U.S. DEPARTMENT OF INTERIOR

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Geochemical and lead-isotopic studies of stream and river sediments, Alamosa River basin, Colorado

by

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EXECUTIVE SUMMARY

Studies of a suite of stream- and river-sediment samples collected from selected sites in the Alamosa River basin in 1976 and 1994 were undertaken to determine the geochemical baseline prior to and following open-pit mining at Summitville. Leaching experiments were conducted on the minus-100-mesh fraction to determine the mineralogical sites of residence for ore metals. In addition, the isotopic composition of lead was analyzed on all samples from the 2M $HCl-H_2O_2$ leachate solution to document the changes in isotopic character of the hydrous iron- and manganese-oxide mineral phases which carry the bulk of the ore metals. These studies demonstrate the following:

- The leach studies clearly demonstrate that the dominant site of residence for the ore metals is the hydrous iron- and manganese-oxide coatings and chemical precipitates in the stream sediments. Hydrous iron- and manganese-oxides are known to coprecipitate transition metals from acidic metal-bearing waters forming amorphous coatings on detrital rock fragments in the stream sediments.

- The concentration of the metals copper, lead, and zinc in the sediments of the Wightman Fork downstream from the Summitville deposit were significantly elevated above crustal abundance values for these metals in both the 1976 and the 1994 sample suites. The Summitville deposit was the major source of the ore metals to the sediments of the Alamosa River basin in both 1976 and 1994.

- The concentration of aluminum in the river sediments of the Alamosa River below the confluence of the Wightman Fork was substantially higher in the sediment samples collected during 1994. This increase in aluminum concentration is estimated to be about thirty percent. We interpret the data to indicate that the increase in aluminum content is a result of erosion of clays exposed by the open-pit mining at the Summitville site.

- The isotopic composition of lead from acidic metal-bearing seeps in the Summitville open pit matches well with three published lead-isotopic determinations on galena (Doe and others, 1979). On the basis of these data, we conclude that the isotopic composition of lead in the Summitville deposit appears to be uniform with $^{206}Pb/^{204}Pb = 17.82$, $^{207}Pb/^{204}Pb = 15.51$, and $^{208}Pb/^{204}Pb = 37.18$.

- The isotopic composition of lead in the 1976 stream sediments collected from the Wightman Fork below the confluence with Cropsy Creek does not match that of the ore lead from the Summitville deposit. The most reasonable explanation of the lead isotopic data is that it is controlled by the lead released from weathering of the South Mountain quartz latite which hosts the Summitville deposit.

- The isotopic composition of lead in the 1994 stream sediments collected from the Wightman Fork below the confluence with Cropsy Creek has shifted from the value measured in the 1976 sediments toward the isotopic composition of lead in the base-metal veins in the Summitville deposit. We calculate that there is a forty percent increase in the metal load to the Wightman Fork derived from the funneling of surface water into the adit drainage system that was drained by flow from the Reynolds adit.

INTRODUCTION

The concentrations of metals in stream sediments have long been used to provide a convenient measure of the geochemical baseline. Stream sediments represent a well mixed average of the material in the drainage basin from which they are collected. Furthermore, the stratigraphic layers that accumulate over time preserve a chronologic record of erosion of the earth's surface. In this study we use metal concentrations measured in stream sediments to document the changes in the geochemical baseline due to the open-pit mining activities at Summitville. The deposit was open-pitted by the Summitville Consolidated Mining Company, Inc. (SCMCI) from 1986 to 1992. Two sets of regional stream-sediment samples, one collected in July, 1976 as a part of the National Uranium Resource Evaluation (NURE) program, and a second set collected in Sept., 1994 by the Environmental Protection Agency (EPA), were studied to obtain geochemical and lead-isotopic baseline data from stream sediments for these two time periods. The changes between the metal concentrations in the two baselines provides a direct measure of the contribution of metals to the Wightman Fork and the Alamosa Rivers by SCMCI whereas the contrast between the metal concentrations in sediments from the Wightman Fork and the other tributaries of the Alamosa River provide a measure of the elevated metal concentrations in mineralized areas.

Geology of the Alamosa River basin

The Alamosa River has its headwaters on the eastern side of the continental divide in southwestern Colorado. The headwaters are underlain by Oligocene volcanic and intrusive rocks largely associated with the eruption of the Platoro caldera which is a part of the larger San Juan volcanic field (Lipman, 1974, 1975) formed in southern Colorado. During a period of intense volcanic activity in Oligocene time, large volumes of andesitic to rhyodacitic lavas were erupted forming the San Juan volcanic field in south-central Colorado (Steven and Lipman, 1976). The geology of this region is discussed in detail in Lipman (1975) and the evolution of the volcanic rocks that make up the San Juan volcanic field is developed in Lipman and others (1978). The Alamosa River drains much of the Platoro caldera and extends east into the older rocks of the Conejos Formation at Terrace Reservoir. The geology of the Platoro caldera and the surrounding area is summarized in figure 1 (Gray and Coolbaugh, 1994). Shown on the location map are other calderas within the San Juan Volcanic field, many of which have major mining districts associated with them. The Alamosa River basin is largely underlain by the Summitville andesite, the Treasure Mountain tuff, and to a lesser extent, the Park Creek rhyodacite. Several plutons subsequently intruded this volcanic pile, substantially altering the rocks and mineralizing several areas in the upper Alamosa River basin (fig. 2). Within the Alamosa River basin, there are three areas of alteration that will be discussed here: the South Mountain area, a volcanic dome of South Mountain quartz latite in which the Summitville open-pit mine is located, the Iron, Alum, and Bitter Creek drainages, referred to collectively as the Stunner altered area on the upper Alamosa River (Bove and others, 1995; Walton-Day and others, 1995), and the altered area surrounding the Jasper stock (the area underlain by the Jasper and Burnt Creek drainage basins).

