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**Geochemical and lead-isotopic studies of river
and lake sediments, upper Arkansas River basin,
Twin Lakes to Pueblo, Colorado**

by

S.E. Church, S.A. Wilson, R.B. Vaughn, and D.L. Fey¹

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¹U.S. Geological Survey, P.O. Box 25046-MS 973, Denver, Colo. 80225

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Executive Summary

- More than ninety percent of the lead and zinc metal-load in the sediments of the Arkansas River between Leadville and the confluence of Chalk Creek below Buena Vista are from the Leadville mining district. Lead and zinc concentrations in fine-grained sediments of the Arkansas River vary from a high of 1,900 ppm lead and 5,200 ppm zinc at Leadville to 260 ppm lead and 1,200 ppm zinc at Buena Vista. In contrast, background concentrations of lead and zinc in fine-grained sediments in the Arkansas River just above the confluence with California Gulch prior to mining were about 39 ppm lead and 158 ppm zinc (Church and others, 1993).
- Copper, arsenic, and cadmium concentrations are also elevated in this stretch of the Arkansas River (610 ppm copper, 83 ppm arsenic, 33 ppm cadmium at Leadville, Church and others, 1993; 16 ppm copper, 15 ppm arsenic, and less than 2 ppm cadmium at Buena Vista) and are associated with the metal suite characteristic of the Leadville mining district.
- Additional lead and zinc are being added to the metal load of the sediments of Arkansas River at Chalk Creek, but the total contribution to the lead and zinc metal load is small. Further research is needed to quantify the amount of metal being added to the Arkansas River, the source of these metals, and their impact on the riparian and aquatic habitat of Chalk Creek.
- Two additional sources of zinc contamination have been documented near or below Salida; both are probably associated with mining, or the smelting of ores in or near Salida. These mineral deposits near Salida have distinctively different mineralogy, metal chemistry, and lead-isotopic fingerprints, and their contribution can be unequivocally separated from that of the Leadville mining district. Further research is required to document the point-sources of this metal contamination.

Introduction

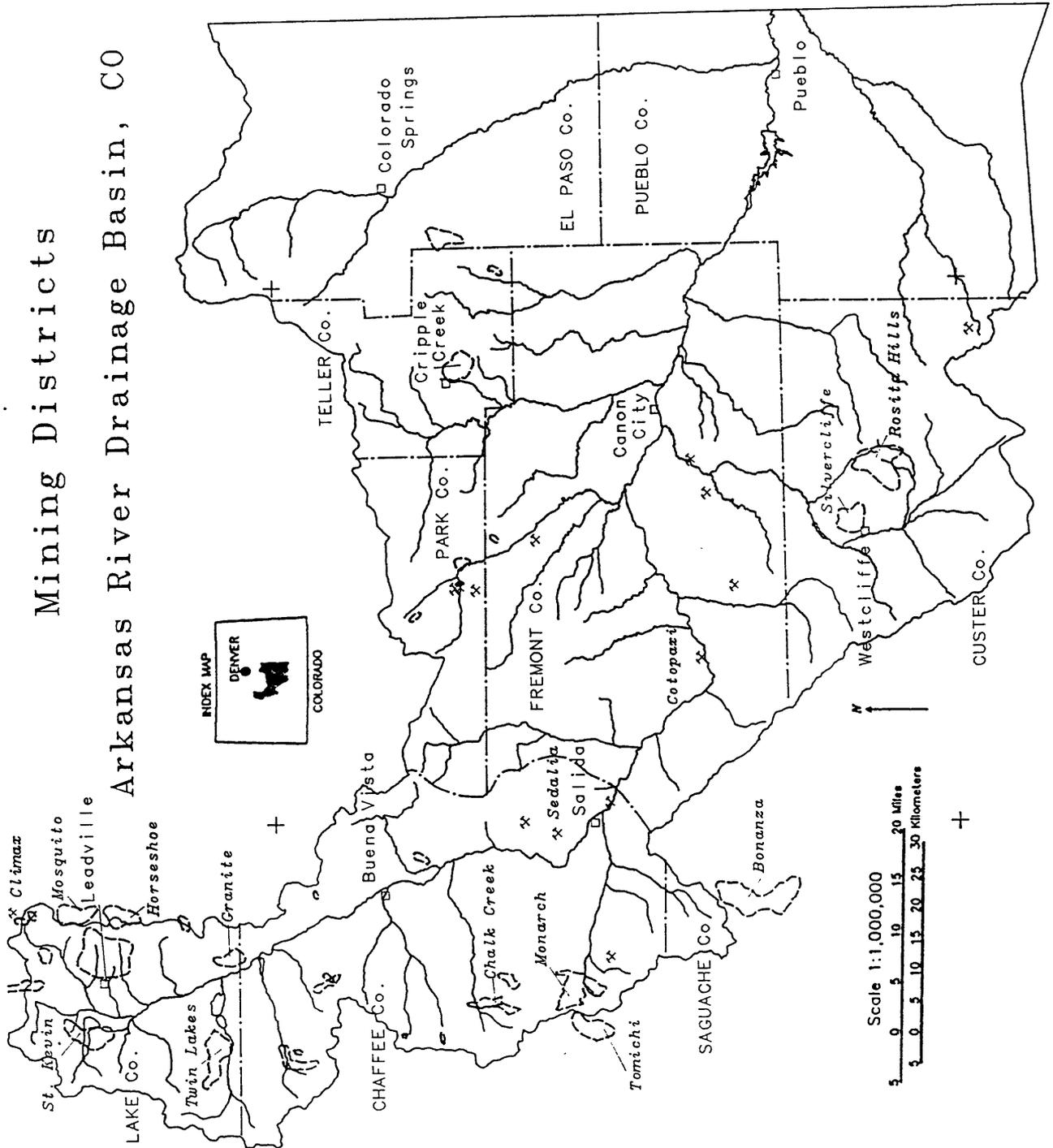
The Arkansas River has its headwaters in the Rocky Mountains of central Colorado (fig. 1). This area has a long history of mineral resource extraction beginning in the 1860's with the discovery of placer gold at Leadville, Colo. Within the upper Arkansas River drainage basin, there are numerous mining districts (see fig. 1), some of which have had major mineral production. In addition to the mining activity, there were also a number of mills and smelters which processed the ores. Mining practices of the past have resulted in exposure of mine waste which, in turn, has resulted in accelerated weathering of pyrite and other sulfide minerals. The weathering process produces elevated concentrations of several metals in many of the stream reaches within the upper part of the drainage basin. The U.S. Geological Survey (USGS) is currently conducting an environmental assessment of the upper Arkansas River basin using both element distribution maps and profiles, and lead-isotope fingerprinting to determine the potential extent of environmental degradation of the Arkansas River and its impact on riparian and aquatic habitat.

Phase I of this study was initiated in July, 1993 to examine the distribution of elements in river sediments from the Arkansas River basin in Lake County, Colo. (Church and others, 1993). The objective of that study was to determine the origin and time-of-deposition of a fluvial tailings deposit in the Arkansas River immediately south of the confluence with California Gulch. We sampled the Arkansas River and its major tributaries (fig. 2, phase I sample sites) to evaluate the contribution of lead from each of the potential sources north of the fluvial tailings deposit. Cores of river sediments were taken at selected sites along the Arkansas River to provide sedimentological and geochronological control.

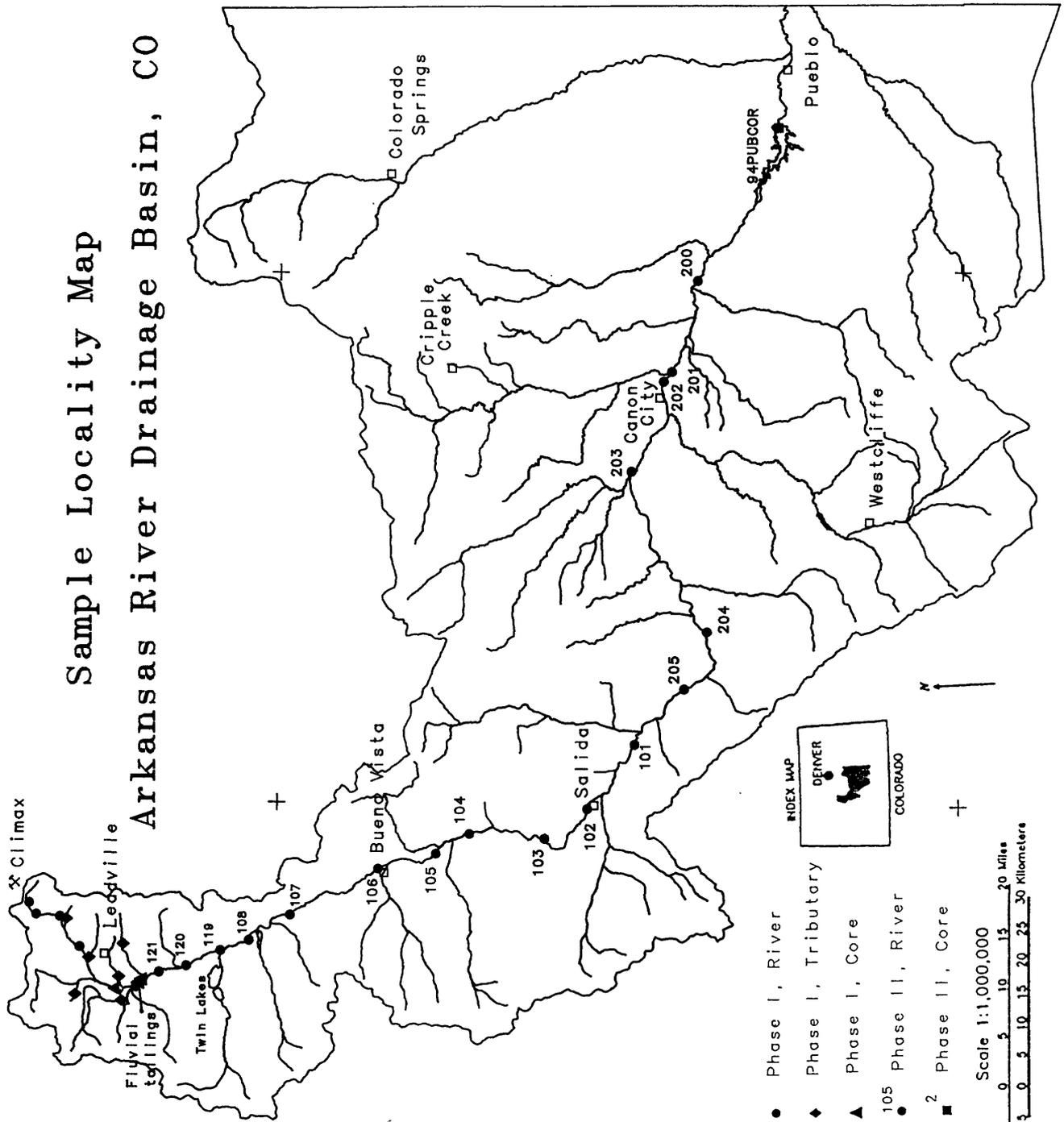
In phase II of the study, we retrieved geochemical data from numerous geologic studies conducted over the last several decades to prepare geochemical maps showing the distribution of copper, lead, and zinc in the upper Arkansas River basin (Smith, 1994). As a result of this work, we identified ten additional source areas in the Arkansas River basin where the concentration of lead in stream sediments exceeds 400 ppm, seven areas where it exceeds 200 ppm, and fourteen areas where it exceeds 100 ppm in addition to the known source of metals in the Leadville mining district. These thresholds are respectively 30, 15, and 8 times that of crustal abundance of lead as defined in Fortescue (1992). Multi-element geochemical data from several thousand stream-sediment samples provided an excellent resource to guide our selection of sample sites along the Arkansas River. Potential source areas include numerous old mining districts and several milling and industrial sites. Using these geochemical maps, seventeen sample sites along the course of the Arkansas River and a composite core sample from Pueblo Reservoir were selected for geochemical and lead-isotopic analysis (fig. 2; phase II sample sites). Geologic, geomorphic, wildlife habitat, land access, and land ownership were also evaluated during the site-selection process.

Figure 1. Map of the Arkansas River basin study area showing major gold and base-metal mining districts; some district boundaries are from Streufert and Davis (1990).

Mining Districts Arkansas River Drainage Basin, CO

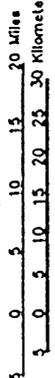


Sample Locality Map Arkansas River Drainage Basin, CO



- Phase I, River
- ◆ Phase I, Tributary
- ▲ Phase I, Core
- 105 Phase II, River
- 200 Phase II, Core

Scale 1:1,000,000



Mining History and Production

Much has been written about the ore deposits of the central Colorado Rockies. The following discussion is intended to briefly summarize the geologic setting, mineralogy, and the mining and production history of the mining districts located in the upper Arkansas River basin in sufficient detail to give the reader some information to evaluate the relative size of the mineral districts and their major periods of mineral production. The data summarized in our discussion of the Precambrian volcanogenic massive sulfide (VMS) deposits is largely from Sheridan and others (1990) and Sheridan and Raymond (1984). A more detailed examination of the economic geology of the deposits associated with the latest phase of mineralization in this region is included in Carbonate-Hosted Sulfide Deposits of the Central Colorado Mineral Belt (Beaty and others, 1990).

Chaffee County

Chalk Creek district--The Mary Murphy mine was the chief producer of the district; Vanderwilt (1947) estimated 75 percent of the total production from the district was from the Mary Murphy mine. The mineral deposit is in a series of quartz veins hosted in the Mt. Princeton batholith of Tertiary age. Quartz vein systems are up to fifty feet thick and over a mile in length with ore zones up to 1 foot in thickness. Galena and sphalerite were the major sulfide minerals with minor chalcopryrite in pyritic quartz veins. Veins are deeply weathered, up to 400 feet at depth on the side of Chrysolite Mountain. There has been intermittent production from 1932 (Vanderwilt, 1947, p. 43-44; Del Rio, 1960, p. 91-92). Total value of production through 1970, expressed in terms of 1970 dollars: \$6,490,000 (Marsh and Queen, 1974).

Monarch mining district--The ores of the Monarch district are replacement deposits in limestone and dolomite that occur along major faults. The deposits are especially well developed along the east side of Taylor Gulch and Cree Creeks; the best ore is in the Manitou Dolomite, which was deposited on granite in many places throughout the district. Most of the ore had been oxidized to limonite, cerrusite, smithsonite, and calamine; primary ores are galena, sphalerite and chalcopryrite in pyritic quartz veins. Ore in quartz veins also occurs in the Mt. Princeton quartz monzonite (Vanderwilt, 1947, p. 45-46; Del Rio, 1960, p. 92-94). Total value of production through 1970, expressed in terms of 1970 dollars: \$13,200,000 (Marsh and Queen, 1974).

Cottonwood mining district--Small veins of galena and sphalerite are described in Precambrian rocks; there is no recorded production. (Vanderwilt, 1947, p. 45).

Granite mining district--Extensive placer activity for gold was undertaken using hydraulic mining methods. There was some lode production of gold from quartz veins associated with Tertiary dikes cutting Precambrian rocks (Vanderwilt, 1947, p. 46-47). Total production through 1970, expressed in terms of 1970 dollars: \$1,107,000 (Marsh and Queen, 1974).

Figure 2. Map of the Arkansas River basin study area showing sample localities
← for phase I (Church and others, 1993) and phase II of this environmental study.

Twin Lakes mining district--Several prospects are located on either side of Twin Lakes Creek. These veins are small quartz veins containing small amounts of gold in rhyolite; very small production recorded (Vanderwilt, 1947, p. 50).

