Prepared in cooperation with the Bureau of Land Management

Review of Samples of Water, Sediment, Tailings, and Biota at the Little Bonanza Mercury Mine, San Luis Obispo County, California

By James J. Rytuba, Roger L. Hothem, Daniel N. Goldstein, Brianne E. Brussee, and Jason T. May

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Abbreviations, Definitions, Datum Used, and Conversion Factors

Vertical and horizontal coordinate information is referenced to the North American Datum of 1927
DOC, dissolved organic carbon
DOM, dissolved organic matter
EE/CA, engineering evaluation/cost analysis for “non-time-critical removal actions,” as defined by the U.S. Environmental Protection Agency’s Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).
Hg, elemental symbol for mercury; does *not* denote speciation.
$Hg_{T,}$ total mercury (inorganic plus organic).
$Hg_{F,}$ total mercury (inorganic plus organic) in a filtered sample (either 0.1 or 0.45 μm, as specified in the text).
MMeHg, monomethylmercury, methylmercury, and monomethylmercury ion (CH_3Hg^+)
ng/g, nanogram per gram, equivalent to parts per trillion.
ng/L, nanogram per liter, approximately equivalent to parts per trillion.
ppm, parts per million, equivalent to mg/kg or μg/g.
SC, specific (electrical) conductivity, reported in units of millisiemens per centimeter (mS/cm).
Flask, 34.5 kg or 76 lb of Hg
RPD, relative percent difference
ANOVA, analysis of variance
ASTM, American Society for Testing and Materials
BLM, Bureau of Land Management
CDFG, California Department of Fish and Game
Cl^-, chloride
CVAFS, cold-vapor atomic-fluorescence spectroscopy
CVAAS, cold-vapor atomic-absorbption spectroscopy
CVRWQCB, Central Valley Regional Water Quality Control Board
HCl, hydrochloric acid
$H_2SO_{4,}$ sulfuric acid
ICP-AES, inductively-coupled plasma atomic-emission spectroscopy
ICP-MS, inductively-coupled plasma-mass spectroscopy
TMDL, total maximum daily load
EPA, U.S. Environmental Protection Agency
USGS, U.S. Geological Survey

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)

gallon (gal)	0.003785	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram	2.205	pound, avoirdupois (lb)
microgram (µg)	0.0000000353	ounce, avoirdupois (oz)
milligram (mg)	0.0000353	ounce, avoirdupois (oz)
nanogram (ng)	0.0000000000353	ounce, avoirdupois (oz)
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F = (1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C = (°F-32)/1.8
Specific conductance is given in microsiemens per centimeter (µS/cm) at 25 °C
Concentrations of chemical constituents in water are given in milligrams per liter (mg/L, parts per million), micrograms per liter (µg/L, parts per billion), or nanograms per liter (ng/L, parts per trillion).
Concentrations of chemical constituents in tissues are given in micrograms per gram (µg/g, parts per million).
Concentrations of chemical constituents in sediment are given in micrograms per gram (µg/g, parts per million) or nanograms per gram (ng/g, parts per billion)

Review of Samples of Water, Sediment, Tailings, and Biota at the Little Bonanza Mercury Mine, San Luis Obispo County, California

By James J. Rytuba,[1] Roger L. Hothem,[2] Daniel N. Goldstein,[1] Brianne E. Brussee,[2] and Jason T. May[3]

Introduction

Background and Objectives

The Little Bonanza mercury (Hg) mine, located in San Luis Obispo County, California, is a relatively small mine with a historical total Hg production of about 1,000 flasks (fig. 1). The mine workings and tailings are located in the headwaters of the previously unnamed west fork of Las Tablas Creek (WF Las Tablas Creek), which flows into the Nacimiento Reservoir. Wasterock and tailings eroded from the Little Bonanza Hg Mine have contributed Hg-enriched mine wastes to the headwaters of WF Las Tablas Creek. The mine is located on Federal land managed by the U.S. Bureau of Land Management (BLM), which requested that the U.S. Geological Survey (USGS) measure and characterize Hg and other geochemical constituents in tailings, sediment, water, and biota at and downstream from the minesite. This report is in response that request, from the lead agency which is mandated to conduct a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) - Removal Site Investigation (RSI). The RSI applies to removal of Hg-contaminated mine waste from the Little Bonanza minesite as a means of reducing Hg transport to WF Las Tablas Creek.

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[1] U.S. Geological Survey, Menlo Park, California.
[2] U.S. Geological Survey, Dixon, California
[3] U.S. Geological Survey, Sacramento, California

This report summarizes data obtained from field sampling of mine tailings, wasterock, sediment, water, and biota at the Little Bonanza Mine that was completed on April 6, 2010. Conditions during sampling were dry and no rain had occurred in the watershed for several weeks. Our results permit a preliminary assessment of the mining sources of Hg and associated chemical constituents that could produce elevated levels of monomethyl mercury (MMeHg) in WF Las Tablas Creek and in biota.

History and Geology

The history of the Little Bonanza Hg mine is summarized here from Yates (1943) and other references as cited. The Little Bonanza Mine, located 20 mi west of Paso Robles, was discovered in 1862. Although production was minor until 1900, from 1900 to 1906, the mine produced about 1,000 flasks of Hg. Intermittent production continued into the 1940s but was relatively limited. Underground workings, now caved and inaccessible, include about 3,000 ft of drifts, crosscuts, and raises on three levels extending 260 ft downward (figs. 1, 2).

The workings at the Little Bonanza Mine explore a zone of fault breccia, which trends northwest (fig. 1). The breccia is composed of fragments of sandstone, greenstone, serpentine, and chert in a shale matrix. The serpentine has been hydrothermally altered to silica-carbonate rock, and the Hg deposit is hosted within the zone of alteration. The veins are discontinuous and irregular, but form a steplike pattern along the fault zone (figs. 3, 4). The principal mineralization occurring in the veins is irregular, consisting of disseminated zones of cinnabar. Most of the veins in the mine area contain cinnabar.

Sample Sites and Methods

Samples were collected to assess the concentrations of Hg and biogeochemically relevant constituents in tailings and wasterock piles at the Little Bonanza Hg mine. Tailings are present adjacent to a three-pipe retort used to process the Hg ore (figs. 5, 6). The tailings occur in the upper 15 cm of the soil adjacent to the retort (fig. 7) and slag from the retort is present on the surface (fig. 8). An area of disturbed soil and rock uphill from the retort was likely formed during construction of a dam that provided water for mining activities. Wasterock in these piles was sampled (fig. 6). The largest amount of tailings is exposed to the west of the retort in the bank of WF Las Tablas Creek (fig. 9). Water, sediment, and biota were sampled from WF Las Tablas Creek, which flows through the mine area. Sample-site locations are shown in figures 10 and 11 and listed in table 1. Samples were collected when streamflow was low and no precipitation had occurred.

Field Sampling Methods

Dry and Wet Sediment and Tailings

Samples consisting of 100 to 500 g of mine tailings and wasterock were collected from piles at the Little Bonanza Hg mine, stored, and shipped in Ziploc® bags at ambient temperature. Wet sediment was collected in polycarbonate jars (100-mL capacity) and frozen with dry ice immediately after collection (freezing time, approx 20-30 minutes). Samples were kept frozen until shipped overnight on dry ice to the analytical laboratory (Brooks Rand, Seattle, WA), where they were kept frozen until analysis. The temperature of samples arriving at the laboratory ranged from 1°C to 4°C, within the limits specified in USEPA method 1631E.

Water

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

Water variables, including pH, conductivity, and temperature, dissolved oxygen, and oxidation-reduction potential (ORP), were measured in the field, using a battery-powered Sonde hydrolab. Measurements were taken by placing the probe directly into the flowing streamwater.

Samples for total Hg (Hg_T) and MMeHg analyses were collected in trace-metal-free certified 250 mL bottles (Nalgene ICHEM) with no headspace. The MMeHg bottles contained an HCl preservative provided by the analytical laboratory. Procedures for Hg_T analysis followed ultra clean sampling and handling protocols (Bloom, 1995, Gill and Fitzgerald, 1987) during the collection of field samples and subsequent analysis to avoid introduction of Hg. Samples were kept on ice until shipped. Samples were shipped on icepacks and arrived the next morning at the analytical facilities at temperatures ranging from 1 to 4° C, as specified by EPA method 1631E, to minimize biologically induced phase changes and MMeHg degradation.

During every sampling event, a field blank was collected by processing deionized water and collecting the same subsamples (except for alkalinity), following the same procedures as used for the field samples. Laboratory blanks and acid blanks were processed periodically to determine whether our equipment, containers, reagents, and procedures introduced significant contamination.

Invertebrates

The target macroinvertebrates for this study were predatory insects, depending on their abundance and availability at each sample site. Taxa collected were larval dragonflies (order Odonata, families Aeshnidae and Gomphidae), adult water striders (order Hemiptera, family Gerridae), predaceous diving beetles (order Coleoptera, family Dytiscidae), and larval dobsonflies (order Megaloptera, family Corydalidae).

Invertebrates were collected with dipnets and by hand and placed in Ziploc plastic bags with native water. Samples were kept in a cooler and allowed to depurate in native water on wet ice for 4-24 hours before being sorted at the end of the collection day. Individuals were sorted by family and placed in disposable plastic weighboats using Teflon-coated forceps or by hand while wearing disposable latex gloves. When possible, we collected replicate samples, multiple size classes within a taxon, or both to assess variations in concentration and to identify any relations of tissue concentrations to size. Organisms were thoroughly rinsed with deionized water and patted dry with a clean paper towel. Then, samples were sorted and composited by family with the goal of obtaining at least 1g of wet biomass per sample. Each sample consisted of 3 to 15 individuals of the same family. Samples were weighed on an electronic balance (±0.01 g) and placed in chemically cleaned glass jars with Teflon-lined lids. The lids were sealed with Parafilm, and the samples were frozen until they could be shipped to the analytical laboratory on April 13, 2010, for analysis of Hg_T, MMeHg, and total solids.

Analytical Methods

Sediments and Tailings

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

Hg and MMeHg analyses of all wet-sediment samples were performed at Brooks Rand Laboratories in Seattle, WA. Dry-sediment samples analyzed by ALS CHEMEX were also analyzed by Brooks Rand for Hg. For these analyses, the sediment was leached with cold aqua regia, followed by stannous chloride ($SnCl_2$) reduction, two-stage gold amalgamation, and cold-vapor atomic-fluorescence spectroscopy (CVAFS) detection. Monomethylmercury was determined by acid bromide/methyl chloride extraction, followed by aqueous-phase ethylation, isothermal gas-chromatographic (GC) separation, and CVAFS detection (Horvat and others, 1993). Results reported on both a wet- and dry-weight basis are listed in Table 2 for analyses provided by Brooks Rand, and on a dry-weight basis for the analyses completed by ALS CHEMEX (tables 3, 4).

Water

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

Cations were analyzed by ICP–AES and ICP–MS. Ion chromatographic and alkalinity analyses were performed in USGS laboratories under the direction of Paul Lamothe, and ICP-AES analyses were determined in USGS laboratories under the direction of Paul Briggs. Duplicate water samples, blank samples, and USGS Water Resource Division standard reference waters were analyzed with the dataset.

At Brooks Rand, samples were handled in a Class-100 clean-air station that was monitored routinely for low levels of total gaseous Hg. An ultraclean Hg trace-metal protocol was followed, including the use of rigorously cleaned and tested Teflon equipment and sample bottles and prescreened and purified reagents. Laboratory atmosphere and water supply were also routinely monitored for low levels of Hg. Primary standards used in the laboratory were NIST certified or traceable to NIST certified materials. Following USEPA Method 1631, MMeHg standards were made from pure powder, calibrated against NBS-3133, and cross-verified by daily analysis of Certified Reference Material DORM-2 (National Research Council of Canada Institute for National Measurement Standards, 1999). Hg_T content was determined by bromine monochloride (BrCl) oxidation followed by $SnCl_2$ reduction, two-stage gold amalgamation, and CVAFS detection (Bloom and others, 1988). Monomethylmercury was liberated from water using an all-Teflon distillation system. Distilled samples were analyzed using aqueous-phase ethylation with purging onto Carbotrap, isothermal GC separation, and CVAFS detection (Bloom, 1989). To address accuracy and precision, quality-assurance measures were used with the following minimum frequency: laboratory duplicates, 1 per 10 samples; method blanks, three per analytical batch; filtration blanks, 1 per 10 samples; and spike recovery or standard reference material, 1 per 10 samples.

Biota

Samples were analyzed for Hg_T and MMeHg at Brooks Rand Laboratory, Seattle, WA. A solid sample was homogenized, and an aliquot measured into a preweighed vessel, dried in an oven overnight, and weighed again, and, then, the percentage of dried solid material was calculated. This standard operating procedure (SOP), BR-1501, is analogous to EPA standard method 2540 G (residue, total).