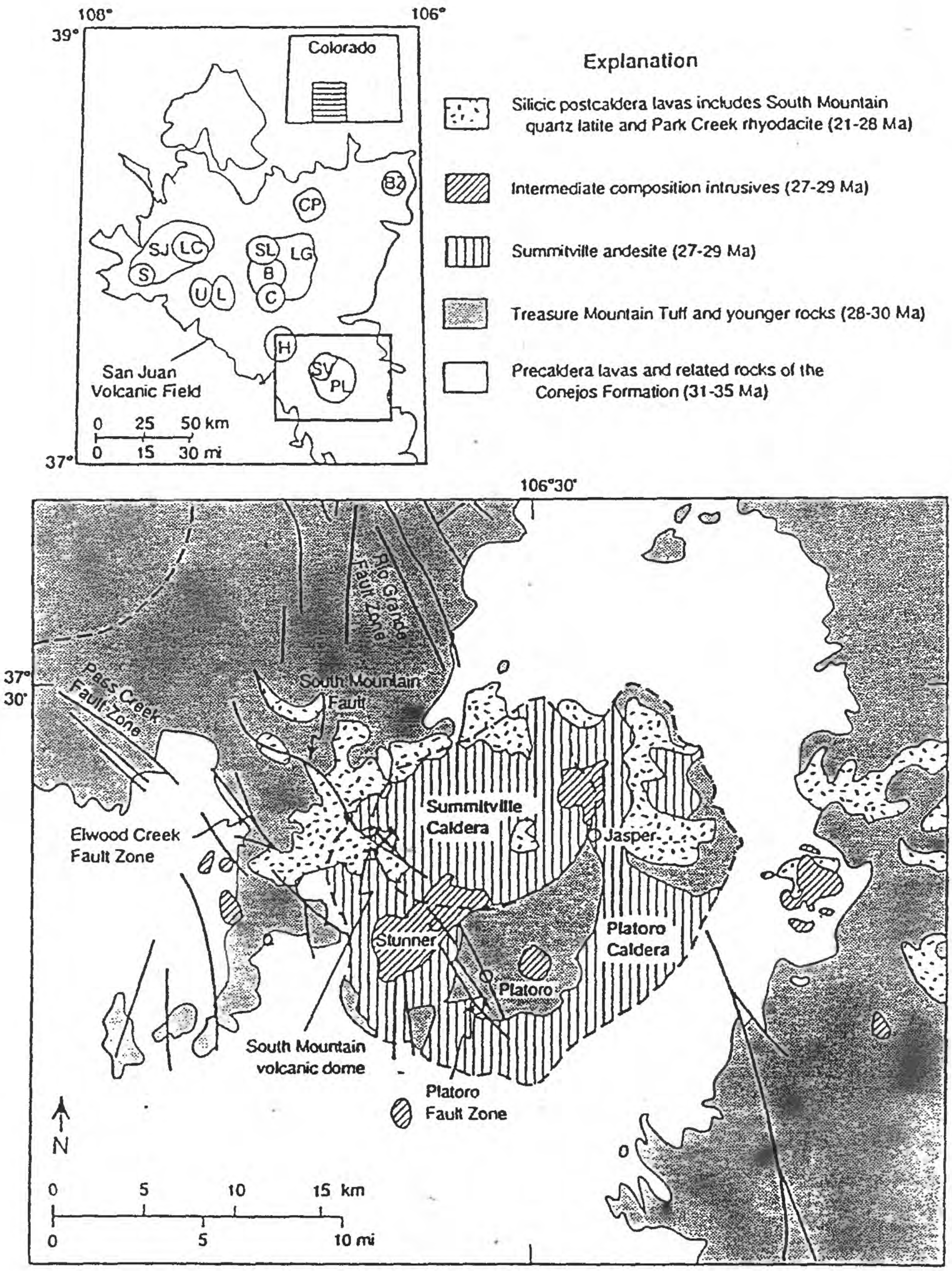


Figure 1. Index map of south-central Colorado showing the extent of the San Juan volcanic field with a simplified geological map of the Platoro caldera (B, Bachelor caldera; BZ, Bonanza caldera; C, Creede caldera; CP, Cochetopa Park caldera; H, Hope Mountain caldera; LC, Lake City caldera; LG, La Garita caldera; L, Lost Lake caldera; PL, Platoro caldera; S, Silverton caldera; SJ, San Juan caldera; SL, San Luis caldera, SV, Summitville caldera in which the Summitville open-pit mine (crossed mining picks) is located; and U, Ute caldera). Figure is from Gray and Coolbaugh (1994); geology is modified from Lipman(1975) and Steven and Lipman (1976).