Sedalia mine--A volcanogenic massive sulfide deposit located in section 18, T. 50 N., R. 9 E., about 3 ½ miles northwest of Salida on the east side of the Arkansas River. Production was mainly from oxidized ores of copper and zinc. Workings consisted of an open-pit and an estimate 8,100 feet of underground workings. The ore was shipped primarily to the lead-zinc plant in Cañon City, although some ore was treated at Smelertown and some at Leadville (Van Alstine, 1974, p. 13). The deposit is oxidized to a depth of about 300 feet and contains limonite, quartz, malachite, and a yellow-brown sulfate of lead and copper; primary sulfides were chalcopyrite and sphalerite (Van Alstine, 1974, p. 15). Total value of production through 1970, expressed in terms of 1970 dollars: \$741,000 (Marsh and Queen, 1974).

The area near Salida was the major VMS producing area in Colorado; the localities of the VMS mines in the Arkansas River basin are shown in figure 1. The largest mine in the state was the Sedalia mine located near Salida, Colo. During the period from 1898-1918, the Sedalia mine produced about 90,000 tons of ore, principally from oxidized zinc and copper minerals in the upper part of the deposit. Ore grades from the 1915-1918 period were 3.39 to 4.85 percent copper and 17.35 to 22.93 percent zinc (Sheridan and others, 1990). Only a small amount of lead (about 13 tons; Sheridan and Raymond, 1984) was produced from the deposit. The lead mineral (galena) is intimately associated with the copper and zinc ore and thus provides a direct tie of the isotopic composition of lead in the VMS deposits with the copper and zinc ore produced.

Custer County

Silver Cliff and Westcliff mining districts--The Bull Domingo mine, the largest in the districts, is a breccia pipe in Precambrian rock. Ore zones contain galena and sphalerite whereas the weathered vein material contains horn silver and silver chloride. Chief production is from veins in (Tertiary?) rhyolite and tuff from Rosita Hills (Vanderwilt, 1947, p. 67-68). Total value of production through 1970, expressed in terms of 1970 dollars: \$5,527,000 (Marsh and Queen, 1974).

Rosita Hills mining district--The district is in a volcanic dome complex of andesite and rhyolite; volcanic breccias fill many of the volcanic necks with ore minerals filling the voids between the rock fragments. The Bassick mine was the chief producer; it contained more gold than other veins in the district; galena, sphalerite, and barite are primary minerals. Only small production is reported (Vanderwilt, 1947, p. 69-70).

Oak Creek mining district--Cerrusite ore (lead carbonate) crops out at the surface on the east side of Oak Creek in sheared Precambrian granite and gneiss; it is a deeply weathered VMS deposit (Sheridan and others, 1990). The Marion mine shipped on small shipment of zinc ore from an on-site concentrating mill in 1909. The Terrible mine had small recorded production (Vanderwilt, 1947, p. 69).

Fremont County

Cotopaxi mine--A VMS deposit that contains a lens of chalcopyrite and sphalerite. The mine reportedly was opened in the 1880's and was operated intermittently into the 1950's.

Produced primarily zinc and copper with some values in byproduct gold and silver (Sheridan and others, 1990). The total value of production through 1970, expressed in terms of 1970 dollars: \$733,000 (Marsh and Queen, 1974).

Grape Creek---There are several shafts and workings in a VMS deposit; small and intermittent production of zinc, copper, lead and silver reported (Sheridan and others, 1990).

Isabel mine--VMS deposit that mined as early as 1906. Small and intermittent production of copper and zinc through 1950's (Sheridan and others, 1990).

Green Mountain mine--Small production from this VMS deposit recorded as early as 1914. Intermittent production through 1950's (Sheridan and others, 1990).

Lake County

Climax porphyry molybdenum deposit--This deposit is a large system of quartz veins containing molybdenite, pyrite, fluorite, and minor amounts of galena in a stock of Tertiary age (33-24 Ma; Bookstrom, 1989, 1990). The deposit has very large production from an open-pit mine and mill located largely in the headwaters of the South Platte River in Summit Co., Colo. Total value of production through 1970, expressed in terms of 1970 dollars: \$1,500,000,000 (Marsh and Queen, 1974). Large-scale production continued through the mid-1980's.

Leadville mining district--A large pyrite, galena, sphalerite replacement deposit associated with Tertiary plutons (Thompson and Arehart, 1990). Production data given below are summarized from Thompson and Arehart, 1990, p. 132). Production began with the discovery of placer gold in California Gulch in the early 1860's; 11,705 kg of placer gold were produced. Oxidized zinc ores and sulfide ores containing sphalerite and galena rich in silver were discovered in 1876. The silver-lead period of production lasted from 1876 to 1902. During this period, 7.7 million metric tonnes of ore were produced averaging 8.6 percent lead, 1.1 percent zinc, 2.8 percent copper, and 681 g silver per tonne of ore. The oxidized zinc ore production period was from 1902 to 1923; weathered zinc ore crops out at surface. During this period, 8.3 million metric tonnes of ore averaging 2.5 percent lead, 5.9 percent zinc, 0.3 percent copper, and 225 g silver per tonne was produced. Complex sulfide ores were mined from 1924-1957 producing 5.1 million metric tonnes of ore averaging 2.0 percent lead, 2.8 percent zinc, 49 g silver, and 4.8 g gold per tonne, and from 1971-1987 producing 3.0 million metric tonnes of ore averaging 8.9 percent lead, 8.0 percent zinc, 73 g of silver, and 2.4 g gold per tonne. Large-scale mineral production continues through the present. Total value of production through 1970, expressed in terms of 1970 dollars: \$497,000,000 (Marsh and Queen, 1974).

St. Kevin-Sugarloaf mining districts--Early production of gold and silver processed largely from oxidized ores; primary minerals include galena, sphalerite in pyritic quartz veins hosted in Precambrian granite (Vanderwilt, 1947, p. 130). Total value of production through 1970, expressed in terms of 1970 dollars exceeds \$1,000,000 (Marsh and Queen, 1974).

Twin Lakes mining district--Small quartz veins occur in Precambrian granite and Tertiary quartz monzonite. The Mt. Champion mine at head of Lackawanna Gulch was the major producer; the veins are small (Vanderwilt, 1947, p. 131). Total value of production through 1970, expressed in terms of 1970 dollars: \$737,000 (Marsh and Queen, 1974).

Park County

Betty and Mill Gulch mines--Several small VMS deposits were mined resulting in

intermittent production of copper-zinc secondary ore from about 1911 through the 1960's (Sheridan and others, 1990).

Horseshoe mining district--Galena and sphalerite veins hosted in Precambrian granite along London fault. Some replacement ores in the Paleozoic limestones of the area very similar to those of the Leadville district (Vanderwilt, 1947, p. 171).

Mosquito district deposits are veins in Precambrian rocks and in Paleozoic limestones similar to that of Leadville district (Vanderwilt, 1947, p. 171-173). Alma is large placer gold district. Total value of production through 1970, expressed in terms of 1970 dollars: \$29,560,000 (Marsh and Queen, 1974).

Teller County

Cripple Creek mining district--Large breccia pipes associated with alkalic volcanic center of Tertiary age. Veins associated with breccia pipes; gold ore is in telluride ores (Vanderwilt, 1947, p. 387-395). Sheeted quartz veins can be up to ten feet in width. Total value of production through 1970, expressed in terms of 1970 dollars: \$337,000,000 (Marsh and Queen, 1974). Large-scale production has continued to the present.

Sampling Plan

For each of the seventeen sites selected for analysis, 5 to 10 individual localities along a 30 m stretch of the Arkansas River were sampled to provide an integrated sample of the detrital sediment material; samples were collected from both sides and the center of the river whenever possible. A clean plastic scoop was used to collect samples from the low-velocity portion of the river. In the field, each sample was sieved through a 10-mesh stainless steel screen into a plastic gold pan, mixed, and transferred to a plastic ziplock bag. Samples of the 93LV119-121 series were collected in September, 1993; samples of the 94ARK100 and 94ARK200 series were collected on February 17-18, 1994; and the core sample from Pueblo Reservoir was collected in August, 1994.

In the laboratory, samples were dried at ambient temperature ($20^{\circ} \pm 5^{\circ}\text{C}$) and sieved to minus-80-mesh (< 177 microns) as described in Church and others (1993, p. 37). The weights of the plus-80-mesh, minus-10-mesh fraction and the minus-80-mesh fractions of each sample were determined. The graph in figure 3 shows the relationship between grain size and distance downstream from Climax at the headwaters of the Arkansas River. Since the gradient of the stream decreases over the course of the river, the velocity of the flow also decreases. Because the sediment-carrying capacity of a stream is directly dependent upon its velocity and volume, the fine-grained fraction of the sedimentary debris is quickly transported downstream to areas of lower stream gradient where it is added to that minus-80-mesh component in the river that is locally derived from the surrounding rocks by erosion.

Geochemical Methods

Church and others (1993) adapted standard chemical procedures developed by the USGS over the last several decades in their mineral resource assessment programs to study the geochemical composition and lead-isotopic signature of labile (available) metals in the minus-80-

mesh fraction of the stream sediments (Chao, 1984). Labile metals were defined as those metals released by a weak, warm-acid leach (2M HCl-H₂O₂). These labile metals are sorbed by clay minerals or by hydromorphic mineral phases such as the iron- and manganese-oxide coatings on sediment grains. In unmineralized areas, weak-acid leaches remove metals that were released during weathering of silicate minerals (Church and others, 1987). The weathering process of unmineralized rock in mountainous areas releases only small amounts of metals. However, in mineralized areas where elevated metal concentrations exist in the rocks (i.e., those metals in groups 1A-5A, 5B-7B and 8 of the periodic table), substantial amounts of metals are released because of the rapid chemical weathering of exposed pyrite and other ore minerals. This process results in pronounced geochemical anomalies being preserved in the iron- and manganese-oxide minerals, because these labile metals are sorbed by or co-precipitated on grain surfaces and enriched relative to the natural geochemical baseline (i.e., the variable geochemical background). Acid drainage caused by the weathering of pyrite leads to precipitation of iron-oxide coatings on sediment grains within the stream when acidic waters are diluted by mixing with neutral pH water. Thus, the process of precipitation of metals carried in these streams is a grain-surface phenomenon, and enrichment by this process is best represented by the surface coatings on the fine-grained size fraction of the river sediment. Since much of the work on stream sediment geochemistry in the Arkansas River basin has been based on minus-80-mesh sediments (see Smith, 1994) we have used this grain-size fraction to tie our study to the extant geochemical data base in the Arkansas River basin. The coating of grain surfaces is the fundamental mechanism of metal enrichment in stream sediments that underlies geochemical exploration methods utilizing partial digestion procedures (Chao, 1984).

Three tables of data are presented in the appendix. In table A1, we present the geochemical data from the total digestion of the minus-80-mesh fraction of the river- and lake-sediment samples; in table A2, we present the geochemical data from the 2M HCl-H₂O₂ leaches of the minus-80-mesh fraction of the river- and lake-sediment samples; and in table A3, we present the geochemical data from the total digestion of the residues following the 2M HCl-H₂O₂ leach digestion of these samples. Analytical procedures used have been described in Church and others (1993, p. 41-42); limits of determination for the analytical methods are given in table A4. Evaluation of laboratory precision and accuracy were based on the analysis of duplicate samples from two sites and the analysis of National Institute for Standards and Technology (NIST) standard reference materials (SRM) 2704 and 2711. Duplicate samples from sites 94ARK101 and 94ARK201 were prepared in the laboratory by splitting the minus-80-mesh (<177 micron) material using a Jones-type sample splitter. As described above, the duplicate samples were analyzed for extractable, total, and residual constituents. Duplicate samples are identified in the field identification code with a letter "D" suffix.

The NIST SRMs 2704 and 2711 were analyzed for their total, extractable, and residual constituents using the previously described procedures. Because NIST SRM's are only certified for their total-element concentrations, a statistical comparison with USGS results is only possible for the total-element analysis of original material. USGS results for certified elements in both SRMs fall within established control limits derived from long-term analysis of these standards. Analytical results from NIST standards used as control samples are given in table A5. Results from the 2M HCl-H₂O₂ leach procedure are very similar to those reported in Church and others (1993). Examination of replicate data for the total-digestion and extraction procedures reveal

Distribution profile <80 mesh sediment Upper Arkansas River, CO

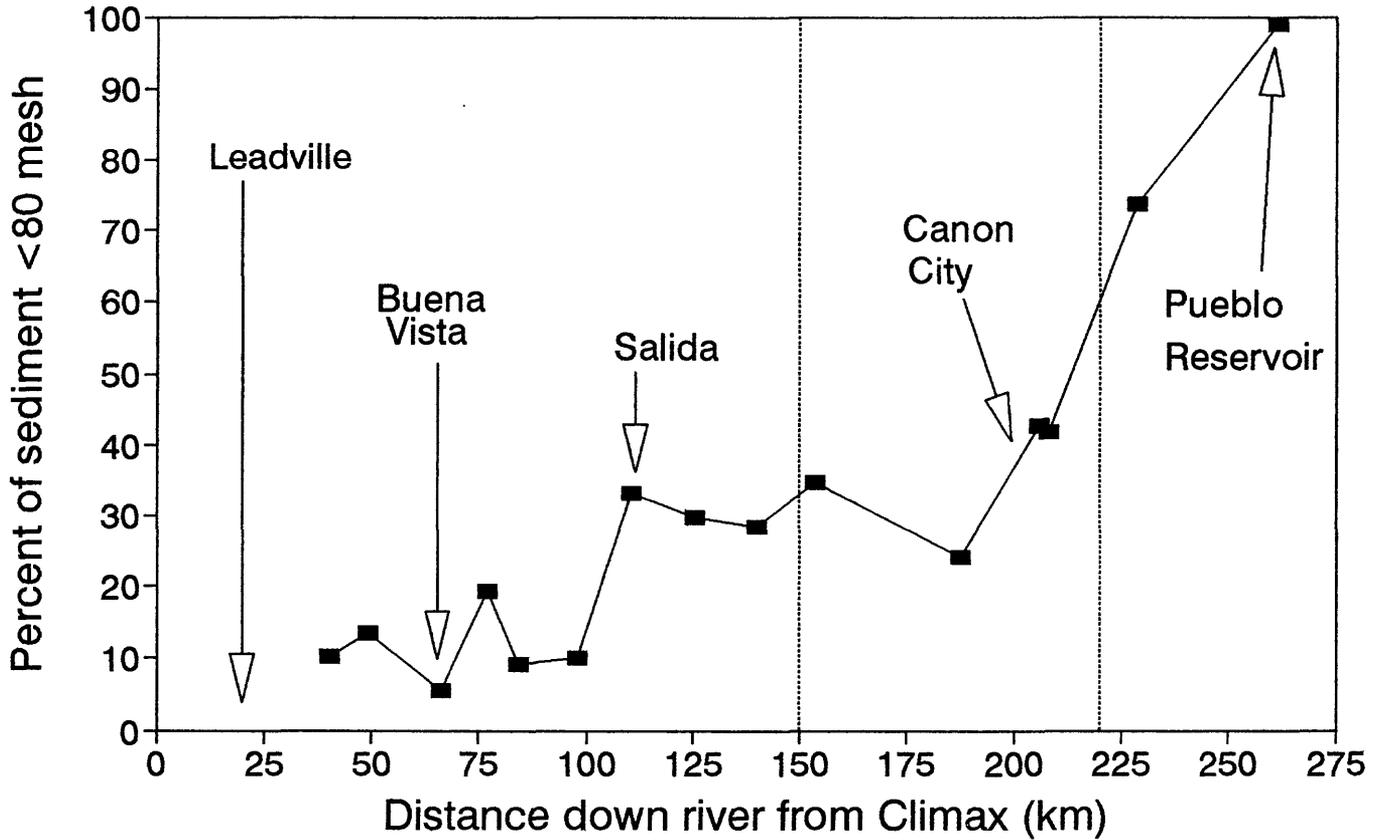


Figure 3. Distribution profile showing the change in particle size that occurs in the minus-10-mesh (2 mm) size fraction with distance measured from Climax (see fig. 2). The vertical dotted lines indicate the major changes in geology as discussed below.

that the precision as measured by the percent relative standard deviation (%RSD) is less than ± 8 percent, which is considered acceptable for the ICP-AES procedure (Briggs, 1990). The precision for lead, thorium, and sodium in the extraction experiments ranged from 10 to 25 percent. Total-element analysis of extraction residue shows a wider range in analytical precision, although most analytical results are $< \pm 20$ percent except for copper and phosphorous.