Once thawed, the samples were homogenized by using precleaned commercial-grade homogenization equipment. A homogenization blank was collected after cleaning the equipment and before homogenizing the samples. The blank was digested as a tissue sample and analyzed along with the associated homogenates. The result for the homogenization blank was less than 10 times the lowest sample result, indicating no significant contamination during homogenization (SOP BR-0106).

Hg_T was determined as outlined in EPA method 1631 (SOP BR-0002). Samples were digested in nitric acid (HNO_3) and sulfuric acid (H_2SO_4) and then further oxidized with bromine monochloride (BrCl). Samples were analyzed by stannous chloride ($SnCl_2$) reduction, single gold amalgamation, and CVAFS detection using a BRL Model III CVAFS Mercury Analyzer. All sample results for low-level Hg analysis were blank corrected.

For MMeHg analysis, samples were prepared by potassium hydroxide (KOH)-methanol (CH_3OH) digestion. Samples were analyzed by aqueous-phase ethylation, Tenax trap collection, GC separation, isothermal decomposition and CVAFS detection, using a BRL Model III CVAFS Mercury Analyzer. All sample results for low-level Hg analysis were blank corrected, as outlined in the calculations section of Brooks Rand SOP BR-0011.

Duplicate samples were analyzed at a rate of 5 percent, with at least one duplicate per matrix per analytical run to estimate the precision of the methods. The relative percent differences (RPD) for the Hg_T duplicates ranged from 0.8 to 23 percent; the RPDs for all results were within the acceptable criterion (RPD $<$ 30 percent). The RPDs for invertebrate MMeHg duplicates ranged from 2 to 19 percent, all within the acceptable criterion of an RPD $<$ 35 percent.

To assure the accuracy of the methods, procedural blanks, spiked samples, and Standard Reference Materials were analyzed. To assure that no analyte was added during the processing of the sample, procedural blanks were analyzed at a rate of 5 percent of the total samples, with at least one blank per matrix per analytical run. The averages for the Hg_T blanks ranged from 0.01 to 0.03 ng/g, with method detection limits (MDL) of 0.04 ng/g. The averages for MMeHg blanks ranged from 0.1 to 0.2 ng/g, with an MDL of 1.0 ng/g. All blank results were less than the acceptable criterion of twice the MDL.

Spiked samples were analyzed at a rate of 5 percent, with at least one spike per matrix per analytical run. Spikes were samples fortified with a known quantity of analyte and analyzed as part of the run. The Hg_T recovery ranged from 78 to 120 percent, with RPDs ranging from 0.2 to 13 percent; MMeHg recovery ranged from 67 to 130 percent. Although one sample had an unacceptable MMeHg recovery of 151 percent, reanalysis produced acceptable results. The MMeHg RPDs ranged from 0.1 to 20 percent. The results met the criterion of 70 to 130-percent recovery with an RPD<30 percent for Hg_T and 65 to 135 percent with an RPD<35 percent for MMeHg.

Standard Reference Materials (DORM-3 2010) were analyzed at a rate of 5 percent to ensure that the method worked with naturally incorporated Hg. Hg_T recovery was 103 to 116 percent, within the criterion of 75 to 125 percent; MMeHg recovery was 80 to 93 percent, within the criterion of 65 to 135 percent.

Results

Tailings at the Little Bonanza Mine Areas

The Hg concentration in waste materials at the Little Bonanza Mine area varies in dependence on material type. Tailings (calcines) have the highest, and wasterock the lowest Hg concentrations. Ores processed in the three-pipe retort produced tailings that were disposed of in the flat area that extends from just west of the retort to WF Las Tablas Creek. The calcines, which are well exposed in the bank of WF Las Tablas Creek (fig. 9), consist of medium- to coarse–grained, well–stratified materials (fig. 12). Four samples of the calcines were collected in the exposure in WF Las Tablas Creek (fig. 11, samples 10LB9-10LB12). One grab sample that was taken at the uppermost exposure of the calcines (sample 10LB9) had an Hg_T concentration of 101 ppm. Channel samples of the calcines were taken from the lower (sample 10LB11), middle (sample 10LB10), and upper part (sample 10LB12) parts of the exposure (table 1). The Hg_T concentration in the calcines increases from 43.7 ppm in the lower part, to 66 ppm in the middle part, to 141 ppm in the upper part of the section (table 2). The highest Hg_T concentration is comparable to that in the grab sample taken from the top of the section.

Calcines with an Hg_T concentration of 142 ppm are present adjacent to the retort and are irregularly distributed in the upper 25 cm of the soil. Calcines in the three-pipe retort have an Hg_T concentration of 27 ppm, and slag from the retort has a relatively low Hg_T concentration of 1.79 ppm and high iron (Fe) and manganese (Mn) concentrations (table 2).

The calcines have elevated concentrations of Co (87 ppm), Cr (4,270 ppm), and Ni (2,410 ppm) that reflect the serpentinite host rock of the Hg mineralization (table 2). Exceptionally high Mg concentrations, up to 13.5 percent, are present in the calcines as a result of the presence of magnesite and serpentinite. No other trace elements are present in high concentrations. Gold was detected in six of the calcine samples, in concentrations ranging from 0.011 to 0.052 ppm. Trace metals that are moderately elevated and exceed the BLM Ecotoxicity screening criteria in calcines include As (13 ppm), Cu (48 ppm), Pb (109 ppm), and Zn (94 ppm, table 2); however, these elements do not exceed the BLM Camper screening criteria or the EPA preliminary remediation goals (PRGs).

Calcines and wasterock are present in the bank deposits of WF Las Tablas Creek upstream from the mine workings located on BLM lands at sample site 10BL3C (fig. 11). The calcines have an Hg_T concentration of 108 ppm and high Co, Cr, and Ni concentrations, similar to concentrations in the calcines exposed farther downstream at sample site 10LB9-12C.

Sediment in WF Las Tablas Creek near the Little Bonanza Mine

The headwaters of WF Las Tablas Creek begin above the Little Bonanza Mine area near an adit located at sample site 10LB2 (fig. 11). Sediment at the partially collapsed adit has a high Hg_T concentration, 72 ppm (table 3). Farther downstream, at sample site 10BL1 (figs. 11, 13), the stream sediment has an exceptionally high Hg concentration, 346 ppm (table 2). This site is located just downstream from the calcines present in bank sediment at sample sites 10LB9 through 10LB12C. Farther downstream in WF Las Tablas Creek, at sample site 10LB4 (fig. 10), the Hg_T concentration in sediment is still elevated, 44.9 ppm (table 3). The sediment in the small tributary that drains the area of the collapsed dam (figs. 11, 14) has a low Hg concentration, 0.228 ppm, typical of background sediment concentrations (sample site 10LB3, table 3). The MMeHg concentration in sediment from WF Las Tablas Creek at all sample sites is relatively low, ranging from 0.042 ng/g to 0.304 at sample site 10LB1 (table 3).

Water Chemistry

All the waters in WF Las Tablas Creek in the mine area are alkaline as a result of the serpentinite that underlies most of the watershed and the presence of carbonate alteration in the mine area (table 1). The sulfate concentration in WF Las Tablas Creek waters is anomalous, ranging from 19 to 78 ppm. The highest sulfate concentration, 146 ppm, occurs in the waters being released from the adit at sample site 10LB2. High Mg and Ca concentrations are present in all waters, with the highest concentrations associated with mine drainage from the adit (tables 4, 5). Dissolved organic carbon (DOC) concentration ranges from 2.6 to 6.6 ppm, comparable to those measured downstream from the Rinconada Hg mine (figs. 15, 16).

Hg_T and MMeHg in waters

Under low flow conditions, the Hg_T concentrations in water samples collected from WF Las Tablas Creek in the mine area are elevated, with the highest concentration, 96.2 ng/L at sample site 10LB1, located just below the exposure of calcines. At 2.5 km downstream from the mine area, at sample site 10LB4, Hg_T concentration decreases considerably to 5.58-5.91 ng/L (table 3). The water emanating from the adit above the mine processing area has a relatively high Hg_T concentration, 46.7 ng/L, and the water that drains the breached dam in the mine area has a considerably lower but anomalous Hg_T concentration, 17.4 ng/L. The Hg_T concentration in the filtered fraction varies, ranging from 13.5 ng/L in water from the adit to 67.6 ng/L at sample site 10LB1 (fig. 15). MMeHg concentrations in water from WF Las Tablas Creek and from the adit are all very low, ranging from 0.02 ng/L at the adit to 0.058 ng/L at sample site 10 LB1. Although the waters have high Hg_T concentrations, MMeHg concentrations are very low, constituting less than 1 percent of the total Hg present in the water column (fig. 16).

Under high-flow conditions, Hg concentrations in unfiltered and filtered waters are considerably higher at all sample sites than under low-flow conditions (fig. 19; table 8). Downstream from the adit, at sample site 11LB2, the Hg_T concentrations in unfiltered and filtered waters are 190 and 51.8 ng/L, respectively. Farther downstream, at sample site 11LB1, located in the mine processing area, the Hg_T concentrations increase to 206 ng/L in unfiltered waters and decrease slightly in filtered water to 51.8 ng/L. The Hg_T concentrations in unfiltered waters decrease downstream from the mine area. At sample site 11LB4, located 1.25 km downstream from the mine area, the Hg_T concentration is about two-thirds that in the mine area. At sample site 11LB5, located 2.5 km downstream from the mine area, the Hg_T concentration decreases to about a third of that in the mine area (fig. 19). Hg concentrations in filtered waters decrease downstream from the mine area but account for an increasing amount of the total Hg present at each site. MMeHg concentrations are considerably higher under high-flow conditions than under low-flow conditions, ranging from 0.163 to 0.236 ng/L; however, no systematic variation in MMeHg concentrations was observed.

Hg_T and MMeHg in Biota

We collected composite samples of aquatic invertebrates (table 6), for analyses of Hg_T and MMeHg from one sample site (LBUP) at the Little Bonanza Mine and another downstream (LBBR) on April 6, 2010.

The highest Hg_T concentration (0.446 µg/g wet weight (ww)) was measured in a composite sample of six dobsonfly larvae (family Corydalidae) collected from Little Bonanza upstream (LBUP); the lowest Hg_T concentration was measured in a sample of six dragonfly larvae (Aeshnidae) from the downstream site, Little Bonanza at the bridge (LBBR) (0.118 µg/g ww). The highest MMeHg concentration (0.148 µg/g ww) was measured in dragonfly larvae (Gomphidae) collected from LBBR; the lowest MMeHg concentration was measured in a sample of three dobsonfly larvae from LBUP (0.057 µg/g ww).

MMeHg in the two dobsonfly samples collected from LBUP averaged 18.1 percent, whereas that in the same taxa at LBBR was 42.0 percent. MMeHg in other taxa collected from LBBR ranged from 66.5 percent in Gerridae to 77.5 percent in Aeshnidae.

The only taxon collected at both sites was dobsonflies. The average Hg_T and MMeHg concentrations at LBUP were 0.0795 and 0.439 µg/g, respectively. The comparable concentrations in dobsonflies from LBBR were 0.057 and 0.136 µg/g, lower by 28 and 69 percent, respectively, than at LBUP.

Conclusions

Past mining and mine wastes at the Little Bonanza Hg mine have contaminated sediment in WF Las Tablas Creek with high Hg_T concentrations. A significant amount of calcines still remains at the Little Bonanza Hg mine and continues to contribute Hg-enriched sediment to the creek. The calcines are well exposed in the bank of WF Las Tablas Creek, and the flat area extending eastward from the exposures in the creek toward the remains of the retort is likely underlain by calcines. Test pits in this area would be necessary to determine the extent and volume of the calcines that may be present in the area.

Although the calcines have only moderately high Hg_T concentrations, 43 to 141 ppm, the Hg_T concentration in the sediment of WF Las Tablas Creek in the mine area is extremely high (max. 304 ppm at sample site 10LB1). Hg_T concentrations higher than 100 ppm in sediment are rare downstream from Hg mines in the Coast Ranges. Only one tributary that drains the Petray Mine in the Cache Creek Watershed, Colusa County, California, is reported to have similarly high Hg_T concentrations in stream sediments (Slowey and Rytuba, 2008). At sample site 10LB4, located about 2.5 km downstream from the mine area, the Hg_T concentration in sediment is still very high, 44.9 ppm. The Hg_T concentration in calcines is not sufficiently high to account for the high Hg_T concentrations in sediment. An unmined Hg mineralized zone is likely being eroded and contributing Hg-enriched sediment to the creek. The calcines also have very high Mg concentrations and elevated Co, Cr, and Ni concentrations that reflect the serpentinite host rock. Other trace metals in the calcines are absent in concentrations of significant environmental concern.