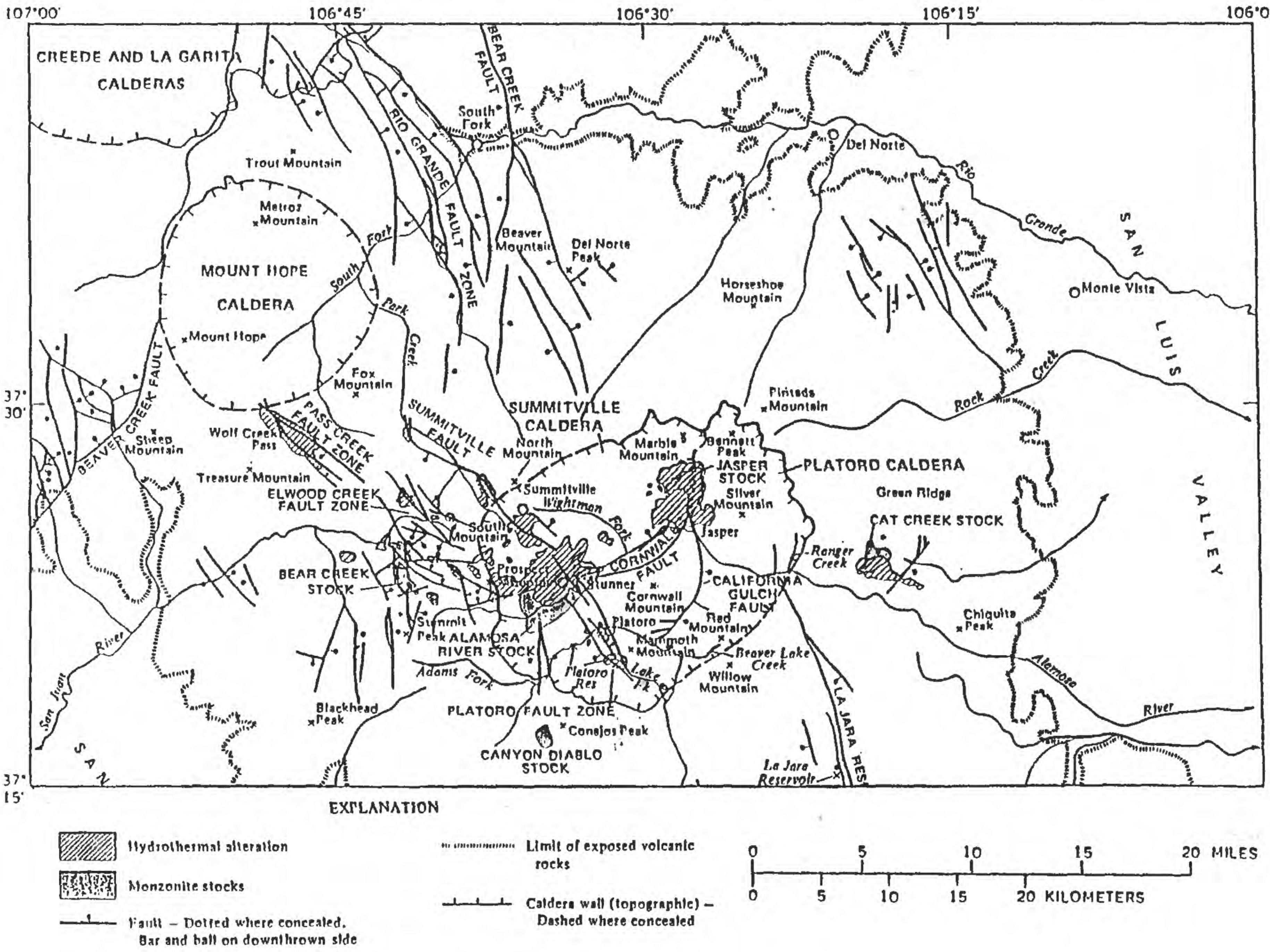


Figure 2. Distribution of faults, stocks, and hydrothermally altered areas in south-central Colorado (Lipman, 1975, fig. 61). The Crater Creek altered area (listed in table 3) is associated with the Bear Creek stock located west of the Platoro caldera.

MINING ACTIVITY AND IMPACT

Mining at the Summitville began in 1870 to 1873 with limited placer-gold production from alluvial deposits along Cropsy Creek and the Wightman Fork (Pendleton and others, 1995). Raymond (1877) visited the Summitville mining district in 1875 to examine the Little Annie mine. He observed that the stream sediments in Wightman Fork contained "red stratum" which, from his experience in southern Colorado, indicated the presence of ore. He described the wall rock of the Little Annie mine as "a highly siliceous feldspathic paste, similar to that of the red stratum, containing siliceous concretions" (Raymond, 1877, p. 172). He further states that the volcanic rocks were impregnated with pyrite, which upon weathering, produced iron oxide minerals freeing the gold. Numerous ferricrite deposits exist along the north edge of the South Mountain quartz latite dome and along the Missionary Fault, further indicating that weathering prior to mining produced naturally occurring acidic-metal springs (Plumlee and others, 1995a). At the time the Summitville placer-gold deposits were first discovered in 1870, the Summitville ore body was exposed at the surface and weathering processes were producing natural acidic drainage conditions resulting in enrichment of iron, gold, and almost certainly other metals in the stream sediments of the Wightman Fork.

Minor open-cut and extensive underground mining was developed on the northeast flank of South Mountain from 1873-1949. Steven and Ratté (1960, table 1) summarize production figures for the Summitville deposit. Production data indicate that about 95 percent of the total production from the Summitville mining district was from gold and 4.6 percent was from silver. The remainder of the production was from copper and minor byproduct lead production. Most of the rich oxidized gold ore in the Summitville mining district was mined out by 1887. In the late 1960's tailings from mining activity diverted the flow of the upper Wightman Fork to the north side of the Wightman Fork stream valley.