Lead-isotopic Methods

Lead has four naturally occurring isotopes: ^{206}Pb accumulates from the decay of ^{238}U , ^{207}Pb accumulates from the decay of ^{235}U , ^{208}Pb accumulates from the decay of ^{232}Th , and ^{204}Pb has no radioactive parent. Since the half-life of each of the parent isotopes differs, the isotopic ratios of lead change systematically with time. Crustal rocks contain low and variable concentrations of lead (generally 5-50 ppm), uranium (2-10 ppm), and thorium (8-40 ppm) and have variable isotopic ratios of lead. However, in mineral deposits, particularly those containing galena (PbS), the hydrothermal processes separate lead from its parent isotopes and thus, the isotopic signature is "frozen in" by the process of ore-deposit formation at the time the mineral deposit is formed. The composition of lead in mineral deposits often has a very limited isotopic range. Weathering of these mineral deposits, as described above, releases and homogenizes the lead in the mineral deposit; the analysis of this homogenized lead in the stream sediments provides a lead-isotopic signature of the mineral deposit (Gulson and others, 1992). We use the lead-isotope signature of the labile lead in iron-oxide coatings deposited on the grain coatings in the minus-80-mesh fraction of the stream sediments (that is, the 2M $\text{HCl-H}_2\text{O}_2$ leachates) to "fingerprint" and quantify the contribution from the mineral deposits within the headwaters of the Arkansas River.

The rock types present in the Arkansas River basin control the chemistry of the sediments derived from them, and the age of the rocks dictates their lead-isotopic characteristics. Crustal rocks in the headwaters of the Arkansas River basin are about 1,000 to 1,700 Ma in age (for further discussion see Church and others, 1993, p. 4-10). These old crystalline rocks are overlain by Paleozoic marine sedimentary rocks in the upper part of the Arkansas River basin. The rocks have been intruded by Cretaceous to Tertiary plutonic rocks; mineral deposits, as represented by the mining districts, are spatially associated with several of these plutons (see fig. 1). In the vicinity of Salida, the VMS deposits are associated with the oldest metamorphic rocks in the area. East of Cañon City, Colo., the Arkansas River basin is underlain by sedimentary rocks of Mesozoic age (Tweto, 1979). Each of these geologic provinces have different lead-isotopic signatures. The approximate trace of the boundaries between these three major geologic provinces are indicated by the two dotted vertical lines shown at 150 and 220 km on figures 3-13.

The samples prepared for lead-isotopic analysis were submitted as blind samples and analyzed using the 2M $\text{HCl-H}_2\text{O}_2$ leach procedure described previously in Church and others (1993, p. 55). Two NIST standard reference materials were analyzed and the results are within analytical error of previous analyses (Church and others, 1993). Two of the samples from the study were also run in duplicate (labeled with "D" suffix). In addition, two bulk sediment samples from the same sites as the duplicate samples were also analyzed (that is, material that

was not sieved to minus-80-mesh; samples labeled with a "B" suffix). The results between duplicate samples are within analytical error, but the analyses of bulk samples lie outside analytical error when compared with the results from the duplicate samples from each site, presumably because of the influence of specific rock fragments in the bulk samples. That is, the bulk sample was not sufficiently large that sampling error was eliminated as a variable. These discrepancies are small, however, and do not affect the validity of the conclusions drawn in this study. Analytical results from this study are in table A6 in the appendix.

Interpretation of the Geochemical Data

The geochemical results for the total, extractable, and residual components of the river-sediment samples indicate that there are several sources of ore metals in the upper Arkansas River basin. One of the procedures used to evaluate the enrichment of metals in the environment is to compare observed metal concentrations with the crustal abundance of the element. In this study, we use the crustal abundance data reported in Fortescue (1992). A comparison of observed data with the crustal abundance of an element provides a measure of element enrichment, which may have resulted from mineral extraction activities, industrial contamination, or weathering of an undisturbed mineral deposit. Comparisons of average, maximum, and minimum total-element concentrations in river-sediment material with average crustal abundance values are presented in table 1. From inspection of these data, it is apparent that, for the majority of elements, average concentrations from the total-digestion data are within a factor of two of most crustal abundance values. Exceptions are noted for the elements cerium (Ce), lanthanum (La), neodymium (Nd), thorium (Th), lead (Pb), and zinc (Zn), which have elevated metal concentration in the river sediments, and magnesium (Mg), phosphorous (P), and nickel (Ni) which are much lower. Mean concentrations of lead and zinc show strong enrichment having values ten and eight times crustal abundance respectively. Because of this pronounced enrichment of lead and zinc in the river sediments, we will focus our discussion in this paper on the distribution of these metals and their relationship to known point-sources of contamination in the Arkansas River basin.

In evaluating the contribution of metals from a point-source, element-distribution profiles are an important technique used to examine the change in metal concentration in the sediment bed-load as a function of distance downstream from Climax. Element-distribution profiles can provide important information on the metal contribution from different point-sources, identify localities where metals may naturally preconcentrate, provide information on the long-term source of metals to the river, and describe the extent of downstream contamination from identified point-sources.

Distribution profiles of two groups of trace-elements clearly demonstrate two distinct types of geochemical behavior along the course of the Arkansas River. One group of metals shows little change in the overall distribution pattern and probably reflects minor changes in the geochemistry of the rocks that underlie the drainage basin. Discrete changes in the elemental distribution profiles for this group of trace-elements are noted below specific stream confluences. These changes can be explained by the presence of silicate or clay minerals in the river sediments. Examples of elements showing such behavior (fig. 4) are cerium (Ce), chromium (Cr), and cobalt (Co). For these elements, metal concentrations are dramatically affected by the

Table 1. Comparison of total-element concentrations in Arkansas River sediments with average crustal abundance of elements

Element	Average conc.	Max. conc.	Min. conc.	Crustal ¹ Abundance
Al, %	6.4	8.1	3.7	8.36
Ca, %	3.0	7.1	0.81	4.66
Fe, %	7.6	29.0	3.0	6.22
K, %	2.2	2.5	1.3	1.84
Mg, %	0.85	1.3	0.41	2.76
Na, %	1.5	2.1	0.47	2.27
P, %	0.16	0.26	0.09	1.12
Ti, %	0.61	1.4	0.26	0.632
Ag, ppm	<2	5	<2	0.08
As, ppm	<10	52	<10	1.8
Ba, ppm	680	820	400	390
Be, ppm	2	2	2	2
Cd, ppm	2	16	<2	0.16
Ce, ppm	230	900	78	66.4
Co, ppm	14	27	8	29
Cr, ppm	67	150	39	122
Cu, ppm	32	63	19	68
Eu, ppm	<2	5	<2	2.1
Ga, ppm	18	28	13	19
La, ppm	120	460	41	35
Li, ppm	24	44	11	18
Mn, ppm	1100	2100	540	1060
Mo, ppm	<2	4	<2	1.2
Nb, ppm	24	44	12	20
Nd, ppm	110	420	35	39.6
Ni, ppm	20	36	10	99
Pb, ppm	140	770	30	13
Sc, ppm	12	16	8	25
Sr, ppm	290	420	170	384
Th, ppm	46	220	12	8
V, ppm	190	690	54	136
Y, ppm	44	100	21	31
Yb, ppm	4	8	2	3
Zn, ppm	700	2800	210	76

¹Data from Fortescue (1992)

addition of new sediment material from tributaries such as Chalk Creek. Downstream from the confluence with Chalk Creek, metal concentrations for these elements tend to decrease continuously over a relatively short distance reflecting the dilution of the impact of material added at the confluence with Chalk Creek change and the gradual change in geology of the rocks underlying the Arkansas River basin.

The distribution profiles of lead, zinc, and copper concentrations versus distance (figs. 5-7) reflect weakly-bound metals sorbed onto the iron- and manganese-oxides. In the lead distribution profile, a gradual and constant decrease in the total-lead concentration in the river sediments is consistent with the pattern associated with a single point-source. In the case of zinc and copper, a gradual decrease in total-element concentration is observed from Leadville south to about 100-120 km near the town of Salida. Downstream from Salida, a gradual increase in metal concentration is observed suggesting the presence of additional local sources of zinc and copper. The source of these metals is unknown; possible point-sources include the Smelertown NPL site, an industrial site near Salida, erosion of the Sedalia VMS deposit upstream from Salida, or some other mineral deposit or tailings near Salida, Colo. In figure 6, note that the concentration of total zinc in the <60-micron fraction drops to meet the total concentration of zinc in the <177-micron (minus-80-mesh) fraction at site 94ARK204 just above Cañon City. These results may reflect the dropping of much of the suspended sediment load and the attenuation of much of the transported bed-load in the sediments of the Arkansas River. A similar rise in concentration of copper (fig. 7) is evident and the trend in the lead profile (fig. 5) is essentially flat.

In evaluating the impact that metal contamination has on the local environment, it is important to determine what fraction of the total-metal concentration is easily mobilized and labile. One method used extensively in the past to determine metal availability is the use of specific chemical leaches (Chao, 1984). Specific leaches dissolve particular mineral constituent(s) and the metals associated with that phase are thus determined in the extract solution. Weak acid extractants, such as the 2M HCl-H₂O₂ leach used in this study, provide information on the weakly-bound metals that are associated with the organic, carbonate, and iron- and manganese-oxide phases or sorbed onto clay surfaces. Quantifying the labile element concentrations associated with these mineral phases will provide information on the metal transport and availability, which ultimately affects their impact on biological populations.

Distribution profiles for extractable lead (Pb), zinc (Zn), copper (Cu), and iron (Fe) were prepared to examine their distribution as a function of distance along the Arkansas River (figs. 8-11). In the case of extractable lead (fig. 8), the distribution profile shows a gradual decrease in concentration downstream from Leadville, very similar to the total-element pattern for lead (fig. 5). In the case of zinc (fig. 9) and copper (fig. 10), the profiles mimic the patterns observed in the total-element data, that is, a gradual decrease in metal concentration downstream from Leadville followed by a significant increase in concentration below Salida. For all three metals (Cu, Pb, and Zn), both the extractable metal and the total-metal concentrations are virtually identical suggesting that the bulk of the metal load is carried on grain surfaces of fine-grained particles in the river. Studies by Callender and others (1991) showed elevated zinc concentration in the <60-micron fraction, which they attribute to sorption on the surfaces of iron- and manganese minerals precipitated from the dissolved metal load of the Arkansas River. In contrast, the total iron and extractable iron distribution patterns differ significantly (fig. 11).

Distribution profiles, total Ce, Cr, Co Upper Arkansas River, CO

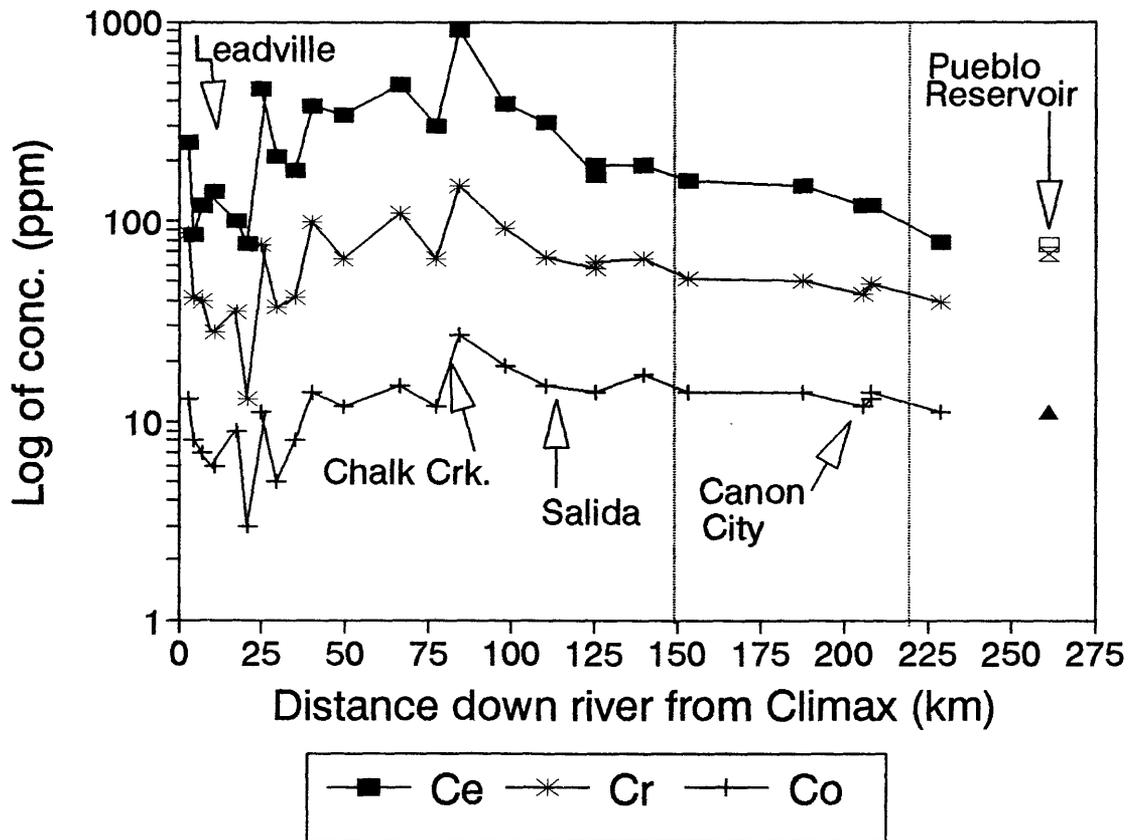


Figure 4. Concentration of total cerium (Ce), chromium (Cr), and cobalt (Co), in sediments from the Arkansas River plotted as a function of distance from Climax. Concentrations of these elements in the lake-sediment core from Pueblo Reservoir are: cerium, □; chromium, X; cobalt, ▲.

