	"
" "	<2		"	"	"
" "	5.3		45	30	80,500
" "	3.3	8.6	"	"	"
" "	5.7		"	"	"
Cucumber Leaves	<2		14.8	14.8	0.0
" "	2.9		"	"	"
" "	4.1		"	"	"
" "	4.1		47	30	52,500
" "	6.4		"	"	"
" "	4.0		"	"	"
Cucumber Fruit	<2	≤0.49	14.8	14.8	
" "	<2		"	"	
" "	<2		"	"	
" "	<2		47	30	52,500
" "	<2	1.43	"	"	"
" "	<2		"	"	"
Tomato Leaves	<2		14.8	14.8	0.0
" "	<2	≤1.1	"	"	"
" "	<2		"	"	"
" "	2.8		200	42	182,000
" "	2.9	1.64	"	"	"
" "	2.8		"	"	"
" Fruit	<2		14.8	14.8	0.0
" "	<2		"	"	"
" "	<2		"	"	"
" "	<2		200	42	182,000
" "	<2		"	"	"
" "	<2		"	"	"

APPENDIX C

DATA FROM BURTON ET AL. (1978)

Because the results of this study were not published and because they bear on this work, the data from Burton et al. (1978) are included here.

Stream sediments: The data from our study and those of Burton et al. are not strictly comparable because the entire stream-sediment sample was analyzed in our study while only the -100 mesh fraction was analyzed in the Burton et al. study. Our study yields a value for the total arsenic in the sample while that of Burton et al. is for the acid-soluble fraction of the -100 mesh part of the sample.

Surface Waters: The Burton et al. data are for May 1977 during a period of high flow and high suspended-sediment load. Our data are for August 1978 during a period of low flow and low suspended-sediment load. The most significant difference is in the treatment of the samples. Unfortunately, because of the high suspended-sediment load, Burton et al. found it very difficult to filter the samples in the field. To avoid loss of arsenic from solution by coprecipitation with iron, it was necessary to acidify the samples immediately. Thus, the samples were acidified in the field and then filtered in the laboratory. This treatment resulted in arsenic being dissolved from the suspended material, yielding arsenic concentrations in the water that are too high.

In our study, we were able to filter the sample in the field prior to acidification because of the light sediment load. This resulted in significantly lower observed concentrations of arsenic.

Vegetation: There was only a slight difference in the two methods used to ash vegetation in our two studies. The results of our study and Burton et al. should be comparable.

TABLE C1: STREAM DATA.