The Reynolds adit was completed in 1897 (Pendleton and others, 1995) to drain water from the underground mine workings. Flow rates from the Reynolds adit range from a low of 100 gal/min to and average high value of 400 gal/min (Pendleton and others, 1995). Peak flows from the Reynolds adit exceed 1,000 gal/min (Brown, 1995). Historical data on the waters flowing from the Reynolds adit (1981-1992) indicate that these waters were quite acidic, averaging a pH of 2.8-3.0 (Brown, 1995), and contained a substantial dissolved-metal load (see data from 1990-1993, table 1, Plumlee and others, 1995b). Copper concentrations prior to open-pit mining were about 20 mg/L whereas in 1992 they peaked at 340 mg/L (Brown, 1995). Water quality from the Reynolds adit was generally quite poor when the Environmental Protection Agency (EPA) took over the Summitville site. Typical average values were pH, 3.0; copper 100 mg/L; sulfate 1,600 mg/L; and total dissolved solids of 2,700 mg/L (Devarajan and others, 1995). Water flowing from the Reynolds adit contributed metals to the Wightman Fork prior to recent open-pit mining, but the opening of the open pit focused surface water into the acid-sulfate alteration zone and through the deposit flushing acidic metal-bearing waters through the underground drainage system dramatically increasing the flow of water out the Reynolds adit into the Wightman Fork.

Summitville Consolidated Mining Company, Inc. (SCMCI) began open-pit mining in 1986. The geology of the open-pit area at Summitville was mapped as the ore was extracted (Gray and others, 1993). Areas of hydrothermal alteration and high gold-ore grades are

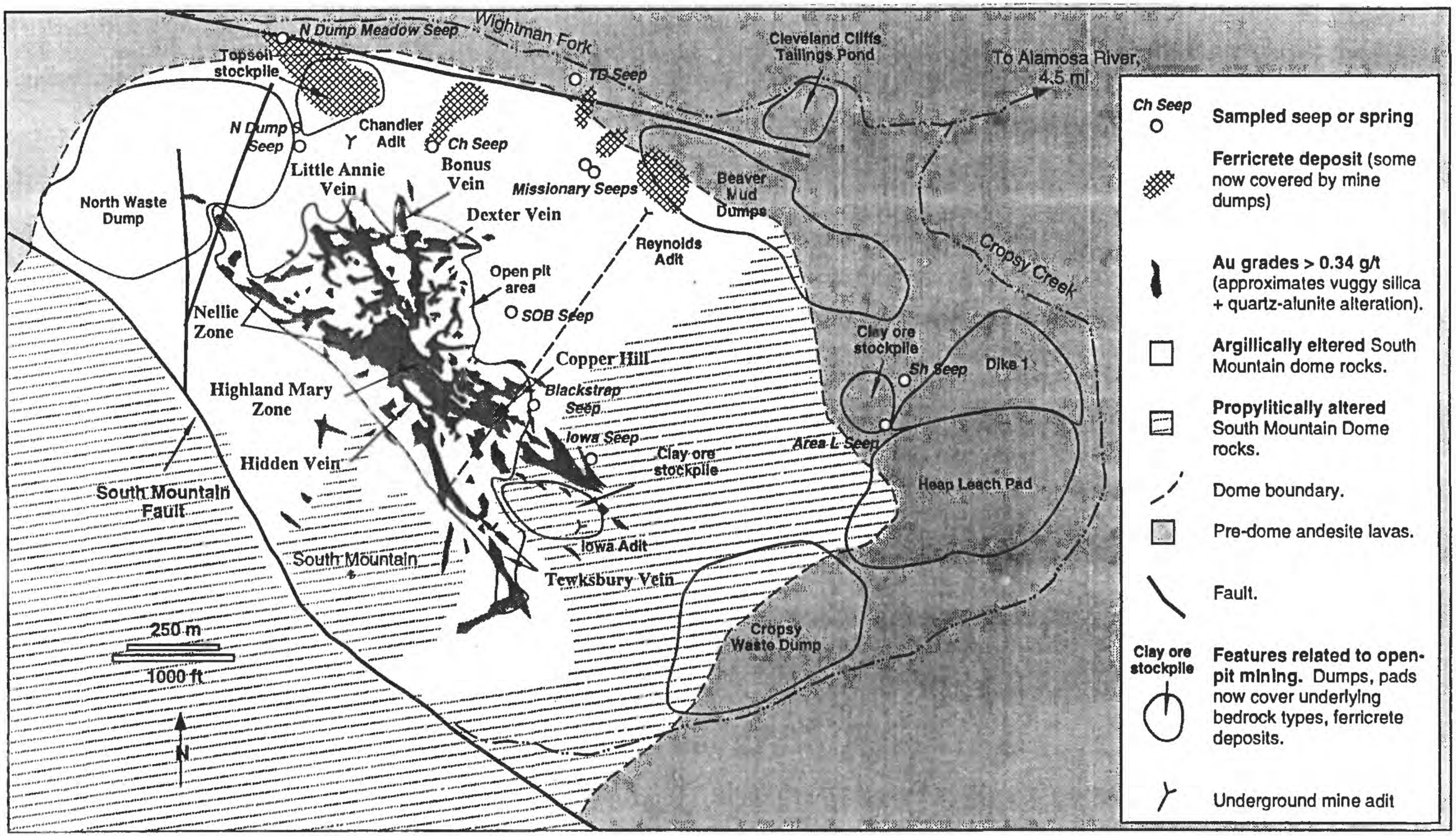
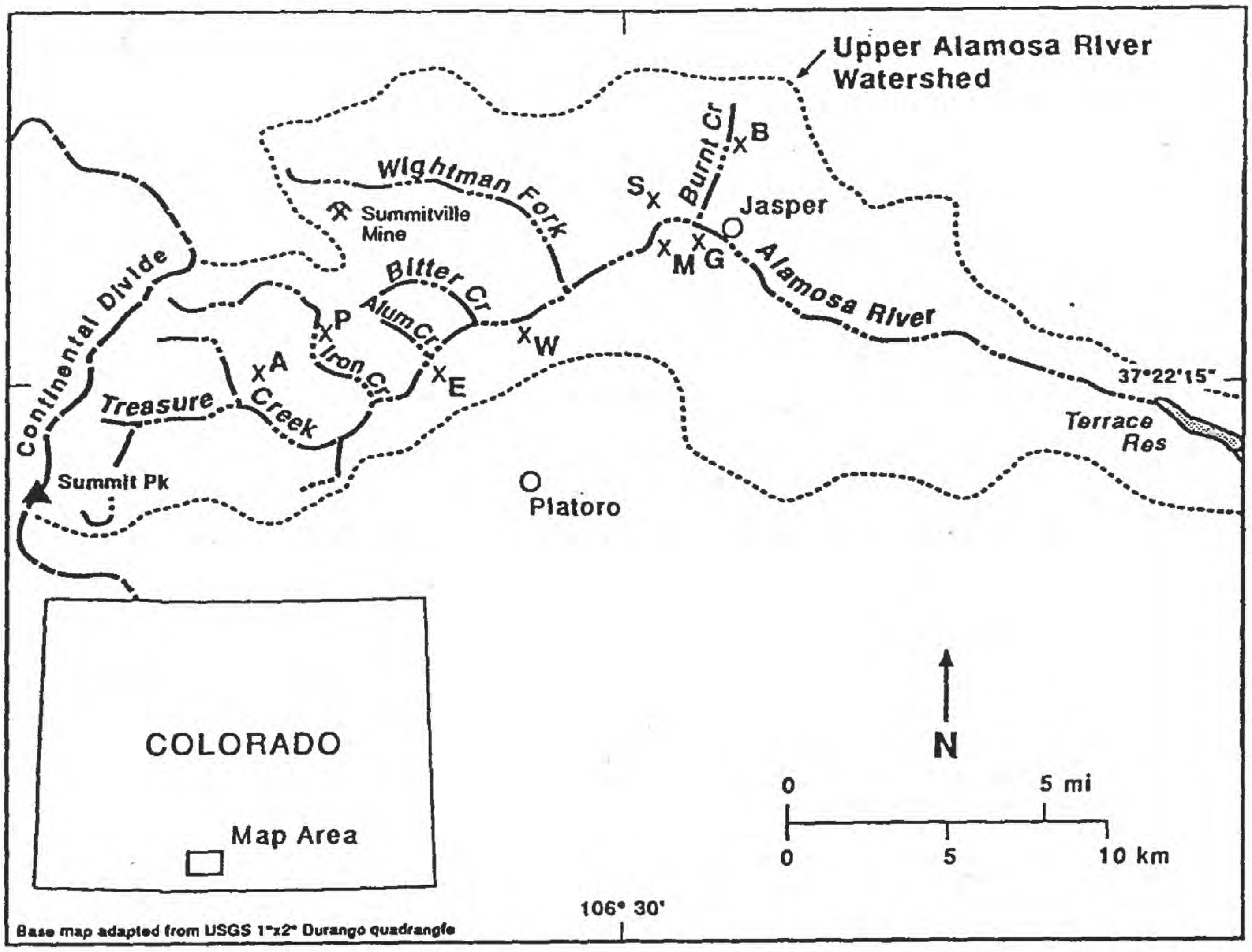