Distribution profile, total lead Upper Arkansas River, CO

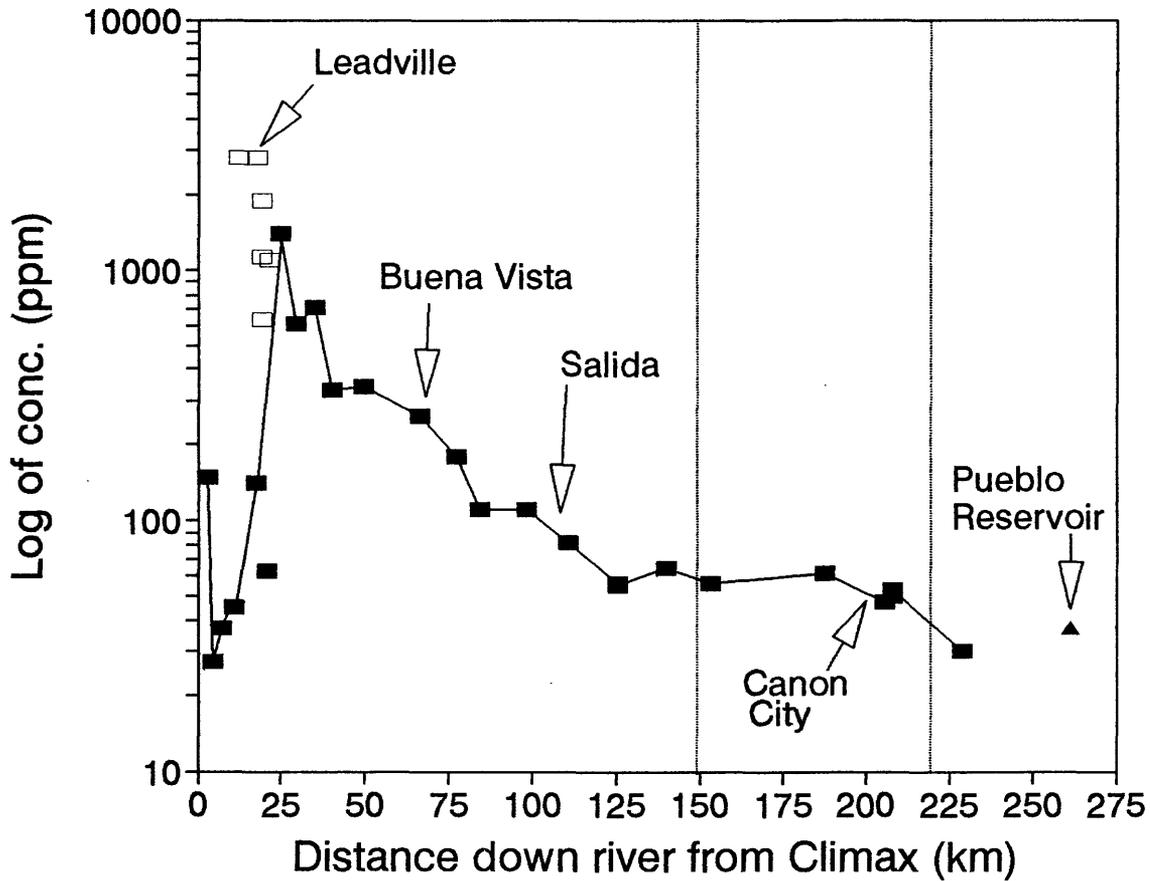


Figure 5. Concentration of total lead (Pb) in sediments from the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir are shown as a triangle (\blacktriangle); data from tributaries from the Leadville mining district are shown as squares (\square ; Church and others, 1993).

Distribution profile, total zinc Upper Arkansas River, CO

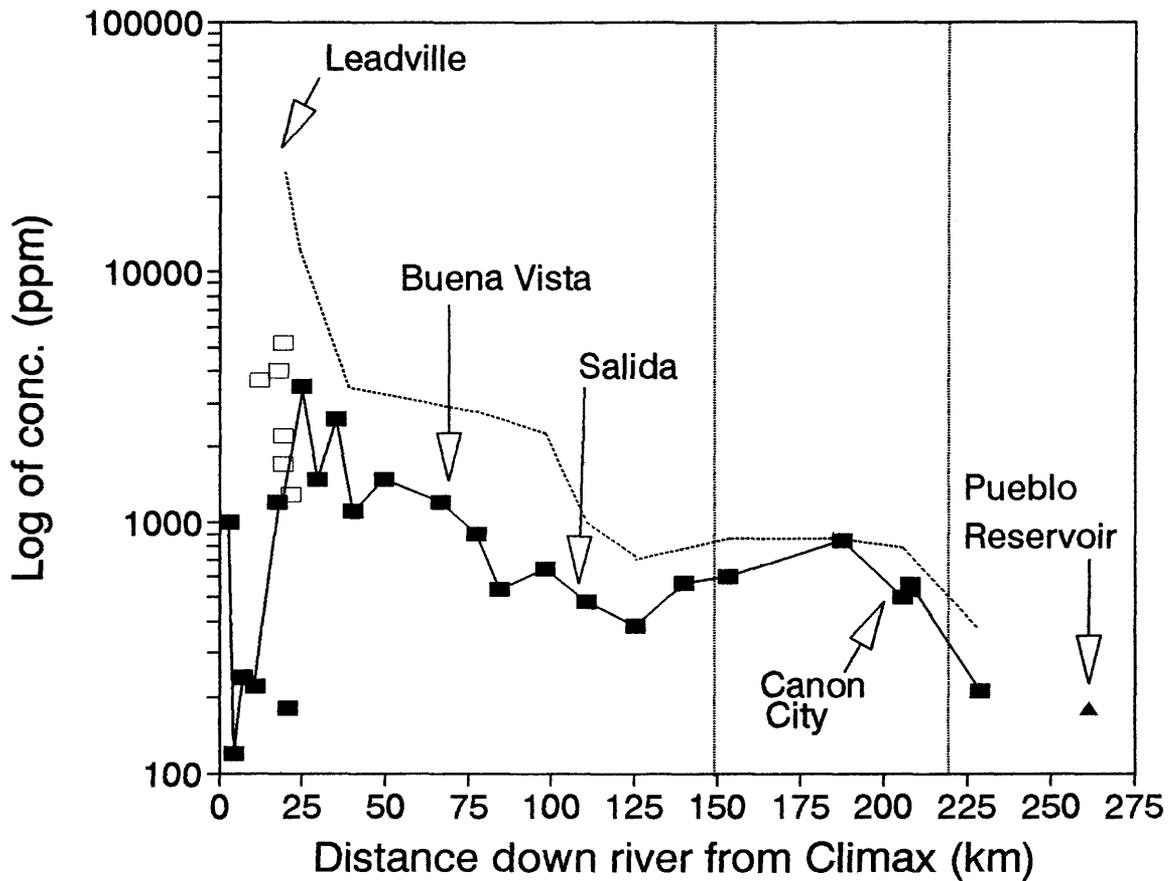


Figure 6. Concentration of total zinc (Zn) in sediments from the Arkansas River plotted as a function of distance from Climax. The concentration of total zinc in the minus-60 micron fraction of the sediments of the Arkansas River are shown by the dotted line (Callender and others, 1991). Data from the lake-sediment core from Pueblo Reservoir are shown as a triangle (\blacktriangle); data from the Leadville mining district are shown as squares (\square ; Church and others, 1993).

Distribution profile, total copper Upper Arkansas River, CO

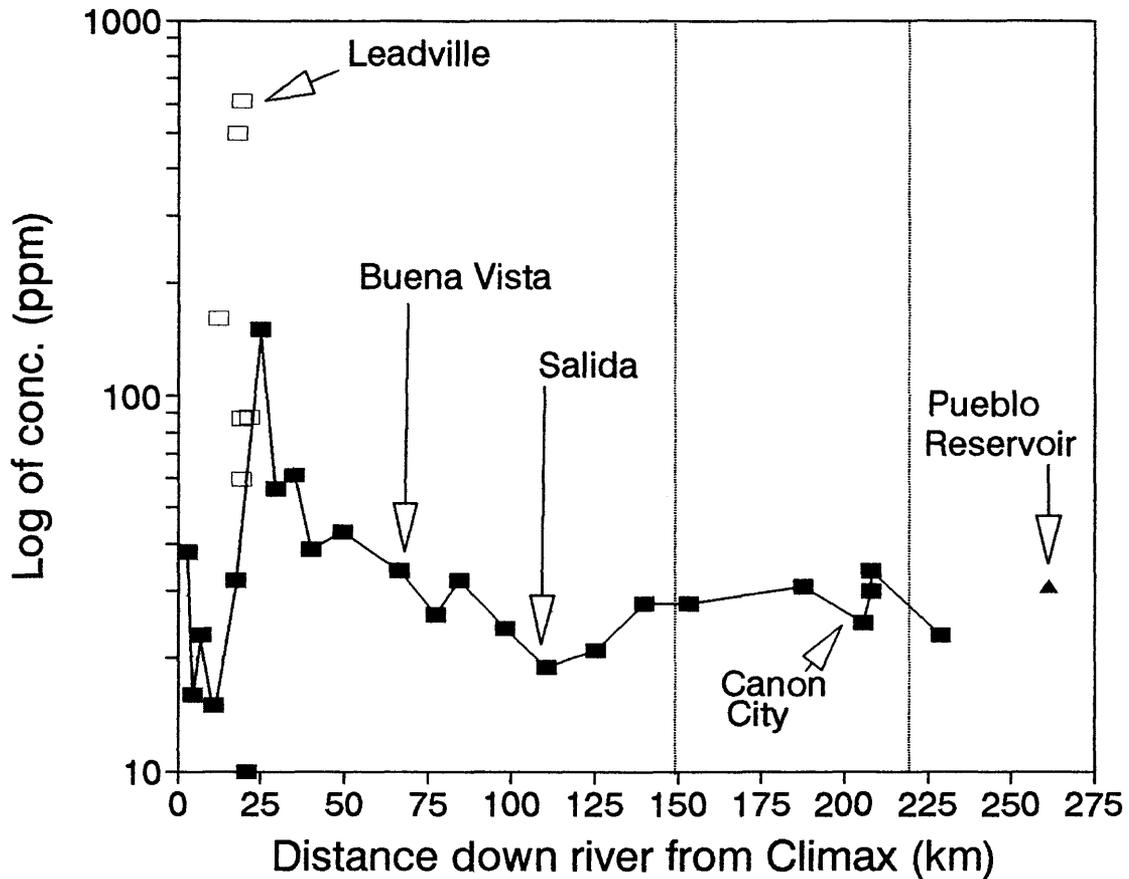


Figure 7. Concentration of total copper (Cu) in sediments from the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir are shown as a triangle (\blacktriangle); data from the Leadville mining district are shown as squares (\square ; Church and others, 1993).

Distribution profile, extractable Pb Upper Arkansas River, CO

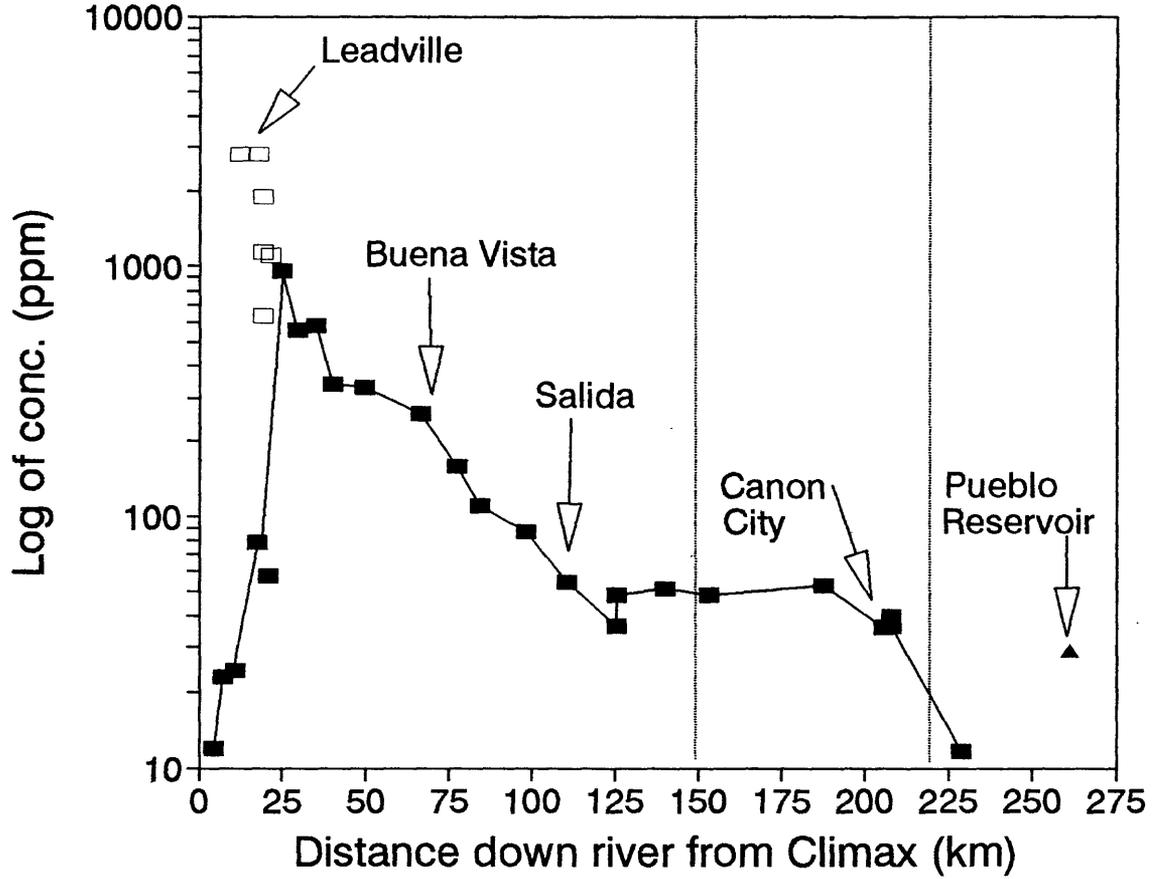


Figure 8. Concentration of extractable lead (Pb) from sediments of the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir are shown as a triangle (▲); data from the Leadville mining district are shown as squares (□; Church and others, 1993).