Sample Number	Water (ppb)	Bottom Sediments (ppm)	Suspended Lode (L=low, H=high)	pH of Water	Temp. (°F)	Collection Date	Distance Downstream From 003 (feet)	Comments	
A	16.6	511	L			5/5/77	Short tributary off map		Roadside creek leaves road. Creek absorbed into vegetation.
B	--	345	L			"	"		
1	60.9	a	L	5.1	34	"	Start right fork	Water on snow	
2	41.5	7,184	L	5.1	33	"	211	"	
3	27.9	1,824	L	5.1	34	"	475	"	
4	751.0	10,240	H	5.1	33	"	713	"	
5	658.4	6,824	L	5.1	33	"	950	"	
6	569.4	a	L	5.1	34	"	1,161	"	
7	1,219.0	a	L	5.2	34	"	1,293	"	
8	979.6	2,790	L	5.2	34	"	1,531	"	
9	1,169.0	1,764	L	5.2	34	"	1,779	"	
10	646.9	2,030	L	5.2	34	"	2,054	"	
11	664.0	1,360	L	5.2	35	"	2,307	"	Small meadow.
12	789.0	2,719	L	5.2	35	"	2,492	"	
13	593.8	3,680	L	5.2	35	"	2,740	"	
14	978.6	1,088	L	5.2	34	"	2,962	"	
15	1,004.6	a	L	5.2	33	"	3,147	"	East fork joins.
16	815.0	a	L	5.2	32	"	3,405	"	
17	1,170.4	a	L	5.2	32	"	3,659	"	
18	983.2	1,196	L	5.2	33	"	3,907	"	Beginning of valley bottom meadow.
19	72.1	a				5/16/77	4,166	"	Small tributary joins from east.
20	82.8	a		5.2	32	"	4,351	"	
21	74.5	a	L	5.2	32	"	4,593	"	
22	75.4	a	H	5.2	32	"	4,757	"	
23	68.5	12,008	H	5.3	32	"	4,942	"	High water sediment sample.
24	171.6	a	L	5.3	32	"	5,185	"	
25	144.2	112	L	5.4	33	"	5,443	"	
26	153.9	a	L	5.4	33	"	5,655	"	
27	112.1	16,808	L	5.5	34	"	5,813		
28	119.6	4,372	L	5.5	34	"	6,077		
29	103.2	5,960	L	5.5	34	"	6,288		Pond, creek partially diverted.
30	103.2	6,180	L	5.5	39	"	6,531		
31	73.5	10,636	L	5.5	36	"	6,795		
32	97.2	6,416	L	5.5	37	"	7,006		
33	81.6	2,114	L	5.6	37	"	7,191		Top of waterfall into eastern dredge pit.
34	141.2		H	5.4	34	5/19/77	7,376		Base of falls.
35	200.1	a	H	5.3	34	"	7,587		Beginning of eastern dredge pit.
36	180.7	a		5.4	34	"	7,709	Creek running on snow	
37	181.9	a		5.4	34	"	7,915	"	Dredge tailings begin.
38	223.5	1,003		5.4	34	"	8,020	"	
39	294.7	5,040		5.3	34	"	8,142		
40	97.2	5,484	L	5.3	34	"	8,321		Dredge tailings end.
41	329.6	205	L	5.3	34	"	8,453		
42	127.9	268	L	5.3	34	"	8,611		
43	228.7	246		5.4	34	"	8,728		
44	322.5	280		5.4	34	"	8,817		
45	222.6	321	H	5.4	34	"	8,934		
46	272.4	184	L	5.5	34	"	9,176		
47	95.8		L		33	5/12/77		Creek along Henderson Road	
48	50.0	272	H		33	"		"	
49	26.7	312			33	"		"	
50	31.4	117	H		33	"		"	
51	27.9	200	H		33	"		"	
52	50.9	201	H		33	"		"	
53	36.4	284	L	5.1	34	"		East fork, Eva Creek	Nearly stagnant.
54	443.7	233	L	5.1	34	"		"	"
55	15.5	299	L		34	"		"	Below Clipper Mine.
56	21.6	349	L			"		"	
57	22.2	419	L	5.2		"		"	
58	11.6	238	L	5.2	45	"		"	Nearly stagnant.
59	119.3	4,268	L	5.7	36	5/18/77			Pond at end of swampy area, beginning of Little Eva #1.
60	66.0		H	5.4	34	"		Little Eva #1	Just before Parks Hgwy.
61	40.3		H	5.4	34	"		"	
62	44.7		H	5.4	34	"		"	
63	38.0		H	5.4	34	"		"	
64	30.9		H	5.4	34	"		"	Nearly stagnant.
65	76.8		L	5.5	34	5/19/77		"	
66	N.D		H	5.5	34	"		"	Large tailings pile on hillside above creek.
67	51.2			5.5	34	"		"	Opposite "Little Eva Mine".
68	49.2		H	5.6	34	"		"	
69	33.9		H	5.4	34	5/18/77		"	
70	31.2		H	5.4	34	"		"	
71	32.2		H	5.3	34	"		"	
72	32.7		H	5.3	34	"		"	
73	22.9		H	5.3	34	"		"	Nearly stagnant.
74	54.9		H	5.2	34	"		"	Just before Parks Hgwy.
75	90.9		L	5.1	34	"		"	
76	N.D	1,380	L	5.4	40	"		Little Eva #2	
77	10.3	1,592	L	5.3	40	"		"	Beginning of Little Eva #2.
78	11.0	1,558	L	5.5	40	"		"	Top of cascade into western dredge pit.
79	41.7	2,208	L	5.5	40	"		"	
80	24.8	1,484	L	5.6	40	"		"	
81	26.6	1,732	L	5.6	40	"		"	
82	22.4	1,478	L	5.6	40	"		"	
83	20.5	1,512	L	5.5	40	"		"	
84	25.1	1,488	L	5.5	40	"		"	
85	13.3	1,460	L	5.5	40	"		"	Nearly stagnant.
86	313.8		L		33	5/12/77			Spring has much organic matter.
87	13.1				33	"		Spring	
88	86.1		H	5.5	32	"	3,094		10 ft below Fe-rich spring which flows into main creek at 017.
89			H	5.6	32	"	3,090		Source of spring, smells of H_2S, dry creekbed above spring.
90	175.0	a	L	5.2	33	5/16/77		Water on snow	Sample from tributary that joins at 020.
91	11.6	a	L	5.2	42	"		"	Stagnant spring.
92	36.8	6,328	L	5.6	34	5/18/77			Stagnant pond.
93	32.0	4,612	L	5.4	38	"			Spring 100 ft west of 047
94	28.8		H	5.3	34	"			Stagnant pool midway down wonderloess fall, main creek.

a Bottom sediment samples unobtainable.