The Hg_T concentrations in water samples collected from WF Las Tablas Creek in and downstream from the mine area are extremely high under both low- and high-flow conditions. The high-flow Hg_T concentrations are comparable to those measured downstream from some of the larger Hg mines in the Coast Ranges, including the Rinconada Hg mine (fig. 15). The calcines present in bank deposits contribute to the high Hg_T and Total Suspended Solids (TSS) concentrations. Effluent from the adit also contributes Hg to the creek, but most Hg from the adit is in the filtered fraction and consists of colloidal and dissolved Hg phases. The Hg_T concentration in waters in the mine area does not meet the 50-ng/L EPA criterion (EPA, 1999) and is above the water-quality objective of 12 ng/L under both high- and low-flow conditions. However, under low-flow conditions, the MMeHg concentrations in the waters of WF Las Tablas Creek are very low, lower than in all waters sampled downstream from the Rinconada Hg mine under all flow conditions (fig. 16). Under high-flow conditions, MMeHg concentrations are considerably higher, comparable to those measured downstream from the Rinconada Hg mine.

The percentages of Hg present as MMeHg in the stream-sediment samples are all very low, ranging from 0.0001 to 0.01 (fig. 17). The percentage of MMeHg (%MMeHg) in sediment (fig. 18, table 3) can be used as an indicator for net production of MMeHg when MMeHg is normalized to Hg_T (Drott and others, 2008). The %MMeHg is calculated by dividing the measured MMeHg concentrations in sediment by the Hg_T concentration present in the same sample:

$$\%\text{MMeHg} = (\text{MMeHg, in ng/g in sediment})/(\text{Hg}_T\text{, in ng/g in sediment})$$

The very low %MMeHg in stream sediment in WF Las Tablas Creek (table 3, fig. 18) indicates that methylation of Hg is not favorable in the mine area. Because there are adequate concentrations of SO_4 and DOC in the water for sulfate reducing bacteria to methylate Hg, the low MMeHg concentrations may result from the Hg phase in the creek sediment not being bioaccessible, as would be the case if cinnabar were the primary phase in the sediment.

Invertebrates collected from the mine area at sample site 10LB1 had elevated Hg_T concentrations, but MMeHg concentrations were similar to those observed at the downstream sample site (10LB4) and in a nearby Hg-mine impacted stream (Rinconada Creek). The %MMeHg at sample site 10LB1 averaged about 18 percent, consistent with the low observed %MMeHg in sediment at that site. Although the MMeHg concentrations in the invertebrates collected from the downstream site were similar to those from sample site 10LB1, the %MMeHg in invertebrates from the lower site was nearly 4 times greater, relating to the lower Hg_T concentration in sediment at the lower site. MMeHg concentrations in water were similar at the two sites, but Hg_T concentration in the water at the minesite was 17 times greater than at the lower site. Overall, the MMeHg concentrations in invertebrates from the Little Bonanza sites were 2.5 to 6 times higher than in similar taxa collected from a nearby stream not impacted by Hg mining (Trout Creek). Transport of Hg in creek waters depends on flow conditions; the highest concentrations and greatest transport of Hg occur under high-flow conditions. The high Hg_T concentrations in sediment in WF Las Tablas Creek in the mine area and the elevated Hg_T concentrations under low-flow conditions sampled during this study indicate that very high Hg concentrations are potentially transported from the mine area during high-flow events. Thus, although the Little Bonanza Mine has a small volume of calcines, it may release a significant amount of Hg to downstream environments during high-flow events. We recommend that at least one high-flow sampling be done during a winter storm to assess the magnitude of Hg release from the mine area.

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Table 1. Sample locations and physical and selected chemical parameters for waters from the Little Bonanza Min

Site Water and sediments	Site Biota	Latitude	Longitude	Sample Site Description	Conductivity micro Siemens	
		WF Las Tablas Creek				
10LB1A	LBUP	35.58414	-120.91121	Little Bonanza Creek	772	
10LB4A	LBBR	35.59845	-120.91093	WF Las Tablas Creek	461	
		Mine Drainage from Adit				
10LB2A		35.583	-120.91109	Mine adit drainage	1,142	
		Reservoir Creek				
10LB3A		35.58424	-120.90997	Reservoir drainage	318	
		Little Bonanza calcines and waste rock				
10LB3C		35.58393	-120.91101	Calcines in creek bank near pipe down from adit		
10LB4C		35.58355	-120.91033	Waste rock and some calcines		
10LB5C		35.58397	-120.91080	Slag from retort		
10LB6C		35.58397	-120.91080	Roasted ore from retort		
10LB7C		35.58397	-120.91080	Calcines adjacent to retort about 25 cm thick		
10LB8C		35.58382	-120.91068	Waste rock on disturbed slope above retort		
10LB9C		35.5838	-120.91103	Calcines exposed in bank of creek west of retort		
10LB10C		35.58393	-120.91101	Calcines in bank of creek west of retort, middle 0.75 m		
10LB11C		35.58393	-120.91101	Calcines in bank of creek west of retort, bottom 0.5 m		
10LB12C		35.58393	-120.91101	Calcines in bank of creek west of retort, top 0.5 m		
		Trout Creek Reference site				
	TRCR	35.38875	-120.58167	Trout Creek reference site	120.58167	120.5

Table 2. Mercury and associated major and minor elements in sediment, precipitates, and calcines from the Little Bonanza Mine.

Field Number	Latitude	Longitude	Date	Sample Site Description	Hg ppm	Ag ppm	Al %
	WF Las Tablas Creek						
10LB1A	35.58414	-120.91121	4/6/10	Little Bonanza Creek	346	0.04	6.78
10LB4A	35.59845	-120.91093	4/6/10	WF Las Tablas Creek	3.79	0.08	7.2
	Mine Drainage from Adit						
10LB2A	35.583	-120.91109	4/6/10	Mine adit drainage	292	0.05	7.4
	Reservoir Creek						
10LB3A	35.58424	-120.90997	4/6/10	Reservoir drainage	0.25	0.05	7.39
	Little Bonanza calcines and waste rock						
10LB3C	35.58393	-120.91101		Calcines in creek bank near pipe down from adit	108.5	0.07	3.53
10LB4C	35.58355	-120.91033		Waste rock and some calcines	30.3	0.03	1.2
10LB5C	35.58397	-120.91080		Slag from retort	1.79	0.16	0.12
10LB6C	35.58397	-120.91080		Roasted ore from retort	27.2	0.05	0.48
10LB7C	35.58397	-120.91080		Calcines adjacent to retort about 25 cm thick	142.5	0.12	2.31
10LB8C	35.58382	-120.91068		Waste rock on disturbed slope above retort	0.29	0.07	5.09
10LB9C	35.5838	-120.91103		Calcines exposed in bank of creek west of retort	101	0.08	5.2
10LB10C	35.58393	-120.91101		Calcine in bank of creek west of retort, middle 0.75 m	66.2	0.02	1.08
10LB11C	35.58393	-120.91101		Calcine in bank of creek west of retort, bottom 0.5 m	43.7	0.03	1.39
10LB12C	35.58393	-120.91101		Calcine in bank of creek west of retort, top 0.5 m	141	0.03	1.36

Table 2 (cont'd)

Field Number	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	In ppm
WF Las Tablas Creek																
10LB1A	10.4	680	0.97	0.21	1.11	0.17	32.6	52.9	1,490	5.58	55.5	6.11	16.2	0.1	2.3	0.065
10LB4A	11.7	460	1.16	0.25	1.32	0.16	39.7	37.7	280	5.13	47.9	5.32	17.35	0.15	2.4	0.066
Mine Drainage from Adit																
10LB2A	9.5	400	0.99	0.19	0.7	0.08	32.3	40.2	663	13.55	56.5	5.41	18	0.16	2	0.072
Reservoir Creek																
10LB3A	12.1	590	1.23	0.3	1.1	0.11	38.7	34.1	464	5.72	44.9	4.92	18.3	0.15	2.4	0.063
Little Bonanza calcines and waste rock																
10LB3C	13.2	190	0.68	0.09	0.84	0.05	8.07	123	2,910	5.76	22.1	7.25	9.97	0.19	1.2	0.03
10LB4C	11	320	0.4	0.03	1.14	0.03	5.13	86.4	2,910	2.26	13.5	4.56	3.18	0.08	0.3	0.01
10LB5C	5.3	10	0.05	0.01	0.08	0.02	1.08	27	70	0.07	78.9	>50	7.62	1.97	0.1	0.005
10LB6C	8.3	80	0.3	0.03	2.36	0.04	1.91	87.1	2,050	1.28	9.2	4.69	1.9	0.1	0.1	0.006
10LB7C	11	360	0.48	0.18	7.13	0.24	10.35	69.7	4,270	3.61	39.6	6.34	5.82	0.12	0.8	0.029
10LB8C	4	330	0.64	0.11	2.37	0.09	20.1	40.3	659	3.46	44.4	4.92	12.25	0.11	1.6	0.044
10LB9C	12.6	340	0.74	0.1	1.5	0.1	25	48.9	788	5.15	48.1	5.74	11.1	0.13	1.7	0.052
10LB10C	3.7	120	0.37	0.02	0.95	0.02	4.62	77.9	2,480	1.58	16.1	4.45	2.97	0.1	0.3	0.011
10LB11C	4.1	130	0.4	0.03	1.38	0.04	6.02	71.7	2,080	1.84	15.9	4.2	3.68	0.12	0.4	0.013
10LB12C	3.5	100	0.36	0.03	0.88	0.04	6.54	71.6	1,820	1.88	13.8	4.31	3.3	0.1	0.4	0.015

Table 2 (cont'd)

Field Number	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm	Se ppm
WF Las Tablas Creek																
10LB1A	1.08	13.9	61.2	4.08	1250	0.93	1.12	7.4	429	510	12.8	56.1	<0.002	0.04	1.1	2
10LB4A	1.43	19.1	52.3	3.07	1010	0.94	1.47	9.3	268	540	15.6	75.5	<0.002	0.01	1.49	2
Mine Drainage from Adit																
10LB2A	1.17	15.5	113.5	1.21	773	1.06	0.8	7.8	592	550	9.9	75.8	<0.002	0.03	1.03	2
Reservoir Creek																
10LB3A	1.57	19.1	50.3	3.27	878	0.86	1.38	9.3	248	540	16	82.5	<0.002	0.01	1.58	2
Little Bonanza calcines and waste rock																
10LB3C	0.59	4.2	64	4.73	1030	0.67	0.06	2	2,410	190	4.4	42	<0.002	0.08	0.73	1
10LB4C	0.19	2.5	36.1	11.05	643	0.25	0.1	1.1	1,790	110	2.9	11.6	<0.002	0.13	0.49	1
10LB5C	0.02	0.5	0.7	0.07	3690	4.11	0.02	1.1	29.3	310	6.2	1.1	0.004	0.07	0.4	1
10LB6C	0.06	0.9	34	12.6	769	0.91	0.04	0.4	1,695	90	100.5	3.3	<0.002	0.1	4.43	1
10LB7C	0.32	5	33.7	8.51	918	2.19	0.35	3.1	1,150	330	109	18.5	<0.002	0.08	5.13	1
10LB8C	0.58	9.3	59	9.46	843	0.38	0.22	5.1	626	460	6.3	27.6	<0.002	0.01	0.5	1
10LB9C	0.75	10.9	65.4	4.49	1060	0.85	0.65	5.1	612	450	9.5	41	<0.002	0.04	1.22	1
10LB10C	0.15	2	37	13.55	616	0.29	0.17	1	1,530	100	3	9	<0.002	0.11	0.41	1
10LB11C	0.19	2.7	34.3	11.25	637	0.36	0.16	1.3	1,415	120	2.6	11.4	<0.002	0.08	0.39	1
10LB12C	0.21	2.9	37.7	13.4	668	0.27	0.16	1.3	1,440	140	3.1	11.6	<0.002	0.12	0.41	1

Table 2 (cont'd)

Field Number	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm	Au ppm
WF Las Tablas Creek														
10LB1A	1.6	129	0.44	<0.05	4.7	0.457	0.39	1.4	143	1.1	21.8	108	79.9	0.009
10LB4A	1.9	127	0.59	0.05	7.2	0.456	0.48	2.2	131	1.4	21.1	101	77.5	0.005
Mine Drainage from Adit														
10LB2A	1.5	248	0.47	0.05	5	0.497	0.53	1.3	151	1.1	21.7	88	64.9	0.008
Reservoir Creek														
10LB3A	2.1	107	0.61	<0.05	7.9	0.432	0.51	2.3	125	1.7	21.1	97	79.2	0.004
Little Bonanza calcines and waste rock														
10LB3C	0.8	105.5	0.13	<0.05	1.6	0.125	0.53	0.6	88	0.6	9.4	75	41.8	0.001
10LB4C	0.3	117.5	0.07	<0.05	0.8	0.064	0.2	0.4	39	0.3	3.3	50	12.5	0.001
10LB5C	3.1	5.9	<0.05	0.17	0.2	0.007	<0.02	0.7	62	6.2	0.5	<2	2.7	<0.001
10LB6C	0.4	135.5	<0.05	<0.05	0.2	0.021	0.21	0.2	29	0.7	1.5	45	4.5	<0.001
10LB7C	1.4	320	0.18	0.05	1.3	0.163	0.34	4.5	78	9.7	8.2	94	30.1	0.001
10LB8C	0.9	384	0.33	0.05	3.4	0.3	0.15	1.1	97	0.7	16	79	58.3	<0.001
10LB9C	1	156	0.34	0.06	3.3	0.365	0.32	1.1	117	0.8	16.6	88	58.8	<0.001
10LB10C	0.2	97.7	0.06	<0.05	0.6	0.062	0.15	0.4	42	0.2	2.8	49	11.6	0.001
10LB11C	0.3	115.5	0.08	<0.05	0.9	0.076	0.17	0.5	40	0.3	3.9	47	16.3	0.001
10LB12C	0.3	102	0.08	<0.05	0.9	0.08	0.16	0.4	44	0.3	3.9	49	15.5	<0.001

Table 3. Mercury and monomethylmercury concentrations in waters and sediment.