Figure 3. Generalized map of the Summitville open-pit mine site showing hydrothermally altered zones, zones of high-grade gold ore, and active seeps within the open-pit area (Plumlee and others, 1995a, fig. 1).

indicated in a summary map of the open pit (fig. 3). Open-pit mining ceased in 1991, the cyanide heap-leaching process ceased in August, 1992, and SCMCI had initiated environmental remediation when it filed for bankruptcy in December, 1992. During this period of operation, SCMCI produced about 249,000 troy ounces of gold (Pendleton and others, 1995). Remediation activities at the Summitville site have been assumed by the EPA at the request of the State of Colorado (Pendleton and others, 1995; Williams, 1995).

Mineral extraction activities and mineral exploration also took place in other mineralized areas in the Alamosa River basin (Kirkham and others, 1995). Historic mining activities in the Alamosa River basin, at sites other than Summitville, were minor (Patton, 1917). The area contains numerous prospects and a few small mines. Mines having some past production are shown in figure 4. Of these, the Pass-Me-By mine on Iron Creek was the largest as indicated by the size of the mine dumps (Kirkham and others, 1995). Kirkham and others (1995) documented acid-mine drainage having pH less than 6 at five sites on the upper Alamosa River (Pass-Me-By, Gilmore Meadow, Ferrocrite, Queen Bird, and Watrous), one site on the Wightman Fork other than the Summitville site, and at all the mines in the Jasper Creek area



Base map adapted from USGS 1°x2° Durango quadrangle

Figure 4. Localities of the larger mine workings in the Upper Alamosa River basin (Kirkham and others, 1995, fig. 1); P, Pass-Me-By; A, Asiatic; E, Eurydice; M, Miser; G, Guadaloupe; B, Burnt Gulch mines; S, Sanger mine; and W, Watrous claims.

(Miser, Burnt adit and dump, and Guadaloupe). They also report several naturally occurring acidic-metal springs (NOAMS) in the Iron Creek drainage. Of the acid-mine drainage sites in the Alamosa River basin, drainage from the Pass-Me-By mine, located on Iron Creek, contributed by far the largest metal load (20.5 kg iron, 8.6 kg of aluminum, 45 g manganese, 11 g of copper, and 26 g of zinc per day). However, NOAMS in the Iron Creek drainage were discharging between 1.5 to 7.2 kg of iron, 1 to 15.5 kg aluminum, 9 to 1,144 g manganese, up to 1 g copper, and 10-230 g zinc per day. Bove and others (1995) document acidic metal-bearing waters from the upper Iron Creek area with a pH of about 4.0 and from the Stunner area in Alum Creek having a pH of 2.6.