TABLE C2: ARSENIC CONTENT OF PLANTS FROM ESTER DOME.

Common Name	Scientific Name	Mean Arsenic (ppm)	High Value Arsenic (ppm)
Alder	Alnus spp.	27.90	117.5
Aspen	Populus fremuloides	29.57	56.1
Labrador Tea	Ledum spp.	22.50	52.50
White Spruce	Picea glavea	13.52	38.52
Willow	Salix spp.	14.79	31.71
Fireweed	Epilobium angustifolium	12.01	26.49
Bunchberry	Cornus canadensis	11.97	21.12
Rose	Rose acicularis	13.03	18.97
Cranberry	Vaccinium vitis-idaea	13.74	17.66
Birch	Betula papyrifera	15.08	16.35
Grass	Gramineae spp.	11.33	13.66
Juniper	Juniperus horizontalis	12.20	12.62
Moss		2.67	2.67

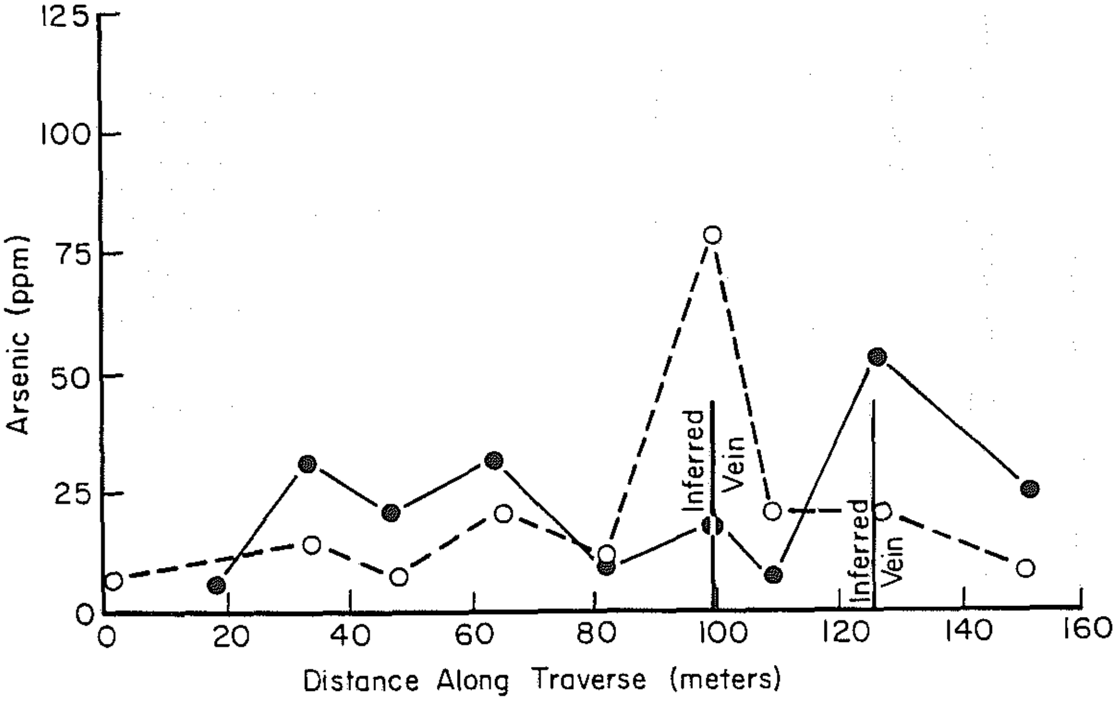

Figure C1. Arsenic concentrations in alder and Labrador tea along middle traverse of Ryan Lode.