Sample	Date	Water Hg Total ng/L	Water Hg Filtered ng/L	Water Total MMeHg ng/L	Sediment Hg ng/g	D.O.C. mg/L	Sediment MMeHg ng/g	% MMeHg (MMeHg/Hg) in sediment
	WF Las Tablas Creek							
10LB1A	4/6/10	96.2	67.6	0.058	304,000	2.7	0.304	0.000001
10LB4A	4/6/10	5.58		0.055	44,900	2.6	0.096	2.13808E-06
10LB4A2	4/6/10	5.91						
	Mine Drainage from Adit							
10LB2A	4/6/10	46.7	13.5	0.02	72,400		0.151	2.08564E-06
	Reservoir Creek							
10LB3A	4/6/10	17.4		0.101	228	6.6	0.042	1.84211E-04
10LB3A2	4/6/10	17						

Table 4. Geochemistry of filtered samples from the Little Bonanza Mine, ICP-MS results (major elements, ICP-AES results).

Sample	Latitude	Longitude	Ag µg/L	Al µg/L	As µg/L	B µg/L	Ba µg/L	Be µg/L	Bi µg/L	Ca mg/L	Cd µg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	1	5	1	123	124	0.05	0.2	35.2	0.02	0.03	0.02	1.6	0.02	1
10LB4B	35.59845	-120.91093	1	11.2	1	66.8	93.5	0.9	0.2	47.1	0.02	0.04	0.02	1	0.02	0.83
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	1	2.3	1	249	119	0.05	0.2	30.1	0.02	0.01	4.78	1.4	1.58	1.5
	Reservoir Creek															
10LB3B	35.58424	-120.90997	1	44.9	1	43.2	76.2	0.05	0.2	28.9	0.02	0.15	0.06	1.3	0.02	1.6

Sample	Latitude	Longitude	Dy µg/L	Er µg/L	Eu µg/L	Fe µg/L	Ga µg/L	Gd µg/L	Ge µg/L	Ho µg/L	K mg/L	La µg/L	Li µg/L	Lu µg/L	Mg mg/L	Mn µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	0.005	0.005	0.01	50	0.05	0.007	0.05	0.005	1.16	0.02	16.2	0.1	70.7	0.3
10LB4B	35.59845	-120.91093	0.02	0.005	0.005	50	0.05	0.02	0.05	0.005	0.7	0.05	2.8	0.1	20.1	1
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	0.005	0.005	0.009	50	0.05	0.005	0.1	0.005	1.94	0.01	48.5	0.1	129	2.4
	Reservoir Creek															
10LB3B	35.58424	-120.90997	0.05	0.03	0.02	86	0.05	0.06	0.05	0.01	0.82	0.13	0.9	0.1	14.7	2

Sample	Latitude	Longitude	Mo µg/L	Na mg/L	Nb µg/L	Nd µg/L	Ni µg/L	P mg/L	Pb µg/L	Pr µg/L	Rb µg/L	Sb µg/L	Sc µg/L	Se µg/L	SiO2 mg/L	Sm µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	2	15	0.2	0.03	5	0.01	0.05	0.01	0.41	0.3	0.8	1	9.5	0.01
10LB4B	35.59845	-120.91093	3.1	12.4	0.2	0.07	0.4	0.01	0.05	0.02	0.17	0.3	0.9	1	9.5	0.01
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	2	17.8	0.2	0.01	476	0.01	0.05	0.01	3.49	0.44	0.7	1	7.8	0.01
	Reservoir Creek															
10LB3B	35.58424	-120.90997	2	8.9	0.2	0.18	1.4	0.01	0.05	0.04	0.13	0.3	0.9	1	10.1	0.04

Table 4 (cont'd)

Sample	Latitude	Longitude	SO4 mg/L	Sr µg/L	Ta µg/L	Tb µg/L	Th µg/L	Ti µg/L	Tl µg/L	Tm µg/L	U µg/L	V µg/L	W µg/L	Y µg/L	Yb µg/L	Zn µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	28	274	0.05	0.005	0.2	0.6	0.1	0.005	0.16	0.6	0.5	0.08	0.006	1.7
10LB4B	35.59845	-120.91093	43	298	0.02	0.005	0.2	3.4	0.1	0.005	0.37	0.5	0.5	0.09	0.006	0.7
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	130	460	0.05	0.005	0.2	2	0.1	0.005	0.14	0.6	0.5	0.03	0.005	1.7
	Reservoir Creek															
10LB3B	35.58424	-120.90997	17	209	0.05	0.008	0.2	10	0.1	0.005	0.14	0.8	0.5	0.28	0.03	0.5

Sample	Latitude	Longitude	Zr µg/L
	WF Las Tablas Creek		
10LB1B	35.58414	-120.91121	0.2
10LB4B	35.59845	-120.91093	0.2
	Mine Drainage from Adit		
10LB2B	35.583	-120.91109	0.2
	Reservoir Creek		
10LB3B	35.58424	-120.90997	0.2

Table 5. Geochemistry of unfiltered samples from the Little Bonanza Mine, ICP-MS results (major elements, ICP-AES results).

Sample	Latitude	Longitude	Ag µg/L	Al µg/L	As µg/L	B µg/L	Ba µg/L	Be µg/L	Bi µg/L	Ca mg/L	Cd µg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	1	22.7	1	127	127	0.05	0.2	36.9	0.02	0.04	0.02	2.2	0.02	1.1
10LB4B	35.59845	-120.91093	1	107	1	67.7	72.7	0.05	0.2	47.2	0.02	0.1	0.04	1	0.02	1.2
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	1	5.9	1	246	116	0.05	0.2	29.3	0.02	0.01	4.67	1.1	1.53	1.5
	Reservoir Creek															
10LB3B	35.58424	-120.90997	1	794	1	45.5	88.6	0.05	0.2	30.3	0.02	0.84	0.7	5.9	0.04	2.7

Sample	Latitude	Longitude	Dy µg/L	Er µg/L	Eu µg/L	Fe µg/L	Ga µg/L	Gd µg/L	Ge µg/L	Ho µg/L	K mg/L	La µg/L	Li µg/L	Lu µg/L	Mg mg/L	Mn µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	0.01	0.007	0.01	50	0.05	0.008	0.05	0.005	1.19	0.02	14.7	0.1	71.9	0.8
10LB4B	35.59845	-120.91093	0.02	0.01	0.007	112	0.05	0.03	0.05	0.005	0.85	0.06	8.9	0.1	20.2	3.2
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	0.005	0.005	0.008	50	0.05	0.005	0.1	0.005	1.96	0.01	45.1	0.1	128	2.5
	Reservoir Creek															
10LB3B	35.58424	-120.90997	0.099	0.061	0.03	912	0.26	0.13	0.05	0.02	0.91	0.35	3.6	0.1	15.5	21.7

Sample	Latitude	Longitude	Mo µg/L	Na mg/L	Nb µg/L	Nd µg/L	Ni µg/L	P mg/L	Pb µg/L	Pr µg/L	Rb µg/L	Sb µg/L	Sc µg/L	Se µg/L	SiO2 mg/L	Sm µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	2	15.2	0.2	0.03	5.4	0.01	0.05	0.01	0.42	0.3	0.9	1	10.1	0.01
10LB4B	35.59845	-120.91093	2	17.6	0.2	0.08	0.4	0.01	0.08	0.02	0.24	0.3	1.4	1	16	0.01
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	2	18.6	0.2	0.01	457	0.01	0.05	0.01	3.27	0.44	0.7	1	7.8	0.01
	Reservoir Creek															
10LB3B	35.58424	-120.90997	2	9.16	0.2	0.44	9.6	0.01	0.3	0.1	0.54	0.3	1.4	1	14	0.1

Table 5 (cont'd)

Sample	Latitude	Longitude	SO4 mg/L	Sr µg/L	Ta µg/L	Tb µg/L	Th µg/L	Ti µg/L	Tl µg/L	Tm µg/L	U µg/L	V µg/L	W µg/L	Y µg/L	Yb µg/L	Zn µg/L
	WF Las Tablas Creek															
10LB1B	35.58414	-120.91121	31.9	278	0.07	0.005	0.2	1	0.1	0.005	0.17	0.8	0.5	0.08	0.005	2.3
10LB4B	35.59845	-120.91093	78.6	317	0.06	0.005	0.2	7.1	0.1	0.005	0.36	0.7	0.5	0.12	0.006	85.1
	Mine Drainage from Adit															
10LB2B	35.583	-120.91109	146.3	434	0.06	0.005	0.2	2	0.1	0.005	0.13	0.5	0.5	0.03	0.005	1.3
	Reservoir Creek															
10LB3B	35.58424	-120.90997	21	220	0.07	0.02	0.2	31.3	0.1	0.007	0.16	2.5	0.5	0.55	0.05	2.5

Sample	Latitude	Longitude	Zr µg/L
	WF Las Tablas Creek		
10LB1B	35.58414	-120.91121	0.2
10LB4B	35.59845	-120.91093	0.2
	Mine Drainage from Adit		
10LB2B	35.583	-120.91109	0.2
	Reservoir Creek		
10LB3B	35.58424	-120.90997	0.4

Table 6. Invertebrate samples collected from the Little Bonanza Mine and Trout Creek on April 6, 2010.

Sample code	Site	Location	Order	Family	No.	Mass (g)	Ave. Mass (g)	% Solids	Hg $_T$ (µg/g ww)	MeHg (µg/g ww)	% MeHg
CR-LBUP-040610-001	LBUP	Little Bonanza Upstream	Megaloptera	Corydalidae	3	1.47	0.490	20.54	0.432	0.085	19.61
CR-LBUP-040610-002	LBUP	Little Bonanza Upstream	Megaloptera	Corydalidae	6	0.53	0.088	NA	0.446	0.074	16.61
CR-LBBR-040610-001	LBBR	Little Bonanza at Bridge	Megaloptera	Corydalidae	3	1.08	0.360	NA	0.136	0.057	41.99
CR-LBBR-040610-003	LBBR	Little Bonanza at Bridge	Odonata	Aeshnidae	6	1.34	0.223	22.74	0.118	0.092	77.54
CR-LBBR-040610-002	LBBR	Little Bonanza at Bridge	Odonata	Gomphidae	5	1.03	0.206	29.58	0.198	0.148	74.75
CR-LBBR-040610-004	LBBR	Little Bonanza at Bridge	Coleoptera	Dytiscidae	7	0.53	0.076	NA	0.129	0.090	69.61
CR-LBBR-040610-005	LBBR	Little Bonanza at Bridge	Hemiptera	Gerridae	15	0.91	0.061	37.71	0.127	0.084	66.46
CR-TRCR-040610-002	TRCR	Trout Creek	Odonata	Aeshnidae	3	1.59	0.530	15.03	0.042	0.037	86.52
CR-TRCR-040610-003	TRCR	Trout Creek	Odonata	Libellulidae	10	2.12	0.212	18.43	0.039	0.035	90.18
CR-TRCR-040610-004	TRCR	Trout Creek	Odonata	Libellulidae	10	2.04	0.204	17.64	0.040	0.039	96.51
CR-TRCR-040610-006	TRCR	Trout Creek	Odonata	Coenagrionidae	20	1.10	0.055	25.09	0.016	0.013	86.45
CR-TRCR-040610-001	TRCR	Trout Creek	Coleoptera	Dytiscidae	13	0.79	0.061	35.85	0.037	0.034	93.19
CR-TRCR-040610-005	TRCR	Trout Creek	Hemiptera	Gerridae	14	0.67	0.048	NA	0.016	0.014	89.10

NA = not analyzed

Table 7. Sample sites and physical and selected chemical parameters for waters from the Little Bonanza Mine collected during a high-flow sampling event.