DEPOSIT GEOLOGY

The Summitville deposit is an acid-sulfate mineral deposit (Gray and Coolbaugh, 1994). The rocks of the South Mountain quartz latite intruded the volcanic rocks of the Platoro caldera forming a volcanic plug that was subsequently altered by hot, acidic hydrothermal fluids. The general features of the altered rock at the Summitville deposit are shown in the schematic cross section (fig. 5) from Gray and Coolbaugh (1994). Structure played a major role in the location of high-grade gold mineralization and the subsequent location of minor base metal sulfide-bearing barite veins emplaced near the end of the mineralization process. According to Gray and Coolbaugh (1994, p. 1912), there were six stages of mineralization that formed the Summitville deposit: 1) widespread acid-sulfate alteration of the South Mountain quartz latite along pre-existing fractures, 2) copper-gold mineralization, 3) intensive and widespread hydrothermal brecciation, 4) deposition of the volumetrically minor base metal sulfide-bearing barite veins, 5) emplacement of the kaolinite breccias, and finally, 6) supergene oxidation and formation of secondary sulfide minerals. Primary ore minerals in the deposit include pyrite, enargite, luzonite, covelite, native gold, sulfur, marcasite, and minor galena, sphalerite, and barite (Steven and Ratté, 1960). Quartz, kaolinite, alunite, illite, chlorite, and smectite are the common primary gangue minerals. Numerous hydrated oxide minerals however are present in the upper oxidized portion of the deposit (table 1). The opal/cristobalite deposit on the west side of the Summitville gold deposit indicates that the Summitville acid-sulfate system originated at shallow levels (near-surface) in the crust. The deposit was exposed at the surface when placer gold was discovered in 1870. Schematic representations of the regional geochemical anomaly profiles for gold (Au), silver (Ag), arsenic (As), and mercury (Hg) over the deposit also are indicated in figure 5. Anomalous concentrations of base metals are related to the presence of the base metal sulfide-bearing barite veins in the deposit (Gray and Coolbaugh, 1994).

Bove and others (1995) studied alteration in the Stunner area associated with the Alum Creek porphyry, an intensely altered and weakly mineralized area of about 11 km^2 centered in the Alum-Bitter Creek areas that predates the acid-sulfate alteration at Summitville. Centered in Alum Creek is a quartz-pyrite-sericite alteration zone containing up to two percent pyrite at depth causes significant naturally occurring acidic-metal drainage described by Kirkham and others (1995).

Table 1. Minerals found at Summitville; minerals listed in bold type have the potential to generate acid during oxidation, weathering, or dissolution. Minerals followed by a question mark are of uncertain origin (from Plumlee and others, 1995a, p. 16).

Minerals formed during advanced-argillic alteration

Silica (quartz)	SiO_2	**Alunite**	$KAl_3(SO_4)_2(OH)_6$
Kaolinite	$Al_2Si_2O_5(OH)_4$	Illite	$KAl_4[Si_7, Al]O_{20}(OH)_4$
Pyrite	FeS_2	Woodhouseite	$CaAl(PO_4)(SO_4)(OH)_6$
Smectite	$Na_{0.7}(Al,Fe,Mg)_4[(Si,Al)_8O_{20}](OH_4)\cdot nH_2O$		
Chlorite	$(Mg, Fe, Al)_{12}[(Si, Al)_8O_{20}](OH)_{16}$	Calcite	$CaCO_3$

Minerals formed during hydrothermal mineralization:

Pyrite	FeS_2	**Enargite**	Cu_3AsS_4
Chalcocite (?)	Cu_2S	**Covellite**	CuS
Chalcopyrite	$CuFeS_2$	**Marcasite**	FeS_2
Native sulfur	S°	Gold	Au
Barite	$BaSO_4$	**Sphalerite**	ZnS
Luzonite	Cu_3AsS_4	**Galena**	PbS
Kaolinite	$Al_2Si_2O_5(OH)_4$	**Tennantite**	$(Cu,Fe,Zn)_{12}As_4S_{13}$
Hinsdalite	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$		

Secondary minerals formed during pre-mining weathering of the deposit:

Jarosite	$KFe_3(SO_4)_2(OH)_6$	Goethite	$HFeO_2$
Limonite	$FeO(OH)\cdot nH_2O$	Scorodite	$FeAsO_4\cdot 2H_2O$
Hinsdalite (?)	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$	**Chalcocite** (?)	Cu_2S (below water table)

Secondary minerals formed as a result of mining of the deposit (this list will likely expand with further study):

Chalcanthite	$Cu(SO_4)\cdot 5H_2O$	Brochantite	$Cu_4(SO_4)(OH)_6$
Jarosite	$KFe_3(SO_4)_2(OH)_6$	Posnjakite	$Cu_4(SO_4)(OH)_6\cdot 5H_2O$
Hinsdalite (?)	$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$	Halotrichite	$Fe^{+2}Al_2(SO_4)_4\cdot 22H_2O$