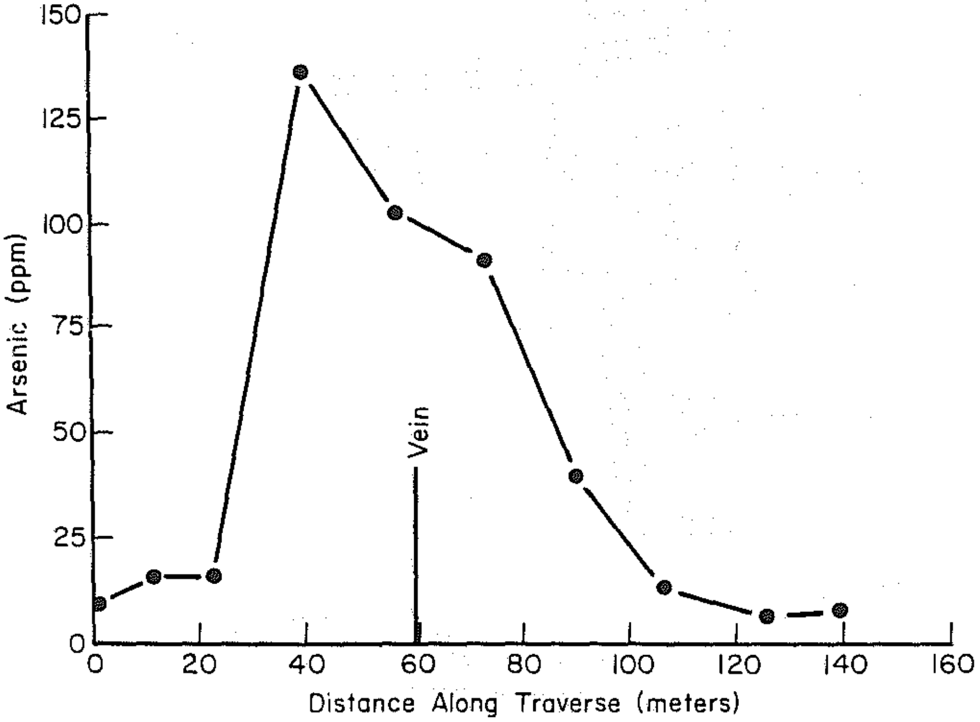

Figure C2. Arsenic concentrations in alder along upper traverse of Ryan Lode.

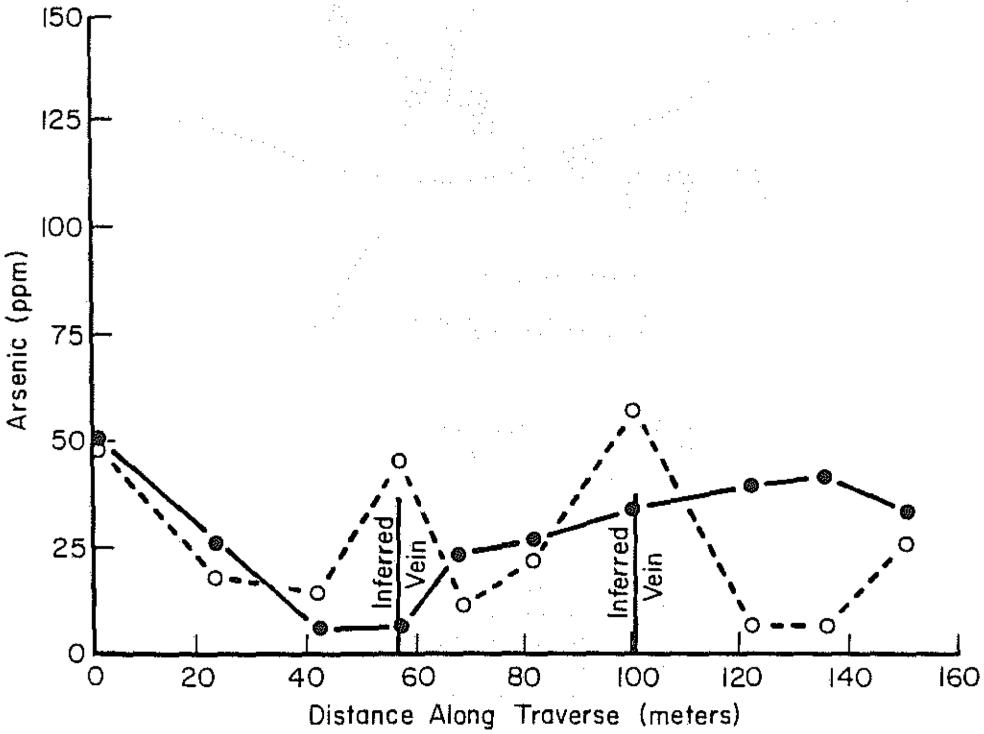

Figure C3. Arsenic concentrations in alder and Labrador tea along lower traverse of Ryan Lode.