Distribution profile, extractable zinc Upper Arkansas River, CO

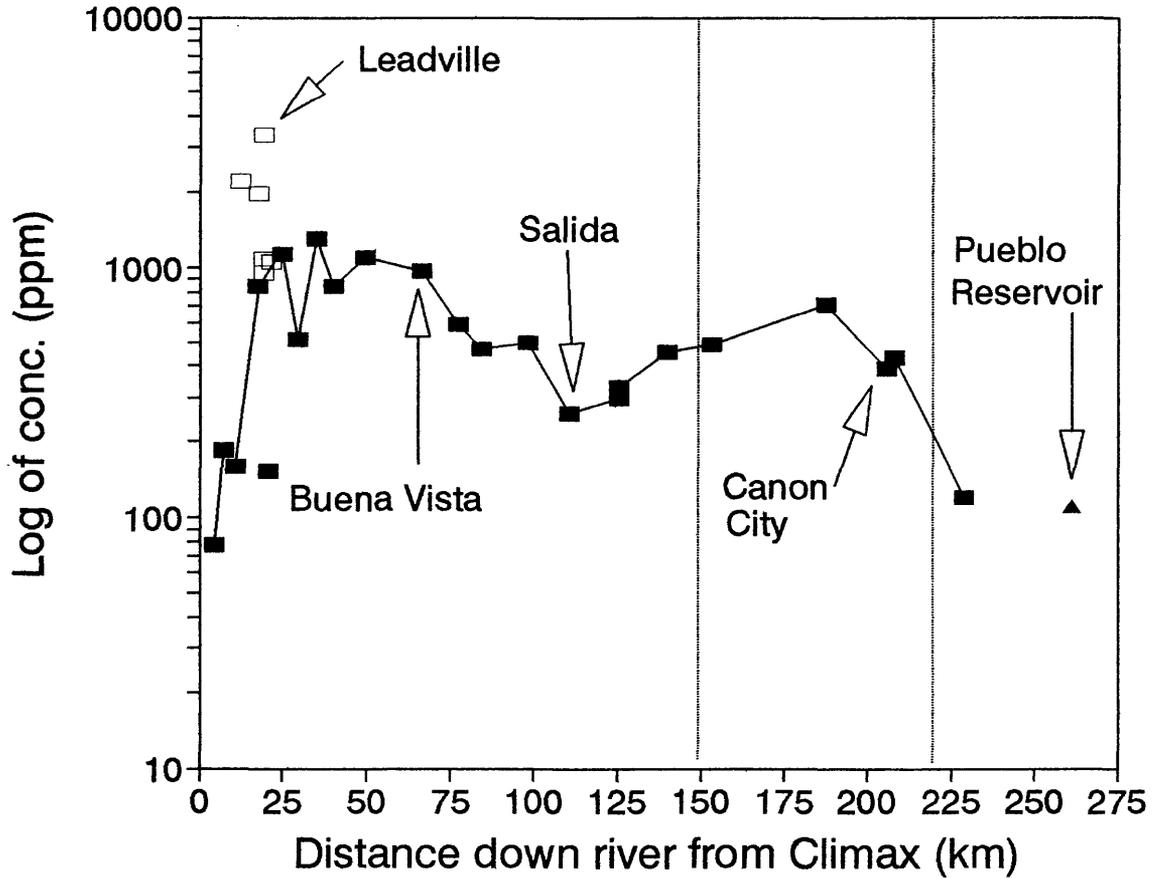
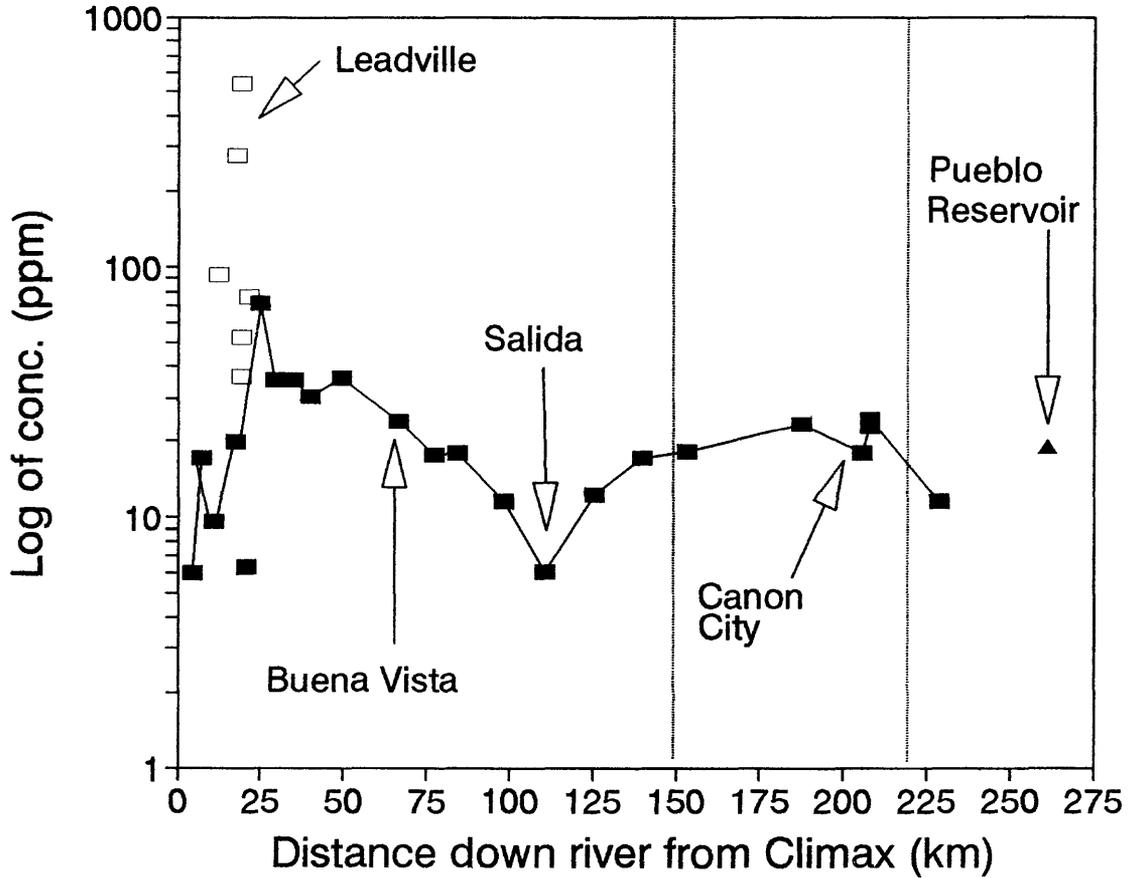


Figure 9. Concentration of extractable zinc (Zn) from sediments of the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir are shown as a triangle (▲); data from the Leadville mining district are shown as squares (□; Church and others, 1993).

Distribution profile, extractable Cu Upper Arkansas River, CO



Distribution profiles for iron Upper Arkansas River, CO

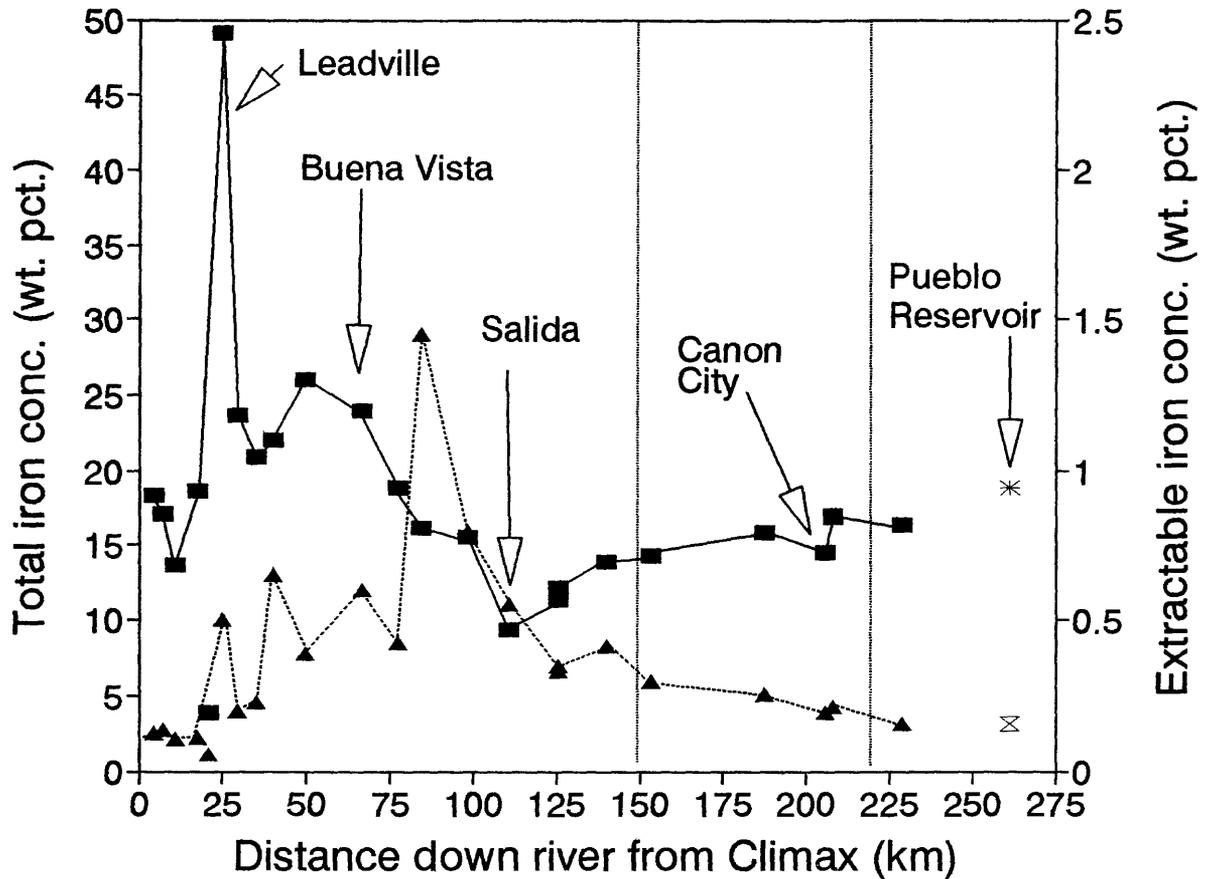


Figure 11. Comparison of total (samples connected with a dotted line) and extractable (samples connected with a solid line) iron in sediments from the Arkansas River plotted as a function of distance from Climax. Total iron in the lake-sediment core from Pueblo Reservoir is shown as an X; extractable iron in the lake-sediment core from Pueblo Reservoir is shown as an asterisk (*).

This implies that there is both an inert and a labile form of iron in the river sediments. The inert forms are not attacked by the 2M HCl-H₂O₂ acid leach and represent iron in silicate and other resistant mineral phases (Church and others, 1987). The labile metals are associated with the iron- and manganese-oxide mineral phase, which is also where copper, lead, and zinc are weakly bound and mobile.

The data suggest that the lead distribution pattern in the Arkansas River is dominated by metals from the California Gulch NPL site in the Leadville mining district. The pattern is interpreted as an essentially continuous dilution profile from a single point-source. Distribution patterns for copper and zinc indicate that there are two or more point-sources of these metals to the Arkansas River, one at the California Gulch in the Leadville mining district, and a second source near Salida. The data from the 2M HCl-H₂O₂ results for copper, lead, and zinc indicate that the metals are associated with the iron- and manganese-oxide mineral phase. The distribution patterns of these labile metals are very similar to those for the total-digestion data indicating that these metals in the river sediments are readily mobile in the riverine environment and may be available to the biological community.

Interpretation of the Lead-isotope Data

The lead data from the leaches and the total digestion of each of the samples (figs. 5 and 8) indicate that the bulk of the lead in the river-sediment samples comes from the iron- and manganese-oxide mineral coatings on the surface of fine-grained sediment. The lead-isotopic results used in this study are from the 2M HCl-H₂O₂ leachates (table A6). The lead-isotopic data are plotted in figures 12 and 13 as a function of distance from Climax and include the some previous lead-isotopic results from Church and others (1993). By applying lever rule calculations to the lead-isotopic data, (discussed below) we demonstrate that the bulk of the lead in the river sediments above Buena Vista is derived from the Leadville mining district.

Fundamental to the understanding of lead-isotopic data is the idea that the isotopic composition of lead in the earth's crust is variable. This is a direct result of the variation of the uranium/lead ratio in rocks that make up the earth's crust and their age. As discussed above, the isotopic composition of lead changes as a result of radioactive decay with time. This phenomenon explains the variable isotopic composition of lead from river sediments sampled upstream from Leadville, Colo. (figs. 12 and 13). Mineral deposits, however, have a relatively uniform lead-isotopic composition within a district, but often vary between districts. Plotted in figure 14 are published data from several mining districts within the Arkansas River basin study area. Numerous lead-isotope data from the Leadville mining district (Thompson and Beaty, 1990; Delevaux and others, 1966) are plotted. However, some mining districts are represented by only one or a few analyses. The variability of the lead-isotopic fingerprints of the various districts is demonstrated (fig. 14). Note in particular, that the isotopic composition of lead from the volcanogenic massive sulfide (VMS) deposits is markedly different from that of the Leadville mining district. These variations in lead-isotopic signature, coupled with the variation in concentration of ore metals contributed by tributaries to the sample sites selected along the Arkansas River, provide the chemical, lead-isotopic, and spatial distribution necessary to identify various point-sources of environmental contamination, which may be related to past mining activity or to weathering of undisturbed mineral deposits or mineralized areas.

Pb-isotope distribution profile Upper Arkansas River, CO

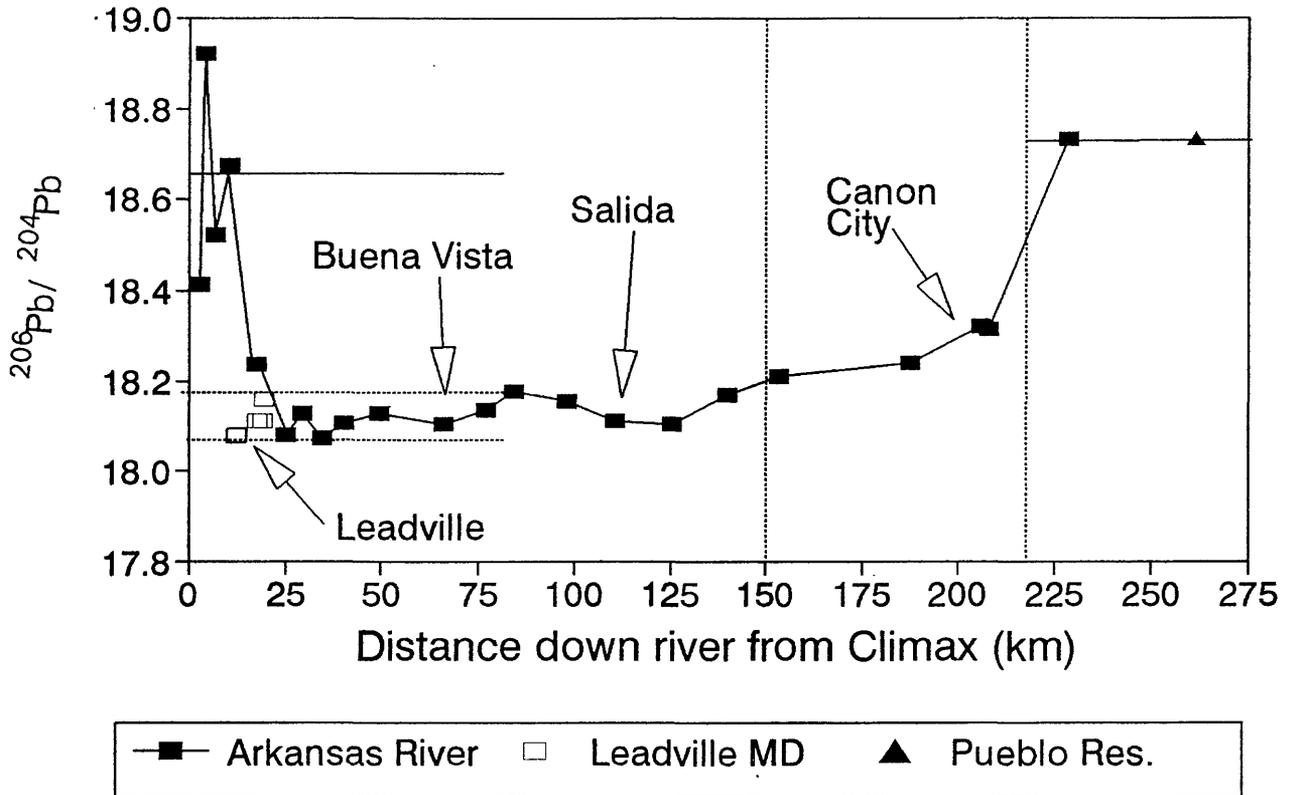


Figure 12. Lead-isotope data ($^{206}\text{Pb}/^{204}\text{Pb}$) for extractable lead in sediments from the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir (Pueblo Res.) are shown as a triangle (\blacktriangle); data from the Leadville mining district (Leadville MD) are shown as squares (\square ; Church and others, 1993). The crustal lead compositions used in the lever rule calculations (table 2) are shown as the solid horizontal lines from Leadville to Buena Vista and at Pueblo Reservoir.