Field Number	Latitude	Longitude	Sampling Date	Sample Site Description	Conductivity micro Siemens	pH	Temperature °C	Dissolved O_2 ppm
	WF Las Tablas Creek							
11LB1A	35.58414	-120.91121	2/21/11	Little Bonanza Creek	189	7.27	11.5	5
11LB4A	35.59845	-120.91093	2/21/11	Tablas Creek, 1.25 km downstream from mine	150.3	7.52	12.55	4.6
11LB5A	35.59845	-120.91093	2/21/11	Tablas Creek, 2.25 km downstream from mine	151	7.2	12.55	4.57
11LB2A	35.583	-120.91109	2/21/11	Downstream from mine adit drainage	101	7.16	12.4	4.7
	Reservoir Creek							
11LB3A	35.58424	-120.90997	2/21/11	Reservoir drainage	199	7.39	12.55	5.03

Table 8. Mercury and monomethylmercury concentrations in waters and sediment collected during a high-flow sampling event

Sample	Water DOC mg/L	Water Hg Total ng/L	Water Hg Filtered ng/L	Water Total MMeHg ng/L	Total Suspended Sediment (TSS) mg/L
WF Las Tablas Creek					
11LB1A	6.28	206	51.8	0.208	14.6
11LB4A	7.04	135	24.7	0.164	56.1
11LB5A	7.32	68.3	27.8	0.163	65.0
11LB2A	9.38	190	55	0.165	22.5
Reservoir Creek					
11LB3A	6.09	49.1	36	0.236	40.5

Table 9. Concentrations of anions and selected cations in filtered water from the Little Bonanza Mine collected during a high-flow sampling event

Sample	Cl ppm	F ppm	NO_3 ppm	SO_4 ppm	$CaCO_3$ ppm	Ca mg/L	Fe µg/L	K mg/L	Li µg/L	Mg mg/L	Na mg/L
WF Las Tablas Creek											
11LB1B						10.1	341	1.1	< 0.1	15.1	4.33
11LB2B						7.79	700	0.92	< 0.1	4.46	4.2
11LB4B						10.6	378	0.98	0.1	7.14	5.59
11LB5B						11.5	260	0.87	0.3	7.04	5.95
Reservoir Creek											
11LB3B						10.2	285	1.2	1.1	14.9	4.49

Table 10. Geochemistry of filtered samples from the Little Bonanza Mine collected during a high-flow sampling event, ICP-MS results (major elements, ICP-AES results)

Sample	Al µg/L	B µg/L	Ba µg/L	Ca mg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L	Dy µg/L	Er µg/L	Eu µg/L	Fe µg/L	Ga µg/L	Gd/P µg/L	Ho µg/L	K mg/L	La µg/L	Li µg/L
	WF Las Tablas Creek																		
11LB1B	274	38.7	36.1	10.1	0.27	0.71	3.3	0.04	1.7	0.063	0.03	0.02	341	0.1	0.062	0.01	1.1	0.14	< 0.1
11LB2B	630	25.7	33.9	7.79	1.3	1.5	4.8	0.05	2.4	0.17	0.098	0.052	700	0.23	0.22	0.04	0.92	0.59	< 0.1
11LB4B	348	35.9	29.9	10.6	0.53	2.4	3	0.03	1.6	0.1	0.053	0.01	378	0.1	0.11	0.01	0.98	0.27	0.1
11LB5B	244	34.2	29.4	11.5	0.44	0.44	2.2	< 0.02	1.5	0.083	0.053	0.03	260	0.08	0.1	0.02	0.87	0.28	0.3
	Reservoir Creek																		
11LB3B	248	39.4	35.7	10.2	0.26	1	3	0.04	1.4	0.058	0.04	0.02	285	0.07	0.056	0.01	1.2	0.14	1.1

Sample	Mg mg/L	Mn µg/L	Na mg/L	Nd µg/L	Ni µg/L	P mg/L	Pb µg/L	Pr µg/L	Rb µg/L	Sc µg/L	SiO_2 mg/L	Sm µg/L	SO_4 mg/L	Sr µg/L	Tb/P µg/L	Ti µg/L	Tm µg/L	V µg/L
	WF Las Tablas Creek																	
11LB1B	15.1	9.6	4.33	0.23	8	0.02	0.16	0.05	0.46	1	7.11	0.05	8.8	73.1	0.01	2.9	0.006	1.2
11LB2B	4.46	19	4.2	0.84	10.6	0.02	0.35	0.2	0.63	1.5	9.52	0.2	9.1	61.3	0.04	18.1	0.02	1.9
11LB4B	7.14	12.2	5.59	0.37	6	0.03	0.16	0.08	0.44	1.3	9.16	0.08	15	89	0.01	14.5	0.007	1.5
11LB5B	7.04	5.9	5.95	0.43	5.1	0.02	0.12	0.1	0.27	1.2	9.51	0.08	16	90.9	0.02	6.8	0.005	1
	Reservoir Creek																	
11LB3B	14.9	8.5	4.49	0.21	7.4	0.01	0.1	0.05	0.37	1	7.03	0.05	8.4	74.7	0.009	1.5	0.005	1

Sample	Y µg/L	Yb µg/L	Y µg/L	Yb µg/L	Zn µg/L
	WF Las Tablas Creek				
11LB1B	0.32	0.03	0.08	0.006	1.7
11LB2B	0.94	0.08	0.03	< 0.005	1.7
11LB4B	0.45	0.04	0.09	0.006	0.7
11LB5B	0.46	0.04			
	Reservoir Creek				
11LB3B	0.29	0.02	0.28	0.03	0.5

Not detected: Ag <1 µg/L, As <1 µg/L, Be <0.05 µg/L, Bi <0.2 µg/L, Cd <0.02 µg/L, Mo <2 µg/L, Nb <0.2 µg/L, Sb <0.3 µg/L, Se <1 µg/L, Ta <0.02 µg/L, Th <0.2 µg/L, Tl <0.1 µg/L, U <0.1 µg/L, W <0.5 µg/L, Zn <3 µg/L, Zr <0.2 µg/L

Table 11. Geochemistry of unfiltered samples from the Little Bonanza Mine collected during a high-flow sampling event, ICP-MS results (major elements, ICP-AES results)

Sample	Al µg/L	B µg/L	Ba µg/L	Bi µg/L	Ca mg/L	Cd µg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L	Dy µg/L	Er µg/L	Eu µg/L	Fe µg/L	Ga µg/L	Gd/P µg/L	Ho µg/L
	WF Las Tablas Creek																	
11LB1A	1,660	40.6	49	0.4	10.8	0.02	0.93	1.8	12.1	0.11	3.3	0.15	0.076	0.05	1,870	0.53	0.16	0.03
11LB2A	1,850	27.2	48	< 0.2	7.93	<0.02	3	1.6	12	0.14	3.8	0.3	0.14	0.072	2,200	0.67	0.33	0.06
11LB4A	2,090	35.7	48.8	< 0.2	11.3	<0.02	2.1	2.4	13.6	0.11	4.2	0.23	0.13	0.063	2,790	0.7	0.27	0.05
11LB5A	1,610	35.8	44.5	< 0.2	12.5	0.02	2.6	1.6	10	0.09	3.5	0.21	0.1	0.072	2,030	0.57	0.26	0.05
	Reservoir Creek																	
11LB3A	1,410	40.7	49.2	< 0.2	10.8	<0.02	0.86	1.6	10.5	0.07	3.1	0.15	0.07	0.04	1,620	0.46	0.15	0.03

Sample	K mg/L	La µg/L	Li µg/L	Mg µg/L	Mn µg/L	Na mg/L	Nb µg/L	Nd µg/L	Ni µg/L	P mg/L	Pb µg/L	Pr µg/L	Rb µg/L	Sc µg/L	SiO_2 mg/L	Sm µg/L	SO_4 mg/L	Sr µg/L
	WF Las Tablas Creek																	
11LB1A	1.3	0.43	2.9	17.3	50.7	4.46	0.54	0.58	24.3	0.02	0.46	0.13	1.1	2	12.4	0.14	8.2	75.9
11LB2A	1.1	1	1.1	5.64	51.7	3.96	0.38	1.4	22	0.04	0.96	0.32	1.7	2.4	14.3	0.31	8	61.6
11LB4A	1.1	0.81	2.4	9.33	78.2	5.46	< 0.2	1.1	25.5	0.05	0.86	0.26	1.3	2.6	16.4	0.26	14	88.1
11LB5A	1	0.77	1.9	9.04	62.9	6.09	< 0.2	0.99	18.8	0.04	0.74	0.22	1.1	2.2	15	0.25	16	93.8
	Reservoir Creek																	
11LB3A	1.3	0.4	2.2	17.4	47.8	4.51	< 0.2	0.53	23.3	0.02	0.42	0.11	0.91	1.8	11.2	0.15	8.7	79

Sample	Ta µg/L	Tb/P µg/L	Ti µg/L	Tl µg/L	Tm µg/L	U µg/L	V µg/L	Y µg/L	Yb µg/L	Zn µg/L	Y µg/L	Yb µg/L	Zn µg/L	Zr µg/L
	WF Las Tablas Creek													
11LB1A	0.07	0.02	25.3	0.21	0.01	< 0.1	4.4	0.81	0.08	5.4	0.08	0.005	2.3	< 0.2
11LB2A	0.09	0.05	53.3	<0.1	0.02	< 0.1	4.8	1.4	0.13	6.2	0.03	< 0.005	1.3	< 0.2
11LB4A	0.05	0.04	56.4	<0.1	0.02	< 0.1	6	1.2	0.11	7.7	0.12	0.006	85.1	< 0.2
11LB5A	0.05	0.03	39	<0.1	0.01	0.1	4.4	1	0.07	5.8				
	Reservoir Creek													
11LB3A	0.05	0.02	11.7	<0.1	0.01	< 0.1	3.7	0.74	0.05	5.2	0.55	0.05	2.5	0.4

Not detected: Ag <1 µg/L, As <1 µg /L, Be <0.05 µg /L, Mo <2 µg /L, Sb <0.3 µg /L, Se <1 µg /L, Th <0.2 µg /L, W <0.5 µg /L

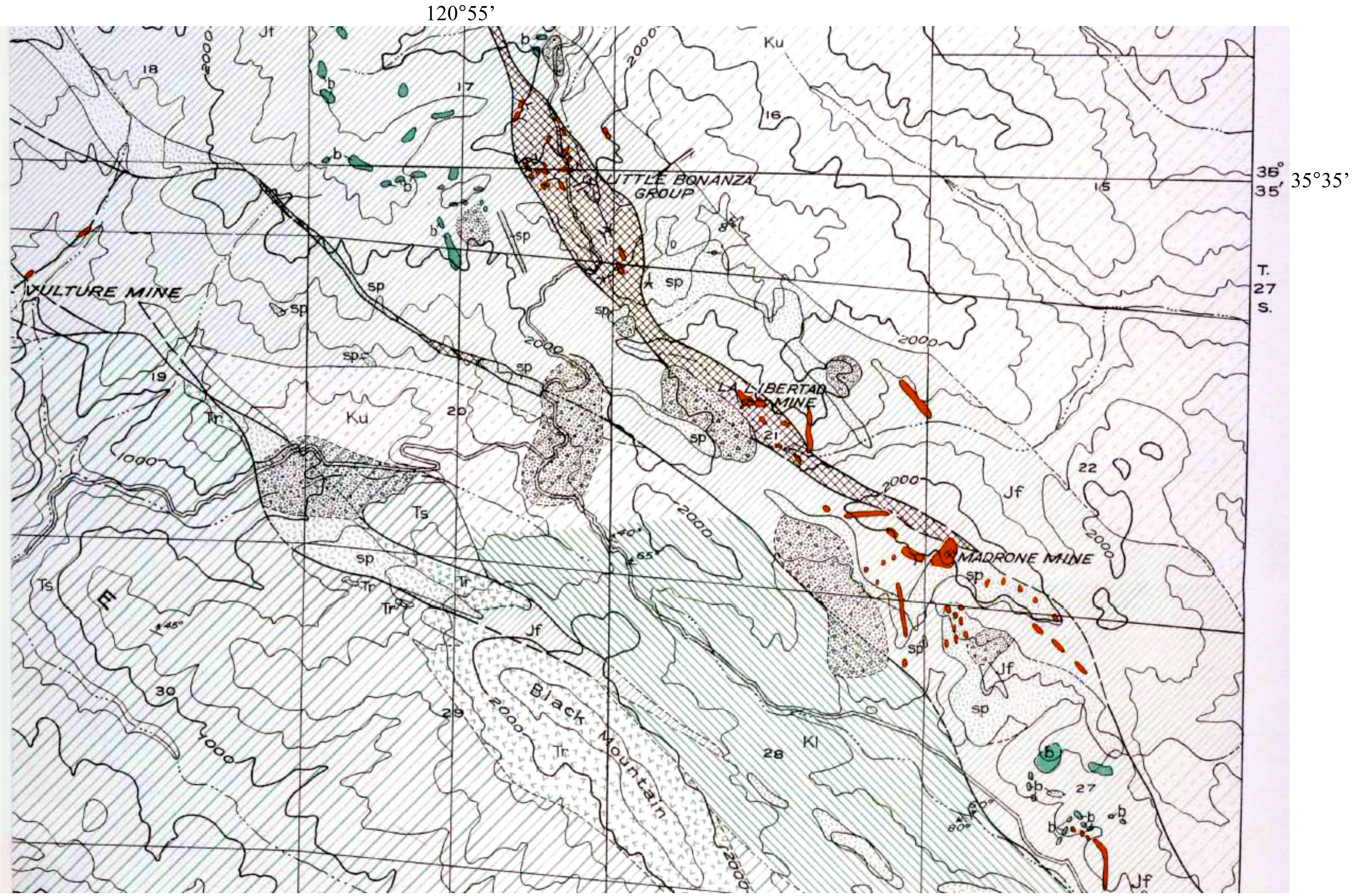

Figure 1. General geology of the Little Bonanza Mine area (Yates and others, 1941). The workings at Little Bonanza explore a zone of fault breccia that trends northwest. The breccia consists of fragments of sandstone, greenstone, serpentine, and chert in a shale matrix.