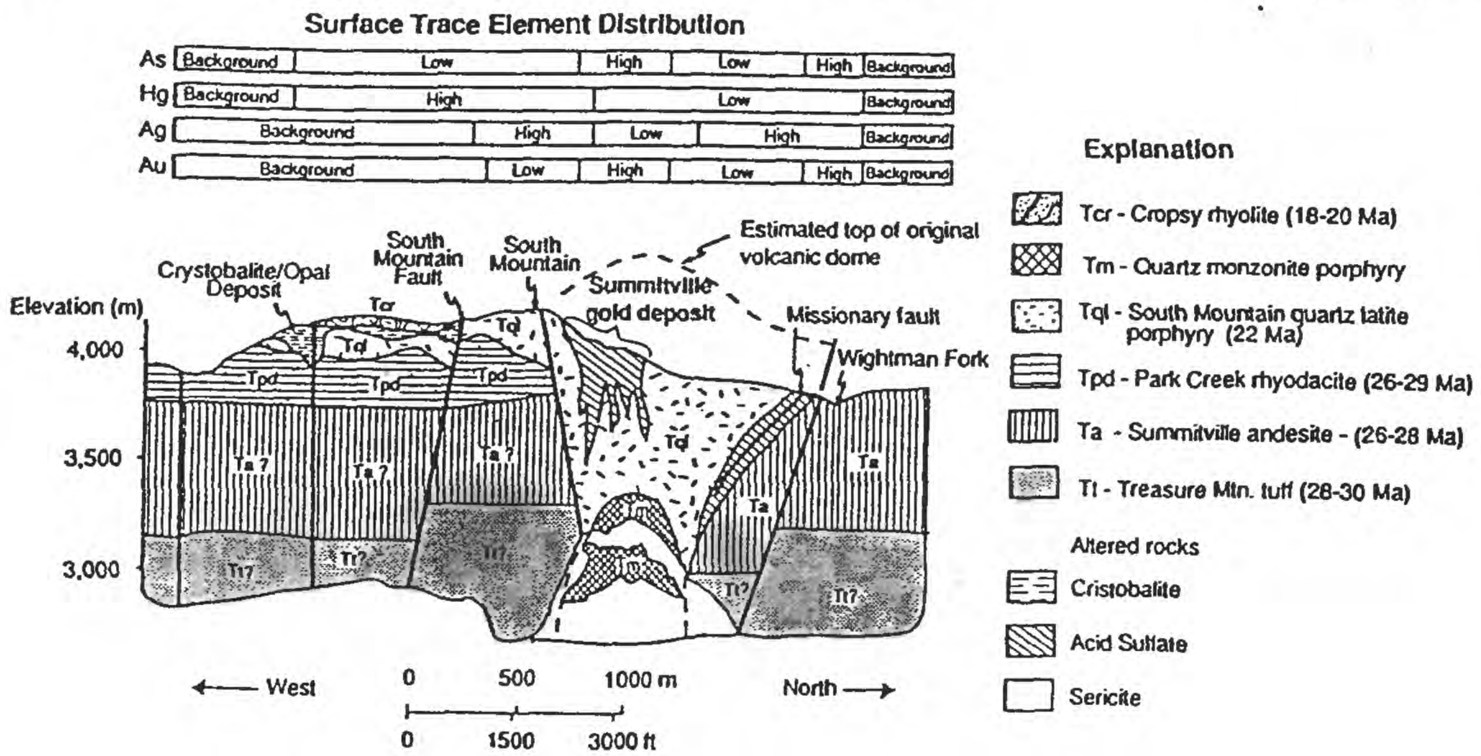


Figure 5. Schematic cross section through the Summitville deposit showing the relationship of the altered zone in the South Mountain quartz latite to the Summitville andesite, the Treasure Mountain tuff, the Park Creek rhyodacite, and the Cropsy Mountain rhyolite.

CHEMICAL AND LEAD-ISOTOPIC STUDIES

In this study, we have used archived stream-sediment samples collected during the NURE program (Dawson and Weaver, 1979; Shannon and others, 1980) and stream-sediment samples collected by the EPA in 1994 (Morrison Knudsen Corporation [MKC], 1994) to determine the geochemical baselines in the Alamosa River basin in 1976 and 1994. Samples were collected from the streams and sieved to retain the minus-100-mesh fraction. Geochemical and lead-isotopic data were obtained on this size fraction to determine the transport of metals in the fine-grained sediment phase and the relative loadings contributed by various segments of the stream to the metal load of the Alamosa River. Geochemical and lead-isotopic data presented in this report are plotted as a function of distance (in miles) measured along the course of the Alamosa and Wightman Fork Rivers to emphasize changes between the 1976 and 1994 geochemical baselines. Distances plotted are relative to the dam at Terrace Reservoir, which has been assigned an arbitrary value of 29 miles. Mileages for samples collected from tributaries are determined at the point of intersection of the tributary with the Alamosa River. For the purpose of discussion, we will divide the Alamosa River into two sections: that section above the intersection with the Wightman Fork (at 10.5 miles) will be called the upper Alamosa River, and the stretch below the intersection with the Wightman Fork above Terrace Reservoir will be called the lower Alamosa River.