Pb-isotope distribution profile Upper Arkansas River, CO

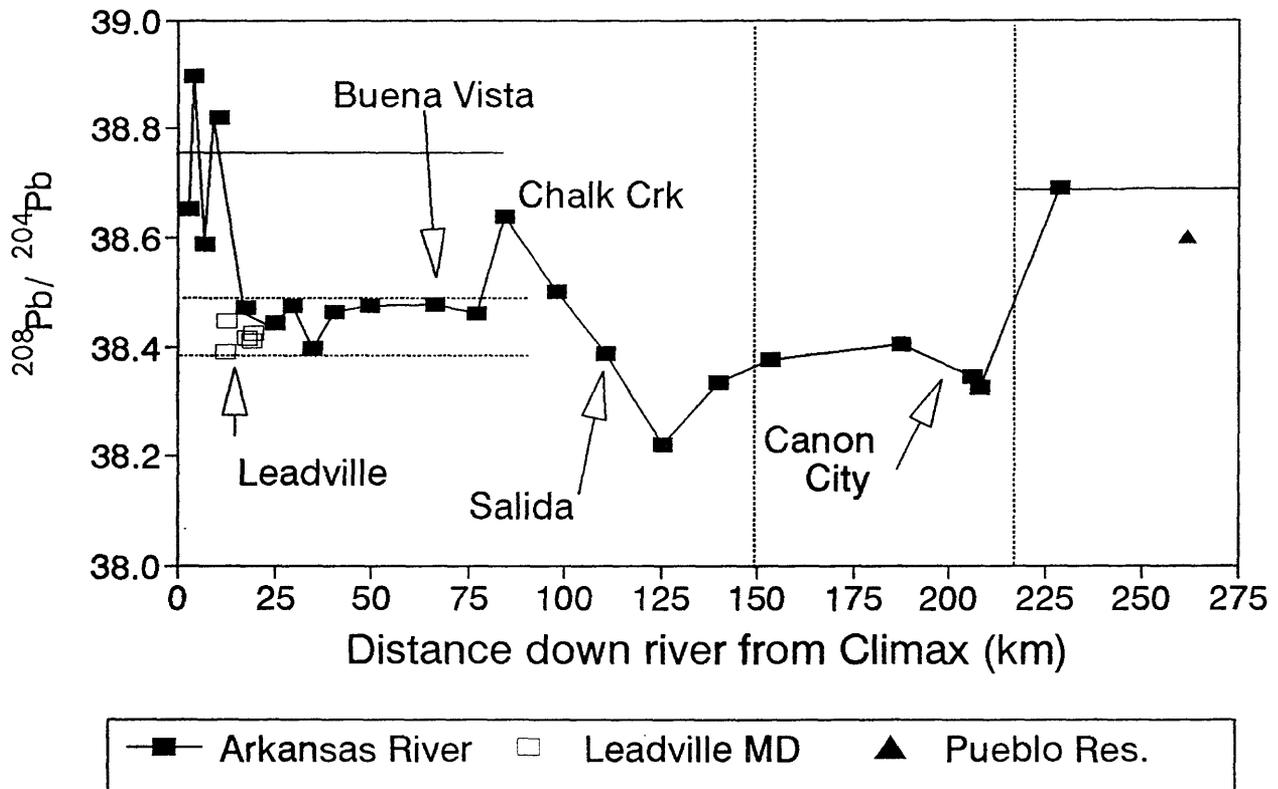


Figure 13. Lead-isotope data ($^{208}\text{Pb}/^{204}\text{Pb}$) for extractable lead in sediments from the Arkansas River plotted as a function of distance from Climax. Data from the lake-sediment core from Pueblo Reservoir (Pueblo Res.) are shown as a triangle (\blacktriangle); data from the Leadville mining district (Leadville MD) are shown as squares (\square ; Church and others, 1993). The crustal lead compositions used in the lever rule calculations (table 2) are shown as the solid horizontal lines from Leadville to Buena Vista and at Pueblo Reservoir.

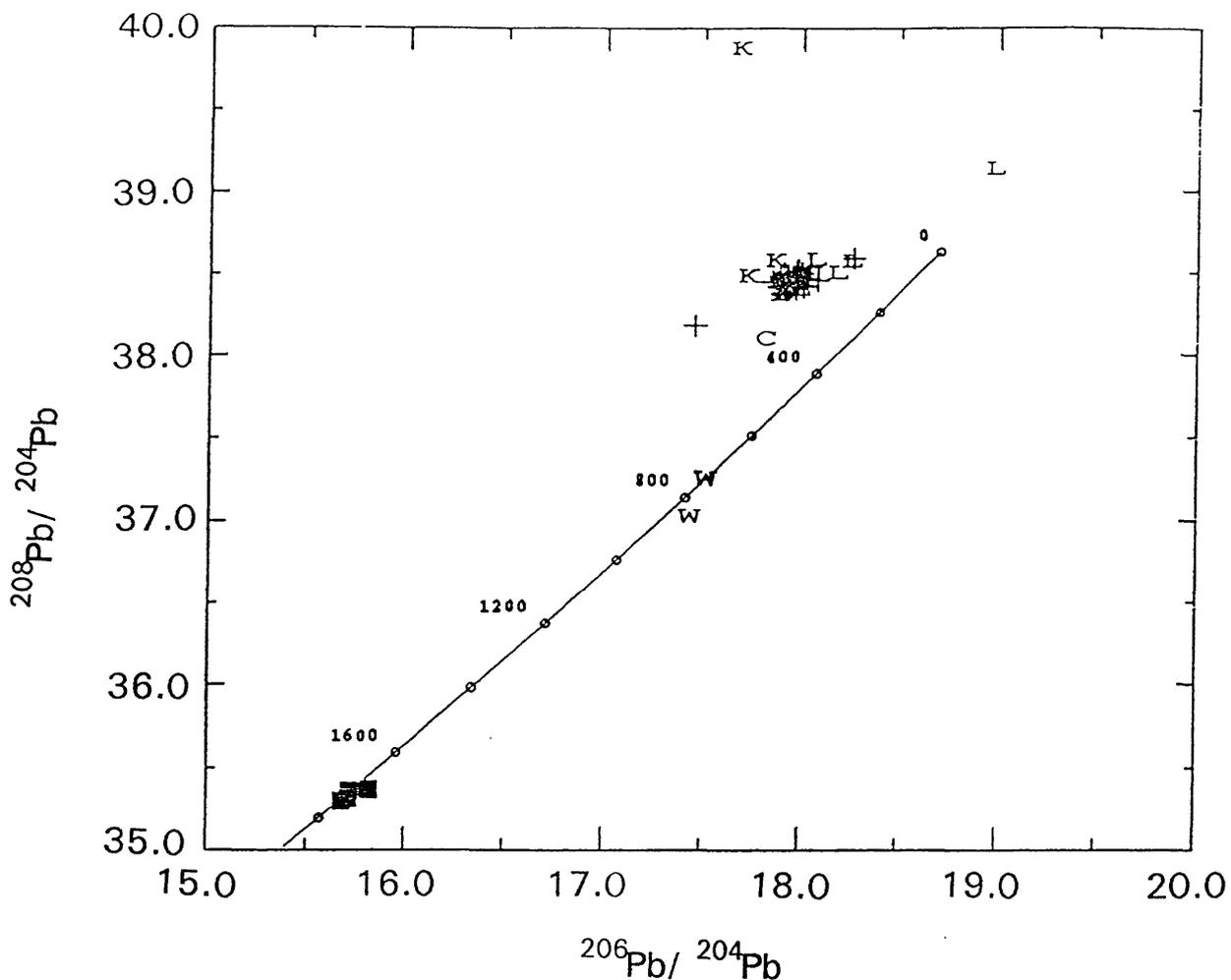


Figure 14. Lead-isotope diagram showing the variation of published lead-isotopic data from mining districts in the upper Arkansas River basin; data from Thompson and Beaty (1990) and Delevaux and others (1966). The data have been coded by district: (+) data from the Leadville mining district (Thompson and Beaty, 1990); (L) data from Leadville mining district; (C) data from the Chalk Creek district; data from the St. Kevin Gulch and Sugarloaf districts; (W) data from the Westcliff district; (■) data from the VMS deposits; (lead-isotope data reported in Delevaux and others, 1966; Church and others, 1993). Lead-isotope data from the two studies of the Leadville mining district plot in the same area on the plot demonstrating that there is no analytical variance between these two data sets following normalization to absolute values of the data from Delevaux and others (1966).

From the results of this study, we recognize at least four sources of zinc and three sources of lead that may be point-sources of elevated metal concentrations that may affect the biota in and along the Arkansas River. Copper, although elevated in concentration in the river sediments below Leadville, does not reach elevated crustal abundance levels in the Arkansas River sediments below the confluence of Twin Lakes Creek, Lake County, Colo. The Leadville mining district represents the major point-source of lead contribution to the river. Labile lead concentrations in river sediments exceed more than four times crustal abundance (52 ppm) in the Arkansas River from the confluence of Evans Gulch in the Leadville mining district to the Smelertown NPL site at Salida, Colo. As demonstrated by the change in the lead-isotopes in figure 13, Chalk Creek also contributes to the lead load in the sediments of the Arkansas River. Extractable lead concentrations do not drop below 52 ppm until the river course is downstream from Salida, Colo. (fig. 8). Elevated levels of extractable zinc (304 ppm) can be traced from the California Gulch in the Leadville mining district, from Chalk Creek, from the vicinity of Salida, Colo., and possibly from an unidentified source along the stretch of the Arkansas River above the Royal Gorge. Evidence for each of these sources is summarized below.

The isotopic composition of lead in the river sediments in the headwaters above Leadville is variable (figs. 12 and 13), reflecting the isotopic heterogeneity of the crust in the area (Church and others, 1993). In contrast, the isotopic composition of lead from sediments in tributaries draining California Gulch in the Leadville mining district show little variation. These lead-isotopic data lie within the range of the lead-isotopic results from the district studies of ore leads by Delevaux and others (1966) and Thompson and Beaty (1990) and represent the bulk lead-isotopic composition of the ore from the Leadville deposits. The marked increase in the concentration of lead, zinc, cadmium, and arsenic (table 1A) in the sediments of the Arkansas River within California Gulch immediately below the Leadville mining district are the result of the contribution of fluvial tailings sediments deposited from milling processes early in this century (Church and others, 1993). Note that the isotopic composition of lead in the river sediments matches that of the ores from the Leadville mining district until sediments having sufficient lead to change the bulk composition of the sediments in the Arkansas River are added near Chalk Creek (fig. 13). The isotopic composition of lead in the Arkansas River below Chalk Creek (site 94ARK104) is sufficiently different to indicate a new source of lead and zinc contamination apparently from this tributary.

Additional sources of zinc contamination can be isolated and fingerprinted using the lead-isotopic data. Along the stretch of the Arkansas River between sites 94ARK103-94ARK101 (that is above and below Salida), the isotopic composition of lead changes systematically and the concentration of labile zinc in the river sediments exceeds 500 ppm in this stretch of the Arkansas River. Note in figure 14 that the isotopic composition of lead from the 1,700 million year old VMS deposits is much less radiogenic than that of the ores from the Leadville or the Chalk Creek districts. The small, systematic change in lead-isotopic composition reflects addition of material probably from the VMS deposits in the vicinity of Salida rather than the Smelertown mill site because much of the VMS ore was not processed at Smelertown (Vanderwilt, 1947).

Below Salida (site 94ARK101), labile zinc concentrations are decoupled from lead (figs. 12 and 13). There are several possible explanations for this decoupling. One possible explanation for this decoupling is that the elevated concentrations of zinc are associated with the breakdown

of the zinc mineral gahnite (Zn_2AlO_4), a metamorphic mineral that does not contain lead and which is associated only with these VMS deposits. This mineral was concentrated but not processed during the mining of the VMS deposits. Erosion of tailings resulting from the mining of the VMS deposits or erosion of the deposits themselves would contribute gahnite to the sediment bed-load of the river. We have identified gahnite in the river sediments from site 94ARK203 where the labile zinc concentration reaches the maximum in this section of the Arkansas River using x-ray diffraction methods (written comun., S.J. Sutley, May 20, 1994). Further field studies are needed to identify possible sources of gahnite. A second possible explanation is that the zinc comes from very elevated zinc-rich ores from the VMS deposits. There are several VMS deposits in the area along this stretch of the river (see fig. 1). However, the decoupling of zinc from the lead-isotopic composition is difficult to rationalize because of the fine-grained nature of the ore. In fact, it was this fine-grained nature that made it difficult to process the ores and resulted in much of the production from the Sedalia mine being shipped to a paint plant in Cañon City rather than to the smelter at Salida.

Below Cañon City, the geology changes substantially and the area is underlain by sedimentary rocks of Mesozoic age (Tweto, 1979). These rocks erode at a much higher rate than the crystalline and metamorphic rocks upstream and as a direct result, the concentrations of many metals and the isotopic composition of lead changes at site 94ARK200 near Portland, Colo. The Mesozoic sedimentary rocks provide the bulk of the fine-grained sedimentary material being deposited in Pueblo Reservoir. The composite core sample from Pueblo Reservoir has an isotopic composition of lead very near that from the sample site at Portland (see figs. 12 and 13).

One of the powerful uses of lead isotopes in environmental geochemistry is the leverage they provide to calculate the contribution of each of the point-sources of metal contamination to the total metal load in the sediments of the Arkansas River. However, without additional data on the isotopic composition of lead in the sediments of the tributaries, we can not calculate the exact percentage of the ore-metals being contributed by each tributary to the metal load in the sediments of the Arkansas River. We can, however, calculate the contribution of sediments from the Leadville mining district to the sediment load of the Arkansas River if we assume the isotopic composition of lead in the Arkansas River above the Leadville mining district represents unmineralized rock within the upper Arkansas River basin. The lever rule calculation is shown in the following equation:

$$Pb_{PS} = \{ [R_{UMR} - R_{Sed}] / [R_{UMR} - R_{PS}] \} \times 100.$$

Where: Pb_{PS} is the percent of the lead load attributed to a specific point-source of lead contamination,
 R_{UMR} is the lead isotope ratio of the unmineralized rock,
 R_{Sed} is the lead isotope ratio of the river sediment at a particular site, and
 R_{PS} is the lead isotope ratio of the point-source of lead contamination.

We have used an average value of $^{206}\text{Pb}/^{204}\text{Pb} = 18.65$ and $^{208}\text{Pb}/^{204}\text{Pb} = 38.75$ for the labile lead isotopic composition of unmineralized rock, and an average value of $^{206}\text{Pb}/^{204}\text{Pb} = 18.10$ and $^{208}\text{Pb}/^{204}\text{Pb} = 38.45$ for the isotopic composition of lead in the vein and replacement deposits from the Leadville mining district. The error in this calculation is about ± 5 percent. On the basis of the lever rule calculations and the lead-isotopic data derived from this study, we can attribute ninety percent or more of the total lead load in the sediments of the Arkansas River between Leadville and the confluence of Chalk Creek below Buena Vista to mining activity in the Leadville mining district (table 2). However, at the confluence of Chalk Creek, the internal consistence of this point-source model is lost (see figs. 12 and 13), indicating that another point-source of lead has added metals to the river sediments and a new model is required to describe the lead load in the river sediments below the confluence of Chalk Creek. Further research is required to document the lead load and the isotopic composition of lead in the sediments of Chalk Creek.

Table 2. Calculated lead load in sediments of the upper Arkansas River from Leadville south to the confluence with Chalk Creek below Buena Vista, Colo.

Sample	Distance (km)	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	Percent from the Leadville mining district	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	Percent from the Leadville mining district
93LV121	24.9	18.08	104	38.44	102
93LV120	29.6	18.13	95	38.48	91
93LV119	34.8	18.07	105	38.40	120
94ARK108	40.3	18.11	99	38.46	95
94ARK107	49.3	18.14	94	38.46	91
94ARK106	66.4	18.11	99	38.48	90
94ARK105	77.2	18.14	94	38.46	96
Chalk Creek confluence					
94ARK104	84.1	18.17	87	38.64	36

Summary and Conclusions

Lead-isotopic data, coupled with both trace-element distribution profiles and the spatial distribution of mining districts in the upper Arkansas River basin demonstrate that contamination in the fine-grained sediment of the Arkansas River can be directly tied to mining activity at Leadville. More than ninety percent of the lead and zinc in the stretch of the Arkansas River between Leadville and the confluence of Chalk Creek below Buena Vista are the direct result of contamination from the Leadville mining district. Arsenic and cadmium concentrations are also elevated in this stretch of the Arkansas River. Although Leadville is a source of copper contamination, the concentration of copper in the sediments of the Arkansas River does not exceed crustal abundance below Twin Lakes Creek.