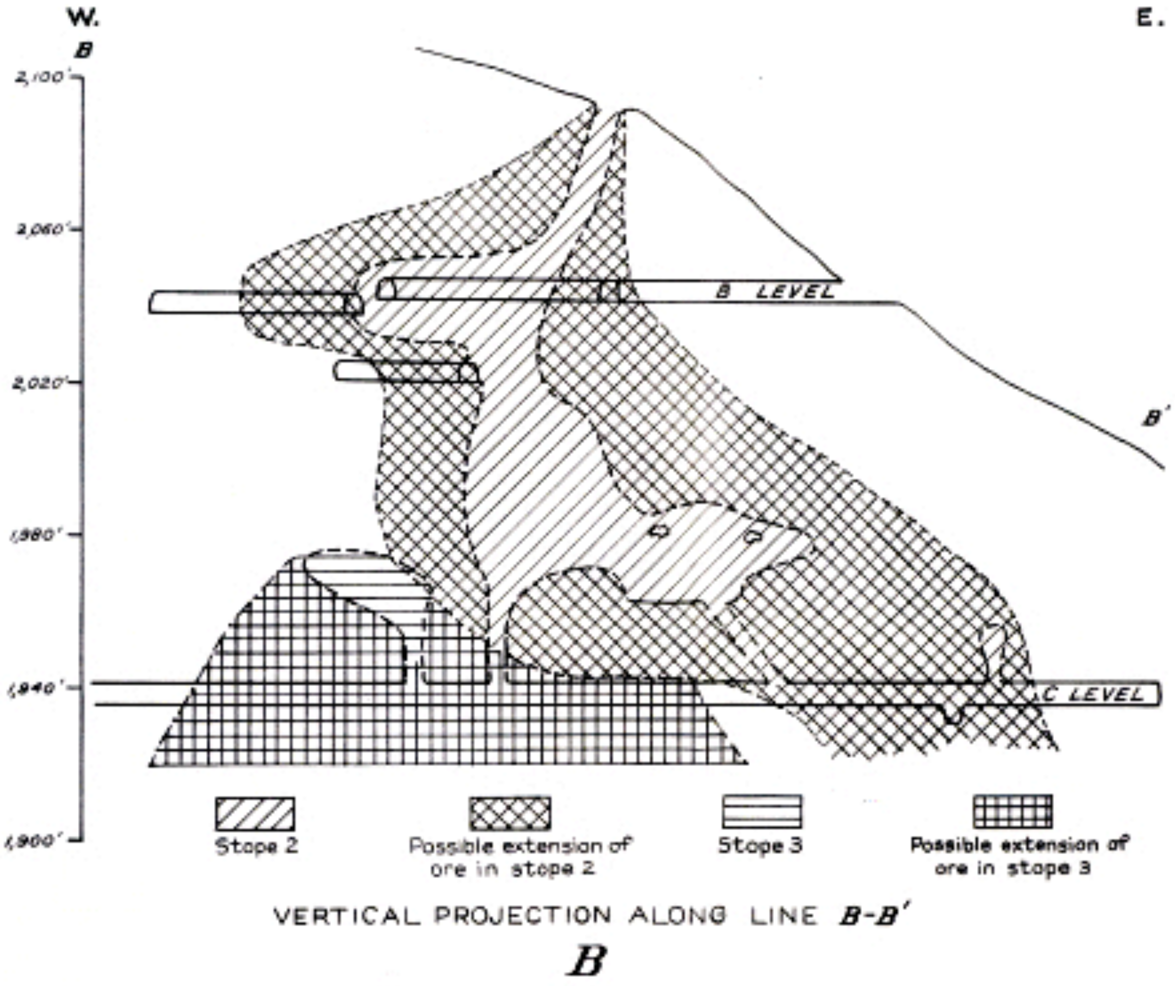

Figure 2. Vertical projection of workings at the Little Bonanza Mine (Yates and others, 1941).

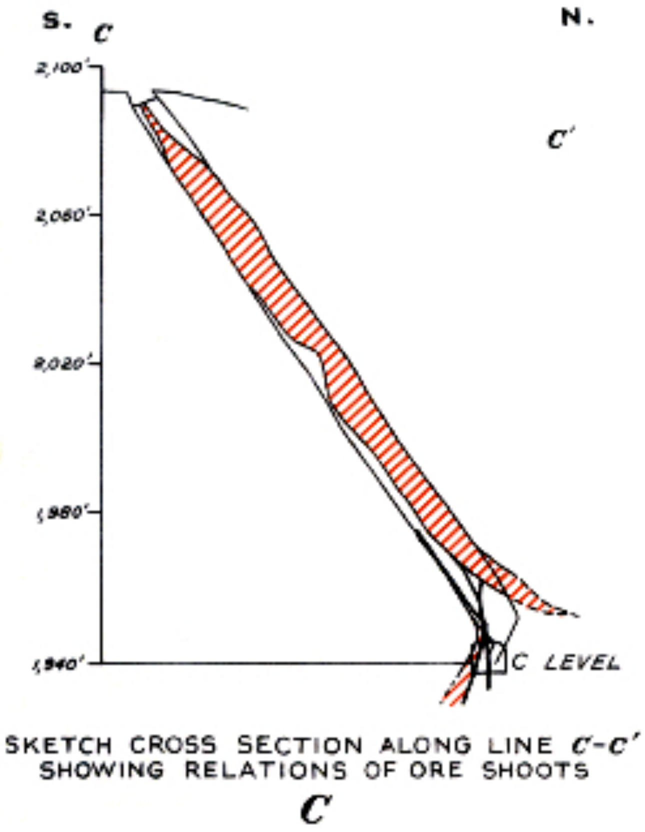

Figure 3. Cross-section of ore shoots at the Little Bonanza Mine (Yates and others, 1941).

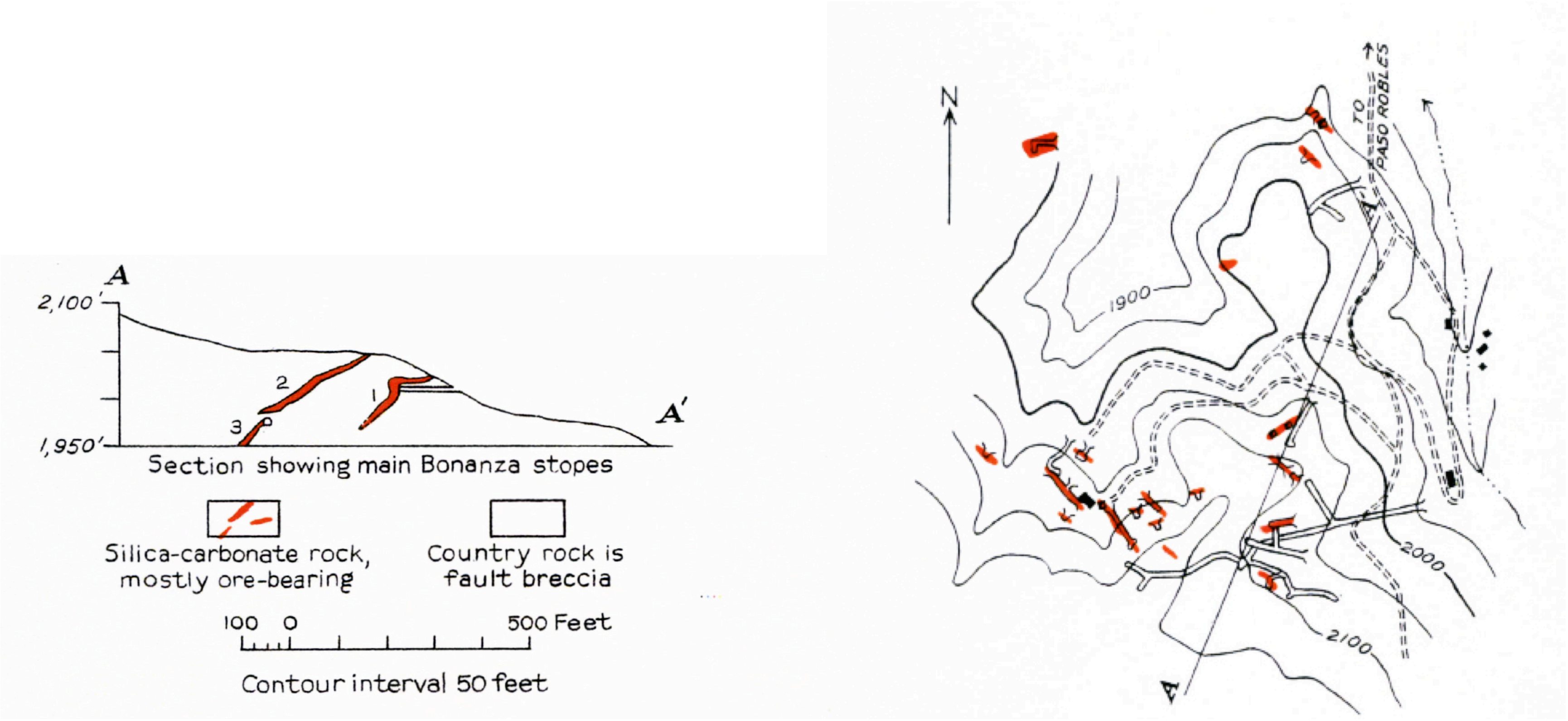

Figure 4. Mine workings at the Little Bonanza Mine, with a cross section showing alteration and mercury ore zones (Yates and others, 1941).

Figure 5. Three-pipe retort at the Little Bonanza Mine that was used to process Hg ores.

Figure 6. Mine processing area at the Little Bonanza Mine, showing remains of a three-pipe retort.

Figure 7. Calcines (mine tailings) adjacent to retort at the Little Bonanza Mine.

Figure 8. Sulfides that formed in three-pipe retort at the Little Bonanza Mine.

Figure 9. Calcines (mine tailings) at the Little Bonanza Mine exposed along bank of WF Las Tablas Creek.

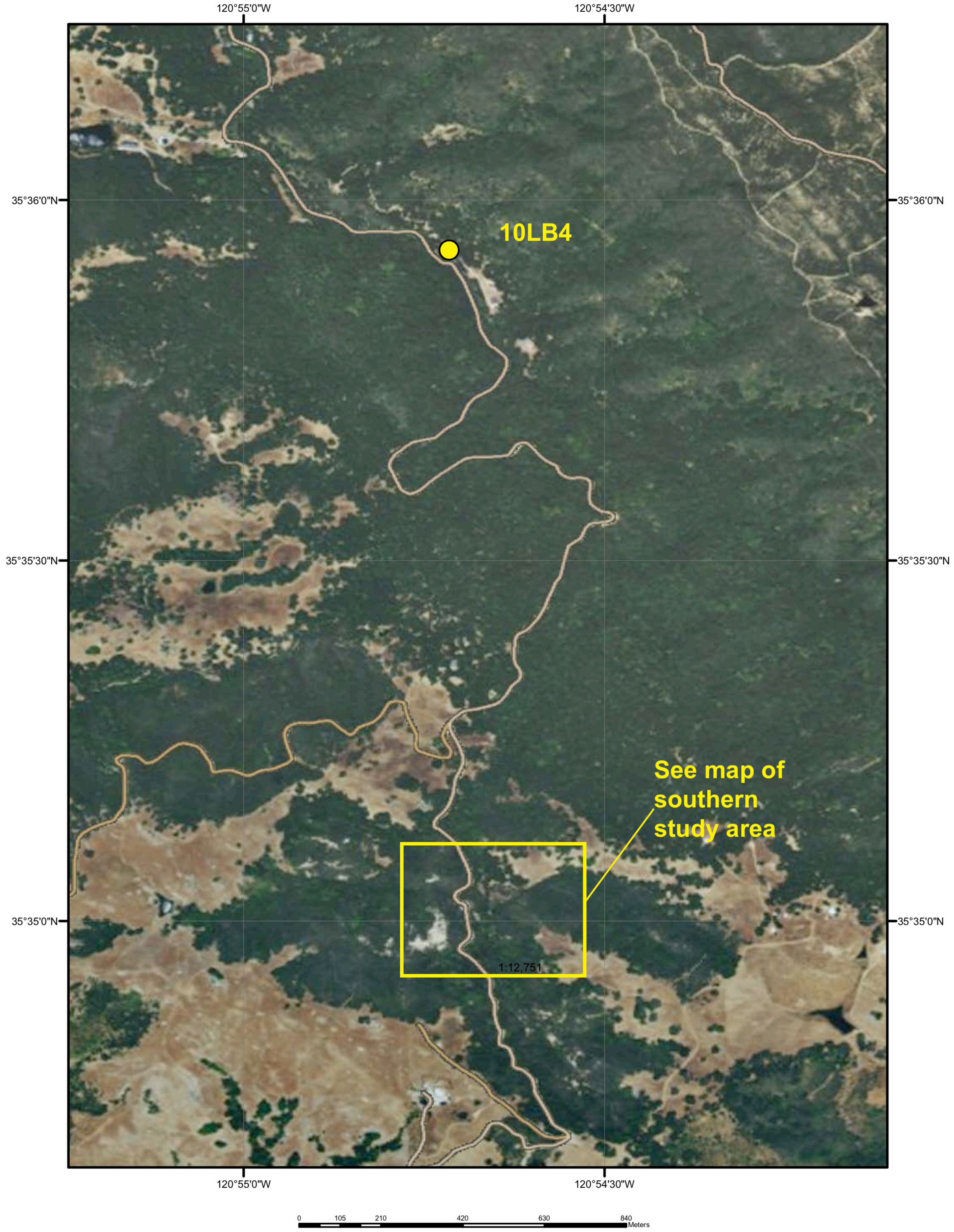

Figure 10. Little Bonanza Mine area, showing locations of all sample sites (Google Earth). Area in yellow box is shown in detail in figure 11.