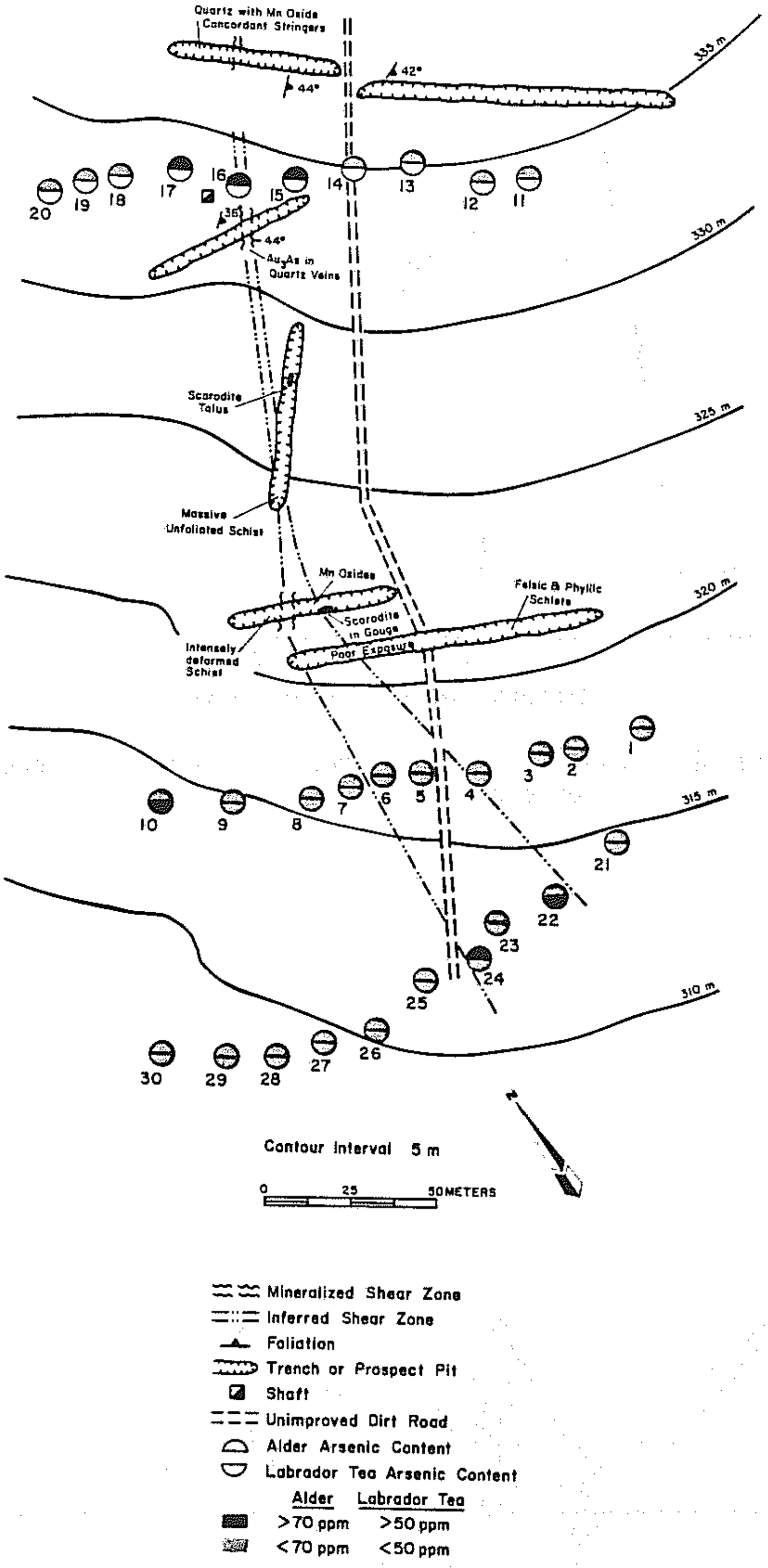

Figure C4. Biogeochemical traverses of Ryan Lode.