Additional contributions of lead and zinc are added to the metal load of the Arkansas River by the sediments from Chalk Creek; further work on the sediments in the Chalk Creek tributary is needed to quantify the metal load in the sediments of this tributary and to calculate the percentage of the metal it contributes to the Arkansas River.

Two additional sources of zinc contamination are also indicated by the lead-isotope data. Both are associated with the Precambrian VMS deposits near Salida, Colo. One source of zinc and lead is above the town of Salida and may be directly associated with the Sedalia mine. Another unidentified source of zinc contamination is indicated by the elevated zinc concentrations below Salida. Further work is required to identify the sources of these metals.

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Table A1. Analytical data from total digestions of stream-sediment samples, Arkansas River basin, Colo.

Sample Number	Latitude	Longitude	Distance Al-pct. (in km)	Al-pct.	Ca-pct.	Fe-pct.	K-pct.	Mg-pct.	Na-pct.	P-pct.	Ti-pct.
93LV121	39° 10' 7"	106° 19' 26"	24.9	5.1	0.78	10.0	1.9	0.53	0.89	0.18	0.48
93LV120	39° 7' 23"	106° 18' 41"	29.6	5.7	0.81	4.0	2.4	0.42	1.3	0.14	0.24
93LV119	39° 4' 46"	106° 16' 53"	34.8	5.6	0.81	5.1	2.3	0.46	1.2	0.14	0.28
94ARK108	39° 2' 15"	106° 15' 40"	40.3	5.3	1.2	13.0	1.9	0.41	1.4	0.21	1.3
94ARK107	38° 58' 42"	106° 12' 47"	49.3	6.1	1.4	7.8	2.1	0.46	1.6	0.21	0.78
94ARK106	38° 51' 2"	106° 7' 25"	66.4	5.6	1.5	12.0	2.0	0.51	1.5	0.24	0.99
94ARK105	38° 45' 58"	106° 5' 37"	77.2	6.0	1.7	8.5	2.1	0.51	1.8	0.23	0.82
94ARK104	38° 43' 3"	106° 3' 20"	84.1	3.7	1.5	29.0	1.3	0.44	1.1	0.26	1.4
94ARK103	38° 36' 25"	106° 3' 45"	97.9	5.6	1.6	16.0	2.1	0.58	1.7	0.18	0.94
94ARK102	38° 32' 40"	106° 0' 20"	110.6	6.0	1.9	11.0	2.3	0.58	1.9	0.19	0.78
94ARK101D	38° 28' 33"	105° 53' 2"	110.6	6.9	2.4	6.6	2.3	0.84	2.0	0.13	0.57
94ARK101	38° 28' 33"	105° 53' 2"	125.4	6.8	2.4	6.9	2.3	0.85	2.0	0.14	0.57
94ARK205	38° 24' 16"	105° 46' 50"	139.9	6.3	2.2	8.3	2.3	0.95	1.9	0.14	0.67
94ARK204	38° 22' 19"	105° 40' 23"	153.4	6.6	2.5	5.9	2.3	0.99	2.0	0.15	0.54
94ARK203	38° 29' 5"	105° 22' 23"	187.4	6.5	2.6	5.1	2.3	1.1	1.8	0.15	0.49
94ARK202	38° 26' 16"	105° 12' 16"	205.8	6.8	2.9	3.8	2.5	0.97	2.1	0.14	0.41
94ARK201D	38° 25' 33"	105° 11' 10"	208.1	6.3	3.1	4.3	2.3	1.0	1.7	0.14	0.44
94ARK201	38° 25' 33"	105° 11' 10"	208.1	6.4	3.3	4.3	2.3	1.0	1.7	0.15	0.44
94ARK200	38° 23' 20"	105° 0' 56"	228.8	6.0	2.7	3.1	2.2	0.88	1.4	0.09	0.26
94PUBCOR	38° 16' 2"	104° 43' 52"	261.4	7.8	7.2	3.1	2.1	1.2	0.34	0.10	0.34
SRM 2704				6.0	2.6	4.0	1.9	1.2	0.61	0.10	0.25
SRM 2711				6.4	2.9	2.8	2.3	1.0	1.2	0.09	0.26

Table A1. Analytical data from total digestions of stream-sediment samples, Arkansas River basin, Colo.--continued

Sample Number	Mn-ppm	Ag-ppm	As-ppm	Ba-ppm	Be-ppm	Cd-ppm	Ce-ppm	Co-ppm	Cr-ppm	Cu-ppm	Eu-ppm	Ga-ppm	La-ppm
93LV121	2200	11	130	340	1	27	460	11	76	150	< 2	12	240
93LV120	630	2	43	770	2	9	210	5	37	56	< 2	12	100
93LV119	1400	5	52	500	2	16	210	8	44	63	< 2	13	110
94ARK108	1900	< 2	18	640	2	3	380	14	98	39	3	19	190
94ARK107	1700	< 2	22	690	2	5	340	12	64	43	2	17	180
94ARK106	2100	< 2	14	660	2	3	490	15	110	34	3	19	250
94ARK105	1200	< 2	< 10	660	2	2	300	12	64	26	2	17	160
94ARK104	1700	< 2	< 10	400	2	< 2	900	27	150	32	5	28	460
94ARK103	1500	< 2	< 10	660	2	< 2	390	19	92	24	3	19	200
94ARK102	960	< 2	< 10	720	2	< 2	310	15	66	19	3	17	160
94ARK101D	860	< 2	< 10	820	2	< 2	170	14	58	21	< 2	17	92
94ARK101	880	< 2	< 10	810	2	< 2	190	14	62	21	< 2	17	100
94ARK205	1200	< 2	< 10	810	2	< 2	190	17	64	28	< 2	17	100
94ARK204	980	< 2	< 10	810	2	< 2	160	14	51	28	< 2	17	84
94ARK203	1200	< 2	< 10	770	2	3	150	14	50	31	< 2	16	80
94ARK202	850	< 2	< 10	820	2	< 2	120	12	43	25	< 2	16	64
94ARK201D	890	< 2	< 10	790	2	< 2	120	13	48	30	< 2	16	62
94ARK201	910	< 2	< 10	790	2	2	120	14	48	34	< 2	15	65
94ARK200	540	< 2	11	750	2	< 2	78	11	39	23	< 2	14	41
94PUBCOR	660	< 2	11	460	3	2	75	11	68	31	< 2	23	40
SRM 2704	550	< 2	20	400	2	3	60	15	140	90	< 2	14	31
SRM 2711	630	3	92	700	2	35	71	12	44	110	< 2	14	40

Table A1. Analytical data from total digestions of stream-sediment samples, Arkansas River basin, Colo.--continued

Sample Number	Li-ppm	Mo-ppm	Nb-ppm	Nd-ppm	Ni-ppm	Pb-ppm	Sc-ppm	Sr-ppm	Th-ppm	V-ppm	Y-ppm	Yb-ppm	Zn-ppm
93LV121	17	3	21	210	12	1400	20	140	110	94	77	7	3500
93LV120	18	< 2	15	93	7	610	10	180	44	42	38	3	1500
93LV119	18	< 2	14	96	10	770	12	170	44	54	40	4	2800
94ARK108	14	< 2	36	170	13	330	14	220	72	280	61	5	1100
94ARK107	16	< 2	27	160	12	340	13	250	61	140	59	5	1500
94ARK106	14	< 2	32	220	15	260	14	240	100	240	70	6	1200
94ARK105	14	< 2	28	140	12	180	12	270	52	170	56	5	900
94ARK104	11	< 2	44	420	23	110	16	180	220	690	100	8	540
94ARK103	16	< 2	36	180	16	110	12	240	92	360	61	5	650
94ARK102	15	< 2	32	140	15	82	11	290	64	250	58	5	480
94ARK101D	21	< 2	24	79	19	56	10	420	36	150	36	3	380
94ARK101	20	< 2	25	84	18	55	10	420	38	160	37	3	380
94ARK205	20	< 2	29	89	18	65	12	290	34	190	40	4	570
94ARK204	22	< 2	27	78	17	56	12	300	26	140	42	4	600
94ARK203	24	< 2	24	66	18	62	11	280	23	110	38	4	840
94ARK202	21	< 2	20	55	17	47	11	310	17	86	33	3	500
94ARK201D	24	< 2	20	51	19	50	11	290	18	98	33	3	540
94ARK201	25	< 2	20	54	19	53	11	300	17	97	34	3	560
94ARK200	26	< 2	12	36	21	30	8	270	12	88	21	2	210
94PUBCOR	48	6	10	31	35	37	12	330	12	190	23	2	180
SRM 2704	47	2	10	27	43	140	11	130	9	91	21	2	420
SRM 2711	26	< 2	19	30	20	960	9	250	14	80	25	2	330

Table A2. Analytical data from HCl-H₂O₂ leaches of stream-sediment samples from the Arkansas River basin, Colo.

Sample Number	Latitude	Longitude	Distance (in km)	Al-pct.	Ca-pct.	Fe-pct.	Mg-pct.	K-pct.	Na-pct.	Mn-ppm	Ag-ppm
93LV121	39° 10' 7"	106° 19' 26"	24.9	0.21	0.27	2.50	0.11	0.07	0.001	1100	6.0
93LV120	39° 7' 23"	106° 18' 41"	29.6	0.18	0.41	1.20	0.12	0.05	0.001	240	1.8
93LV119	39° 4' 46"	106° 16' 53"	34.8	0.20	0.30	1.00	0.12	0.05	0.003	770	3.6
94ARK108	39° 2' 15"	106° 15' 40"	40.3	0.31	0.51	1.10	0.16	0.10	0.002	840	1.2
94ARK107	38° 58' 42"	106° 12' 47"	49.3	0.37	0.46	1.30	0.17	0.11	0.002	1000	1.2
94ARK106	38° 51' 2"	106° 7' 25"	66.4	0.36	0.55	1.20	0.19	0.13	0.003	1300	0.6
94ARK105	38° 45' 58"	106° 5' 37"	77.2	0.31	0.52	0.94	0.19	0.11	0.003	490	0.4
94ARK104	38° 43' 3"	106° 3' 20"	84.1	0.28	0.63	0.81	0.16	0.07	0.002	440	0.4
94ARK103	38° 36' 25"	106° 3' 45"	97.9	0.32	0.50	0.78	0.21	0.10	0.002	580	<0.4
94ARK102	38° 32' 40"	106° 0' 20"	110.6	0.20	0.44	0.47	0.15	0.05	0.001	190	<0.4
94ARK101D	38° 28' 33"	105° 53' 2"	125.4	0.30	0.86	0.57	0.27	0.09	0.004	350	<0.4
94ARK101	38° 28' 33"	105° 53' 2"	125.4	0.31	0.87	0.61	0.27	0.09	0.005	370	<0.4
94ARK205	38° 24' 16"	105° 46' 50"	139.9	0.36	1.06	0.69	0.32	0.10	0.007	550	<0.4
94ARK204	38° 22' 19"	105° 40' 23"	153.4	0.36	1.30	0.71	0.32	0.09	0.005	430	<0.4
94ARK203	38° 29' 5"	105° 22' 23"	187.4	0.41	1.40	0.79	0.36	0.11	0.007	710	<0.4
94ARK202	38° 26' 16"	105° 12' 16"	205.8	0.35	1.50	0.73	0.32	0.11	0.007	430	<0.4
94ARK201D	38° 25' 33"	105° 11' 10"	208.1	0.41	1.90	0.84	0.37	0.12	0.009	450	<0.4
94ARK201	38° 25' 33"	105° 11' 10"	208.1	0.41	1.90	0.85	0.37	0.12	0.009	460	<0.4
94ARK200	38° 23' 20"	105° 0' 56"	228.8	0.28	1.30	0.82	0.31	0.06	0.005	350	<0.4
94PUBCOR	38° 16' 2"	104° 43' 52"	261.4	0.36	5.70	0.94	0.26	0.08	0.014	490	<0.4
SRM 2404				0.73	2.56	2.12	0.79	0.03	0.00	459	<0.4
SRM 2711				0.74	2.26	0.86	0.53	0.24	0.01	498	3.0

Table A2. Analytical data from HCl-H₂O₂ leaches of stream-sediment samples from the Arkansas River basin, Colo.--continued.

Sample Number	As-ppm	Ba-ppm	Be-ppm	Bi-ppm	Ce-ppm	Cd-ppm	Co-ppm	Cr-ppm	Cu-ppm	La-ppm	Li-ppm
93LV121	42	36	0.4	1.8	12	12	4	6	72	6	3
93LV120	18	65	0.2	1.8	18	3.0	2	4	35	6	2
93LV119	12	71	0.3	<1.0	11	12	4	5	36	6	3
94ARK108	6	90	0.3	1.2	30	3.6	4	6	30	12	4
94ARK107	6	90	0.3	1.8	24	4.2	5	6	36	12	5
94ARK106	5	91	0.3	<1.0	36	4.3	5	6	24	18	5
94ARK105	4	59	0.2	<1.0	30	2.4	4	5	18	18	5
94ARK104	2	48	0.2	3.6	42	1.8	4	5	18	18	4
94ARK103	2	64	0.2	<1.0	35	1.7	3	5	12	17	5
94ARK102	1	36	0.1	<1.0	24	1.2	2	3	6	12	3
94ARK101D	<1	67	0.3	<1.0	30	1.2	4	5	12	18	5
94ARK101	<1	67	0.3	<1.0	30	1.2	4	5	12	18	5
94ARK205	1	85	0.3	<1.0	40	1.7	4	6	17	17	6
94ARK204	1	79	0.4	<1.0	37	2.4	4	6	18	18	6
94ARK203	<1	100	0.4	<1.0	41	3.5	5	6	24	18	6
94ARK202	<1	78	0.3	<1.0	30	1.8	4	6	18	18	6
94ARK201D	1	92	0.4	<1.0	34	2.3	5	6	23	17	6
94ARK201	1	92	0.4	<1.0	37	2.4	5	6	24	18	6
94ARK200	2	81	0.2	<1.0	17	0.6	5	4	12	6	6
94PUBCOR	3	150	0.5	<1.0	27	1.3	7	4	19	13	4
SRM 2704	13	89	0.4	<1.0	15	3.0	10	89	104	7	15
SRM 2711	75	196	0.8	<1.0	30	45	8	9	91	15	8

Table A2. Analytical data from HCl-H₂O₂ leaches of stream-sediment samples from the Arkansas River basin, Colo.--continued

Sample Number	Mo-ppm	Ni-ppm	P-ppm	Pb-ppm	Sn-ppm	Sr-ppm	Ti-ppm	V-ppm	Y-ppm	Zn-ppm	Th-ppm
93LV121	1.8	4	960	960	6	12	120	12	6	1100	3
93LV120	1.2	2	1500	560	2	12	83	12	12	500	3
93LV119	0.5	4	890	580	2	6	100	6	6	1300	1
94ARK108	0.6	5	2200	340	2	12	210	12	24	840	4
94ARK107	1.8	5	2000	330	2	12	260	12	18	1100	4
94ARK106	1.2	6	2400	260	2	12	280	12	24	970	6
94ARK105	<0.5	4	2200	160	2	12	230	12	18	590	5
94ARK104	<0.5	3	2800	110	1	12	170	12	18	470	42
94ARK103	<0.5	4	1800	87	1	17	220	12	12	500	12
94ARK102	<0.5	2	1500	55	3	12	110	6	12	260	12
94ARK101D	<0.5	4	1300	36	1	24	130	12	12	300	3
94ARK101	<0.5	4	1300	49	1	24	150	12	12	330	4
94ARK205	<0.5	5	1400	51	1	34	130	11	11	460	3
94ARK204	<0.5	5	1500	49	1	37	130	12	12	490	2
94ARK203	<0.5	6	1400	53	4	47	120	12	12	710	1
94ARK202	<0.5	5	1300	36	1	48	170	12	12	390	2
94ARK201D	<0.5	6	1300	40	1	69	160	11	11	430	1
94ARK201	<0.5	6	1300	37	1	67	170	12	12	430	1
94ARK200	<0.5	6	540	12	<1	64	40	12	6	120	1
94PUBCOR	0.5	16	600	29	<1	220	<6	18	13	110	1
SRM 2704	1.2	30	930	150	9	30	44	13	10	390	<1
SRM 2711	<0.5	12	740	1100	2	45	320	15	14	260	<1

Table A3. Analytical data from total digestions of residues from stream-sediment samples, Arkansas River basin, Colo.