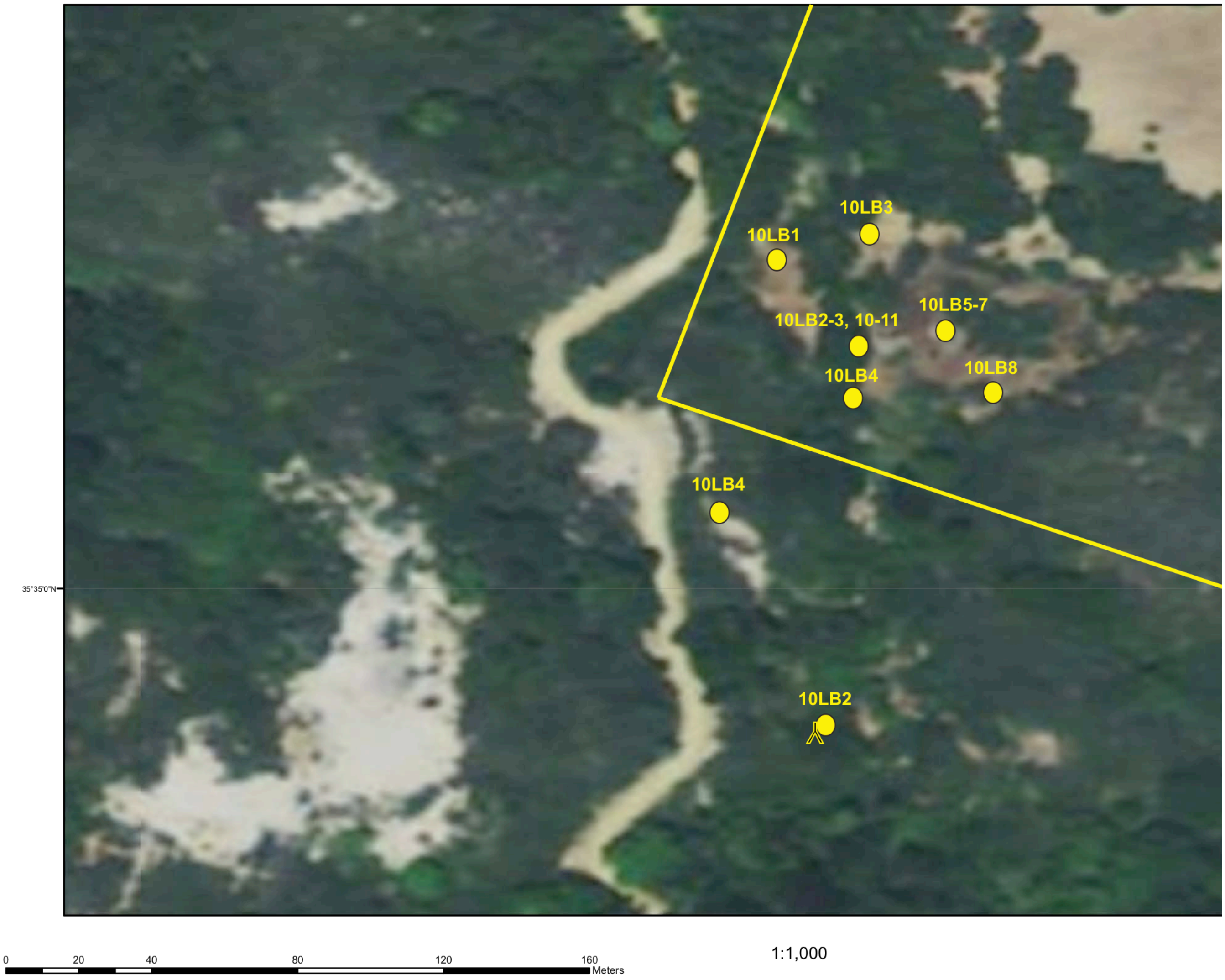

Figure 11. Closeup of figure 10, showing locations of sample sites in mine area (Google Earth). Yellow box delineates land managed by BLM.

Figure 12. Coarse-grained calcines (mine tailings) exposed in bank of WF Las Tablas Creek at the Little Bonanza Mine.

Figure 13. Sample site 10LB1 in WF Las Tablas Creek at the Little Bonanza Mine.

Figure 14. Sample site 10LB3 in creek that extends into area of dam, now failed, at the Little Bonanza Mine.

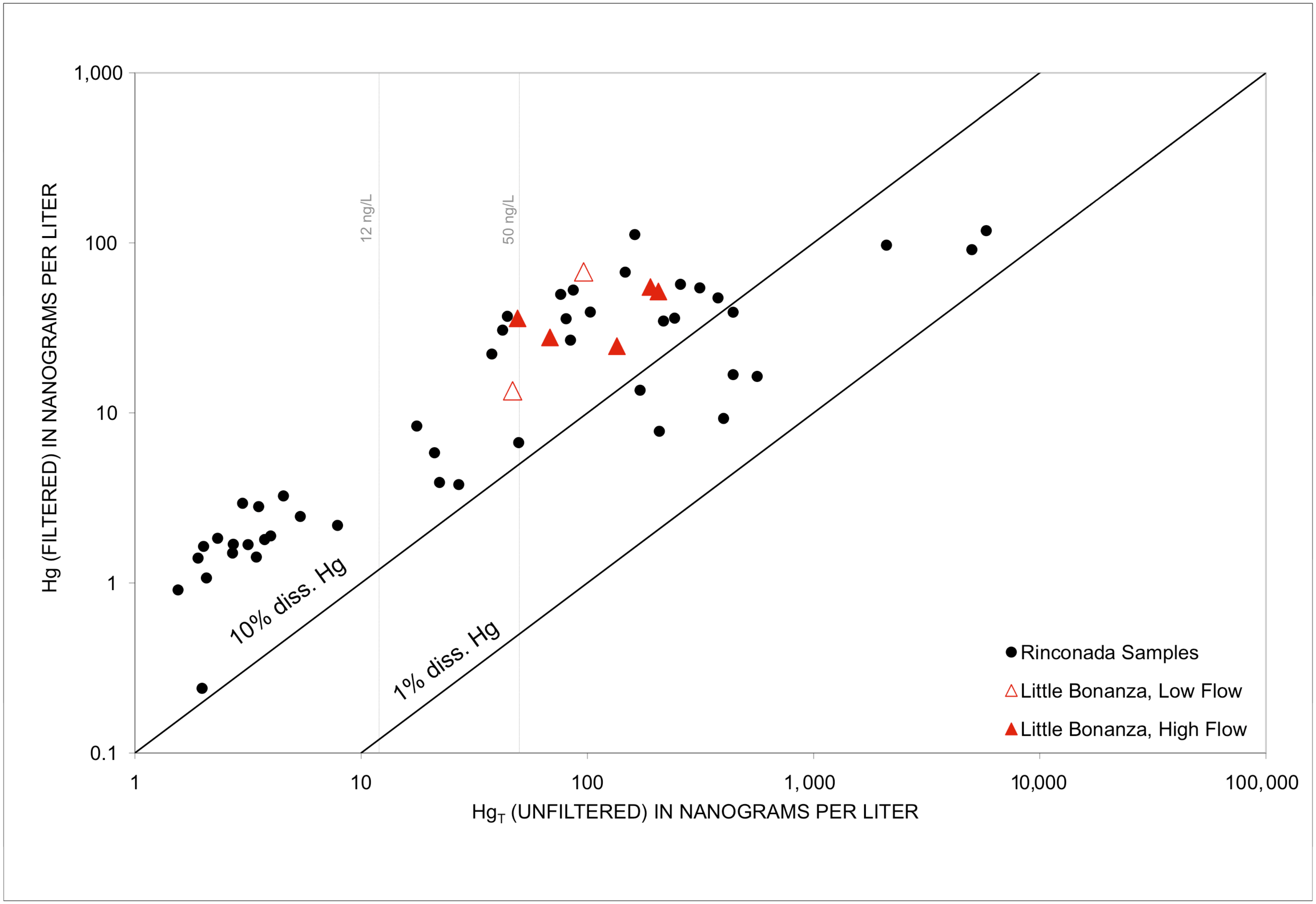

Figure 15. Hg concentration in unfiltered versus filtered samples from the Rinconada and Little Bonanza Mines.

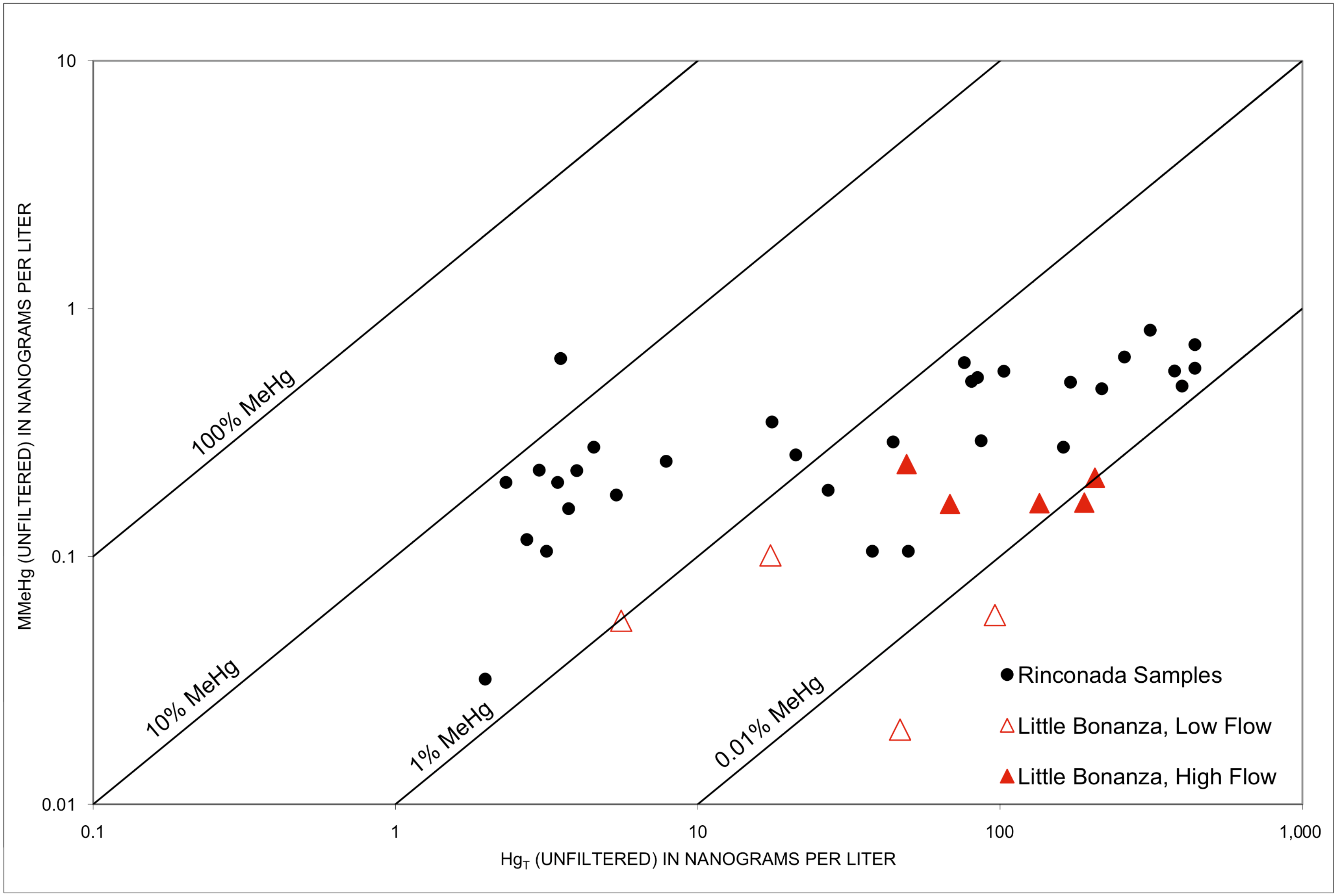

Figure 16. Hg versus MMeHg concentrations in unfiltered water samples from the Rinconada and Little Bonanza Mines.

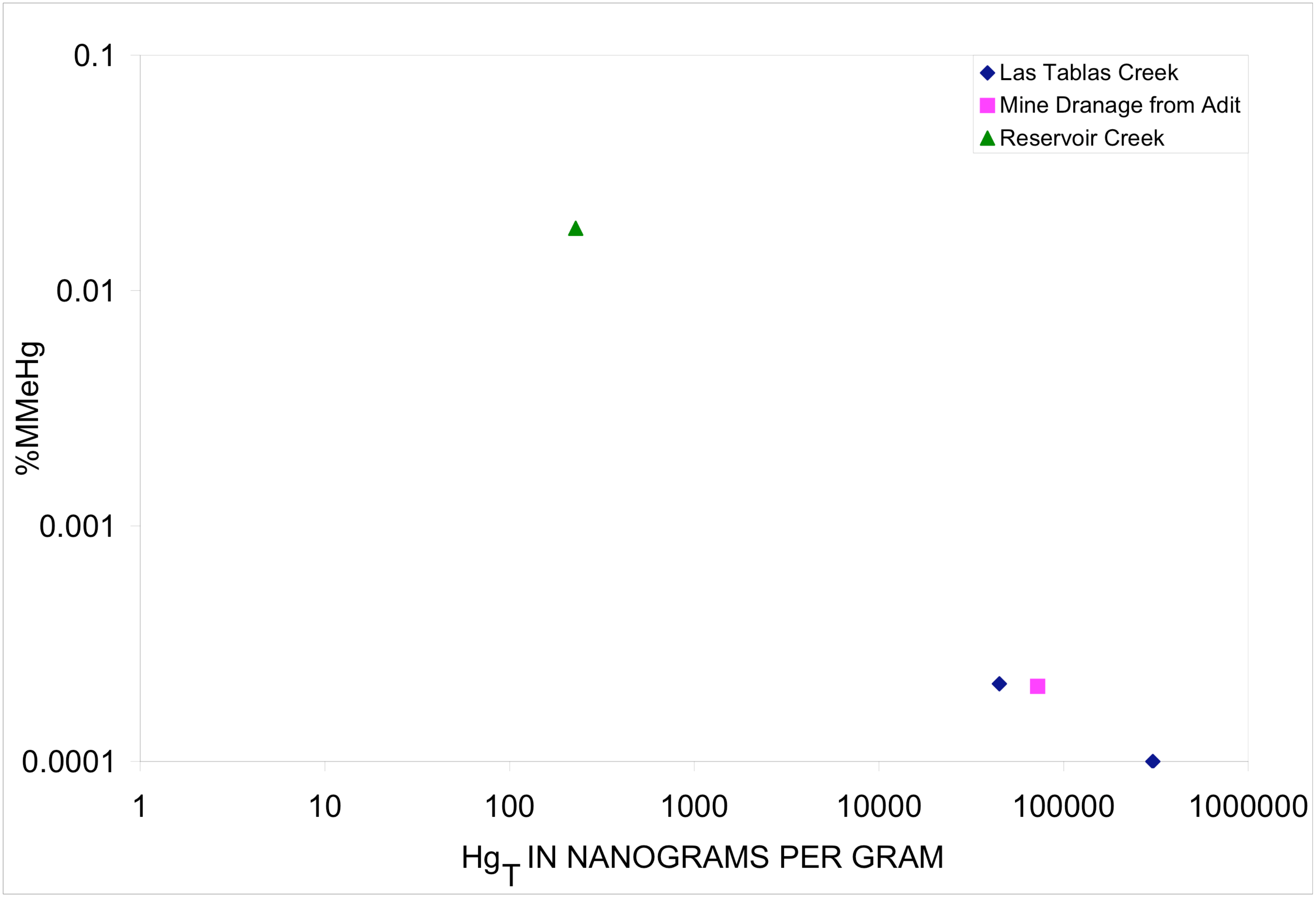

Figure 17. Hg concentration versus %MMeHg in sediment samples from the Little Bonanza Mine.

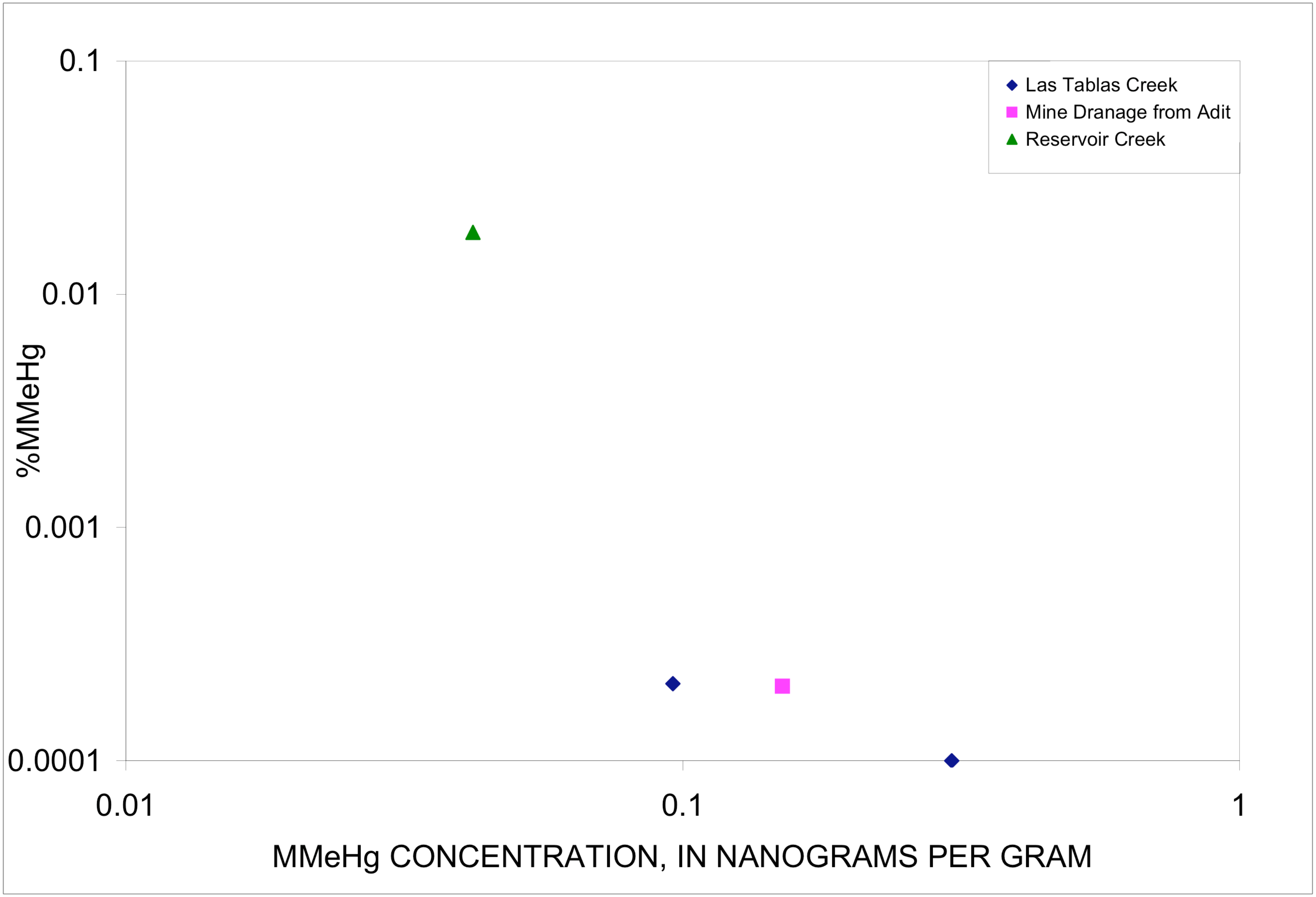

Figure 18. MMeHg concentration versus %MMeHg in sediment samples from the Little Bonanza Mine.

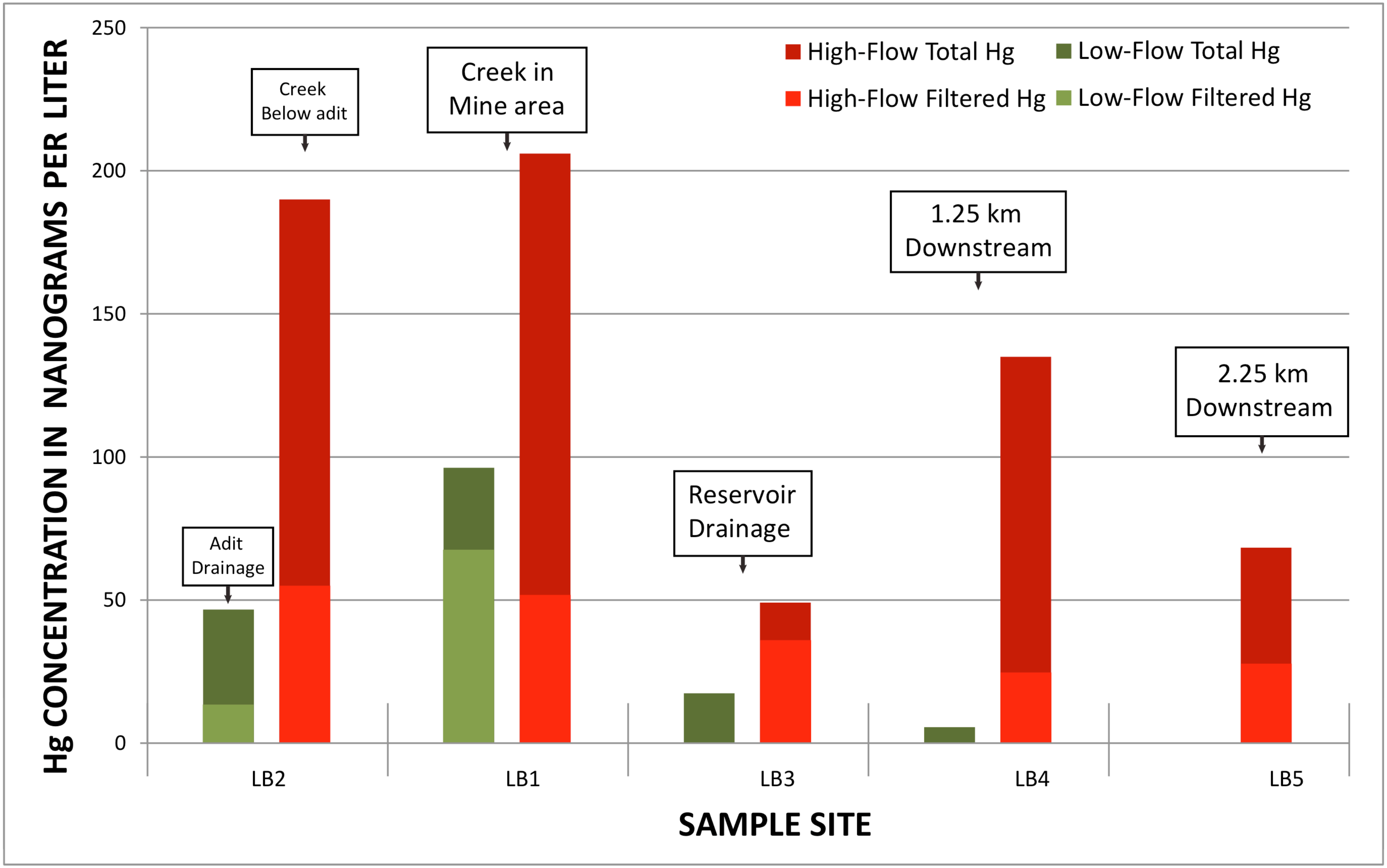

Figure 19. Comparison of Hg_T and dissolved Hg concentrations in waters sampled at the Little Bonanza Mine, beginning with the most upstream sample site, LB2, at the adit, and moving downstream to sample sites LB1, LB3, LB4 and LB5, respectively.