Sample	Latitude	Longitude	Distance (in km)	Al-pct.	Ca-pct.	Fe-pct.	K-pct.	Mg-pct.	Na-pct.	P-pct.	Ti-pct.
93LV119	39° 4' 46"	106° 16' 53"	34.8	5.9	0.9	6.1	2.3	0.50	1.2	0.16	0.35
94ARK108	39° 2' 15"	106° 15' 40"	40.3	5.4	0.9	14.0	1.8	0.28	1.5	0.03	1.5
94ARK107	38° 58' 42"	106° 12' 7"	49.3	6.3	1.1	7.7	2.0	0.30	1.8	0.03	0.86
94ARK106	38° 51' 2"	106° 7' 2"	66.4	5.6	1.1	13.9	1.8	0.34	1.7	0.03	1.2
94ARK105	38° 45' 58"	106° 5' 37"	77.2	6.5	1.4	6.3	2.3	0.32	2.1	0.02	0.71
94ARK104	38° 43' 3"	106° 3' 20"	84.1	3.2	1.2	34.0	1.0	0.28	1.0	0.05	1.6
94ARK103	38° 36' 25"	106° 3' 45"	97.9	5.1	1.3	20.3	1.9	0.33	1.7	0.02	1.1
94ARK102	38° 32' 40"	106° 0' 20"	110.6	6.2	1.5	10.5	2.4	0.39	2.1	0.02	0.82
94ARK101D	38° 28' 33"	105° 53' 2"	125.4	7.4	1.9	6.8	2.4	0.61	2.4	0.02	0.61
94ARK101	38° 28' 33"	105° 53' 2"	125.4	7.5	1.9	5.9	2.5	0.62	2.4	0.01	0.55
94ARK205	38° 24' 16"	105° 46' 50"	139.9	6.9	1.5	8.5	2.4	0.69	2.2	0.02	0.70
94ARK204	38° 22' 19"	105° 40' 23"	153.4	7.1	1.6	7.8	2.5	0.73	2.3	0.02	0.72
94ARK203	38° 29' 5"	105° 22' 23"	187.4	7.2	1.4	5.8	2.5	0.81	2.1	0.03	0.59
94ARK202	38° 26' 16"	105° 12' 16"	205.8	7.3	1.6	3.6	2.7	0.69	2.4	0.02	0.45
94ARK201	38° 25' 33"	105° 11' 10"	208.1	7.1	1.4	4.5	2.7	0.68	2.2	0.02	0.51
94ARK201D	38° 25' 33"	105° 11' 10"	208.1	7.2	1.3	3.8	2.7	0.72	2.1	0.02	0.47
94ARK200	38° 23' 20"	105° 0' 56"	228.8	6.8	0.8	2.1	2.6	0.46	1.8	0.02	0.30
94PUBCOR	38° 16' 2"	104° 43' 52"	261.4	10.0	0.9	3.6	2.8	1.10	1.0	0.05	0.50
SRM 2704				7.5	0.3	2.7	2.5	0.7	0.8	0.04	0.40
SRM 2711				6.2	0.6	4.1	2.5	0.3	1.5	0.03	0.40

Table A3. Analytical data from total digestions of residues from stream-sediment samples, Arkansas River basin, Colo.--continued

Sample	Mn-ppm	Ag-ppm	As-ppm	Ba-ppm	Be-ppm	Cd-ppm	Ce-ppm	Co-ppm	Cr-ppm	Cu-ppm	Eu-ppm	Ga-ppm	La-ppm
93LV119	1500	5	59	770	2.2	16	260	8	53	76	<2	14	140
94ARK108	1400	<2	13	600	2.2	<2	370	12	110	13	2	21	180
94ARK107	820	<2	11	690	2.1	<2	260	6	67	17	<2	17	140
94ARK106	1300	<2	15	590	2.1	<2	400	12	130	16	2	19	200
94ARK105	620	<2	<10	730	2.1	<2	220	7	51	18	<2	16	120
94ARK104	1500	<2	<10	320	1.1	<2	890	28	190	18	5	30	460
94ARK103	1000	<2	<10	580	2.1	<2	300	18	120	12	2	21	150
94ARK102	750	<2	<10	740	2.1	<2	240	12	64	14	2	18	130
94ARK101D	590	<2	<10	860	2.2	<2	160	10	63	11	<2	17	85
94ARK101	550	<2	<10	870	2.1	<2	120	10	56	11	<2	18	64
94ARK205	750	<2	<10	860	2.2	<2	150	12	64	12	<2	18	81
94ARK204	790	<2	<10	840	2.2	<2	160	11	60	14	<2	16	86
94ARK203	600	<2	<10	810	2.2	<2	120	10	53	12	<2	18	67
94ARK202	480	<2	<10	890	2.2	<2	95	9	42	11	<2	17	49
94ARK201	510	<2	<10	890	2.2	<2	98	9	48	7	<2	17	51
94ARK201D	470	<2	<10	850	2.2	<2	88	8	45	16	<2	18	46
94ARK200	210	<2	<10	850	2.3	<2	56	5	36	8	<2	15	30
94PUBCOR	280	<2	<10	660	2.4	<2	67	9	80	21	<2	24	40
SRM 2704	210	<2	<10	470	2.4	<2	60	7	90	18	<2	18	33
SRM 2711	580	2.3	44	810	1.1	4.5	180	3	42	14	<2	14	94

Table A3. Analytical data from total digestions of residues from stream-sediment samples, Arkansas River basin, Colo.--continued

Sample	Li-ppm	Mo-ppm	Nb-ppm	Nd-ppm	Ni-ppm	Pb-ppm	Sc-ppm	Sr-ppm	Th-ppm	V-ppm	Y-ppm	Yb-ppm	Zn-ppm
93LV119	19	<2	17	120	11	860	14	170	58	65	50	5	2900
94ARK108	10	<2	45	160	11	62	15	230	69	320	53	5	390
94ARK107	12	<2	31	120	7	52	13	280	47	160	40	4	400
94ARK106	10	<2	36	170	12	55	16	250	87	290	56	5	330
94ARK105	11	<2	30	100	7	42	11	300	38	130	36	3	340
94ARK104	5	<2	47	410	22	22	17	160	210	830	100	8	200
94ARK103	10	<2	41	140	16	22	12	240	53	470	51	5	150
94ARK102	12	<2	34	110	12	22	11	300	41	250	45	4	130
94ARK101D	15	<2	27	72	15	18	11	450	24	160	31	3	71
94ARK101	16	<2	26	55	15	18	10	460	19	150	27	3	74
94ARK205	16	<2	29	67	15	17	12	310	29	210	29	3	130
94ARK204	15	<2	31	78	14	17	13	310	30	190	38	4	140
94ARK203	20	<2	30	57	15	18	14	290	29	140	32	3	170
94ARK202	16	<2	23	41	12	18	11	310	21	87	24	3	87
94ARK201	17	<2	24	45	12	17	12	290	20	110	26	3	79
94ARK201D	20	<2	26	40	13	18	12	290	17	94	22	3	96
94ARK200	19	<2	15	24	10	15	8	240	15	79	12	1	46
94PUBCOR	50	4	29	27	24	18	17	180	20	200	17	2	120
SRM 2704	45	<2	16	27	24	17	16	150	11	120	16	2	90
SRM 2711	13	<2	15	82	5	100	14	190	38	49	38	5	1000

Table A4. ICP-AES elements and their limits of determination

[Values given for the total digestion procedure are limits in the sample; values given for the HCl-H₂O₂ leach procedure are limits in the solution analyzed. These values have been multiplied by the dilution factor of the sample to arrive at the limits of determination used in table A2.]

Element	Chemical Symbol	Total Digestion Procedure	HCl-H ₂ O ₂ Leach Procedure
aluminum	Al	.005 pct.	1 ppm
calcium	Ca	.005 pct.	1 ppm
iron	Fe	.005 pct.	1 ppm
potassium	K	.01 pct.	1 ppm
magnesium	Mg	.005 pct.	1 ppm
sodium	Na	.005 pct.	1 ppm
phosphorous	P	.005 pct.	1 ppm
silicon	Si	--	1 ppm
titanium	Ti	.005 pct.	1 ppm
silver	Ag	2 ppm	0.04 ppm
arsenic	As	10 ppm	.2 ppm
gold	Au	8 ppm	--
barium	Ba	1 ppm	.02 ppm
beryllium	Be	1 ppm	.02 ppm
bismuth	Bi	10 ppm	.2 ppm
cadmium	Cd	2 ppm	.04 ppm
cerium	Ce	4 ppm	--
cobalt	Co	1 ppm	.02 ppm
chromium	Cr	1 ppm	.02 ppm
copper	Cu	1 ppm	.02 ppm
europium	Eu	2 ppm	--
gallium	Ga	4 ppm	--
lanthanum	La	2 ppm	--
lithium	Li	2 ppm	.04 ppm
manganese	Mn	4 ppm	.04 ppm
molybdenum	Mo	2 ppm	.04 ppm
niobium	Nb	4 ppm	--
neodymium	Nd	4 ppm	--
nickel	Ni	2 ppm	.04 ppm
lead	Pb	4 ppm	.08 ppm
scandium	Sc	2 ppm	--
tin	Sn	5 ppm	.1 ppm
strontium	Sr	2 ppm	.04 ppm
thorium	Th	4 ppm	--
vanadium	V	2 ppm	.04 ppm
yttrium	Y	2 ppm	--
ytterbium	Yb	1 ppm	--
zinc	Zn	2 ppm	.02 ppm

Table A5. Comparison of NIST certified values with USGS observed results for NIST standard reference materials SRM 2704 and 2711

Element	SRM 2704			Element	SRM 2711		
	USGS conc	NIST value	NIST C.I. ¹		USGS conc.	NIST value	NIST C.I. ¹
Al %	6.0	6.11	0.16	Al %	6.4	6.53	0.09
Ca %	2.6	2.60	0.03	Ca %	2.9	2.88	0.08
Fe %	4.0	4.11	0.1	Fe %	2.8	2.89	0.06
K %	1.9	2.00	0.04	K %	2.3	2.45	0.08
Mg %	1.2	1.20	0.02	Mg %	1.0	1.05	0.03
Na %	0.61	0.55	0.014	Na %	1.2	1.14	0.03
P %	0.10	0.0998	0.0028	P %	0.09	0.086	0.007
Ti %	0.25	0.457	0.018	Ti %	0.26	0.306	0.023
Ag, ppm	<2			Ag, ppm	3	4.63	0.39
As, ppm	20	23.4	0.8	As, ppm	92	105	8
Ba, ppm	400	414	12	Ba, ppm	700	726	38
Be, ppm	2			Be, ppm	2		
Cd, ppm	3	3.45	0.22	Cd, ppm	35	41.7	0.25
Ce, ppm	60	72		Ce, ppm	71	69	
Co, ppm	15	14	0.6	Co, ppm	12	10	
Cr, ppm	140	135	5	Cr, ppm	44	47	
Cu, ppm	90	98.6	5	Cu, ppm	110	114	2
Eu, ppm	<2	1.3		Eu, ppm	<2	1.1	
Ga, ppm	14	15		Ga, ppm	14	15	
La, ppm	31	29		La, ppm	40	40	
Li, ppm	47	50		Li, ppm	26		
Mn, ppm	550	555	19	Mn, ppm	630	638	28
Nb, ppm	10			Nb, ppm	19		
Nd, ppm	27			Nd, ppm	30	31	
Ni, ppm	43	44.1	3	Ni, ppm	20	20.6	1.1
Pb, ppm	140	161	17	Pb, ppm	960	1162	31
Sc, ppm	11	12		Sc, ppm	9	9	
Sn, ppm	23	9.5		Sn, ppm	<5		
Sr, ppm	130	130		Sr, ppm	250	245.3	0.7
Th, ppm	9	9.2		Th, ppm	14	14	
V, ppm	91	95	4	V, ppm	80	81.6	2.9
Y, ppm	21			Y, ppm	25	25	
Yb, ppm	2	2.8		Yb, ppm	2	2.7	
Zn, ppm	420	438	12	Zn, ppm	330	350.4	4.8

1. ±95% confidence interval

Table A6. Lead-isotope data from HCl-H₂O₂ leaches of river- and lake-sediment samples from the upper Arkansas River basin, Colo.

Sample Number	Latitude	Longitude	County	Distance (km)	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$
93LV121	39° 10' 7"	106° 19' 26"	Lake	24.9	18.080	15.569	38.444
93LV120	39° 7' 23"	106° 18' 41"	Lake	29.6	18.127	15.573	38.476
93LV119	39° 4' 46"	106° 1' 53"	Lake	34.8	18.072	15.552	38.397
94ARK108	39° 2' 15"	106° 15' 40"	Chaffee	40.3	18.107	15.572	38.464
94ARK107	38° 58' 42"	106° 12' 47"	Chaffee	49.3	18.126	15.577	38.477
94ARK106	38° 51' 2"	106° 7' 25"	Chaffee	66.4	18.105	15.571	38.480
94ARK105	38° 45' 58"	106° 5' 37"	Chaffee	77.2	18.135	15.564	38.463
94ARK104	38° 43' 3"	106° 3' 20"	Chaffee	84.1	18.173	15.606	38.641
94ARK103	38° 36' 25"	106° 3' 45"	Chaffee	97.9	18.154	15.579	38.501
94ARK102	38° 32' 40"	106° 0' 20"	Chaffee	110.6	18.109	15.560	38.388
94ARK101	38° 28' 33"	105° 53' 2"	Chaffee	125.4	18.089	15.554	38.224
94ARK101D	38° 28' 33"	105° 53' 2"	Chaffee	125.4	18.120	15.558	38.215
94ARK101B	38° 28' 33"	105° 53' 2"	Chaffee	125.4	18.084	15.581	38.356
94ARK205	38° 24' 16"	105° 46' 50"	Fremont	139.9	18.167	15.574	38.336
94ARK204	38° 22' 19"	105° 40' 23"	Fremont	153.4	18.209	15.583	38.378
94ARK203	38° 29' 5"	105° 22' 23"	Fremont	187.4	18.240	15.592	38.405
94ARK202	38° 26' 16"	105° 12' 16"	Fremont	205.8	18.321	15.572	38.347
94ARK201	38° 25' 33"	105° 11' 10"	Fremont	208.1	18.327	15.575	38.341
94ARK201D	38° 25' 33"	105° 11' 10"	Fremont	208.1	18.303	15.567	38.313
94ARK201B	38° 25' 33"	105° 11' 10"	Fremont	208.1	18.373	15.578	38.354
94ARK200	38° 23' 20"	105° 0' 56"	Fremont	228.8	18.732	15.609	38.692
94PUBCOR	38° 16' 2"	104° 43' 52"	Pueblo	261.4	18.729	15.605	38.600
SRM2704					18.747	15.637	38.431
SRM2711					17.122	15.467	37.041