Sample localities of the NURE stream-sediment samples are given in the Appendix and are shown in figure 6. Not all the NURE samples from tributaries to the Alamosa River were used. Two composite samples were made from samples C26778-C26782; one of these is called composite and the other duplicate in the data tables. The NURE sample distances (mi) on the upper Alamosa River are: a composite, 0.4; and a duplicate sediment sample from the headwaters of the upper Alamosa River, 0.5; C26776, a sample from lower Asiatic Creek, 2.7; C26776, a sample from lower Iron Creek, 3.1; C26467, a sample from lower Globe Creek, 4.6; and C26456, a sample on upper Alamosa River above the bridge, 4.8. The NURE sample distances (mi) on the Wightman Fork traverse are: C26788, a sample from Park Creek on the west side of the continental divide, 2.0; C26793, a sample from the upper Wightman Fork just above the intersection with Cropsy Creek, 5.4; C26794, a sample on Wightman Fork just below intersection with Big Hollow Creek, 7.1; C26795, a sample on Wightman Fork just below intersection with Whitney Gulch, 9.4; C26796, a sample on the Wightman Fork just above the intersection with the Alamosa River, 10.4. The NURE sample distances (mi) on the lower Alamosa River are: C26805, a sample from the tributary draining Cornwall Mountain, but really in the Alamosa River floodplain, 11.4; C26803, a sample from lower Jasper Creek, 13.8; C26804, a sample from lower Burnt Creek, 14.3; C26806, a sample from lower Spring Creek, 15.1; C26811, a sample from the lower Alamosa River at the bridge below the Alamosa guard station, 22.5; and C26812, a sample from lower French Creek, 23.0.

Sample localities of the EPA stream-sediment samples are given in MKC (1994) and shown in figure 7. The EPA sample distances (mi) on the Upper Alamosa River (upper Alamosa River) are: AR49.5, a sample from the headwaters of the upper Alamosa River above Iron Creek, 3.0; IC-1, a sample from lower Iron Creek, 3.2; AR48.4, a sample from upper Alamosa River above Alum Creek (the same as site C26456 in the NURE sampling program), 4.7; AC-1, a sample from lower Alum Creek, 5.2; AR48.1, a sample from upper Alamosa River above

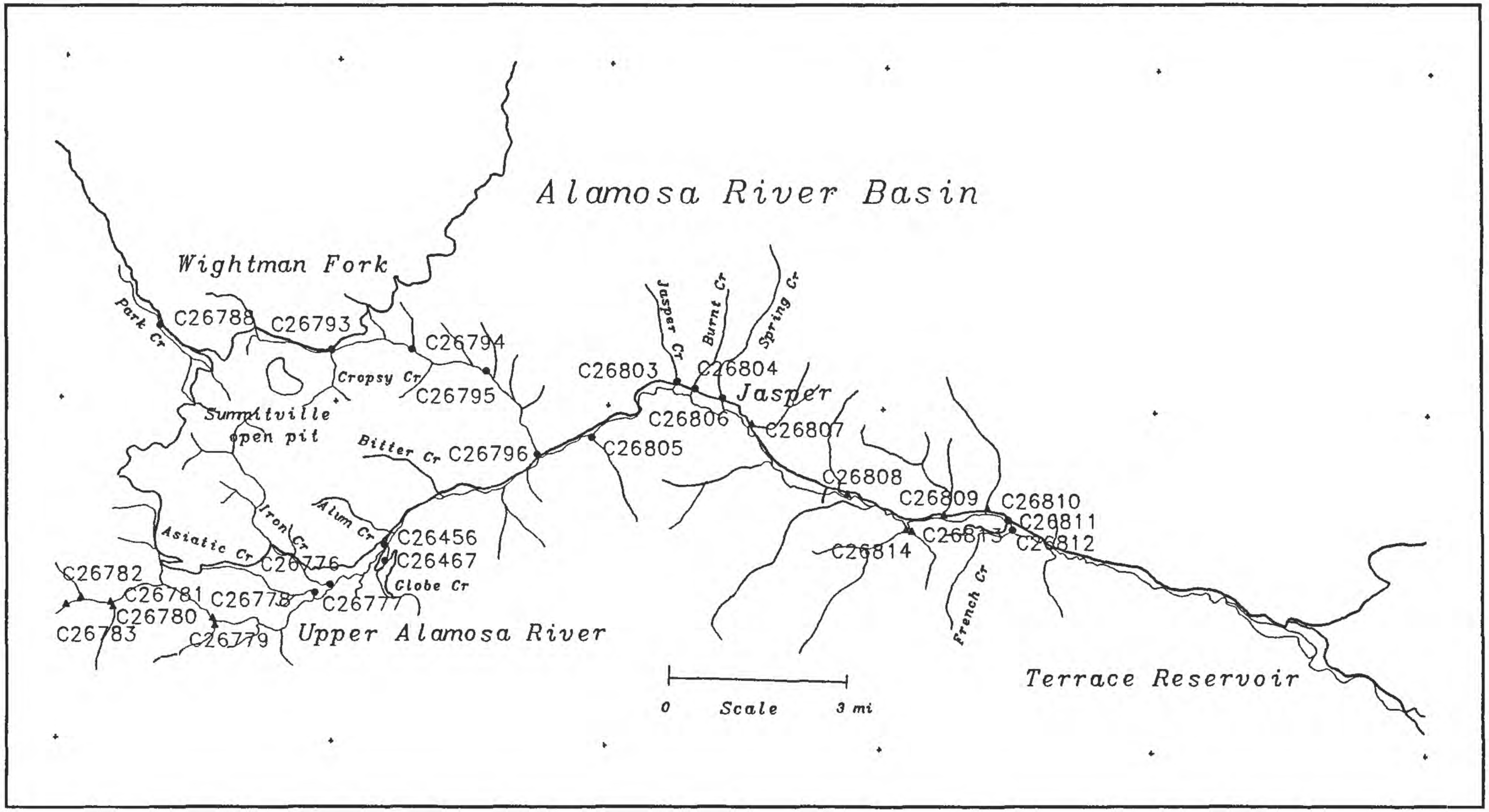


Figure 6. Sample localities for stream-sediment samples collected during July, 1976, as a part of the NURE program (Dawson and Weaver, 1979; Shannon and others, 1980). Localities indicated by the solid dot were used in this study; analytical results are tabulated in the Appendix.

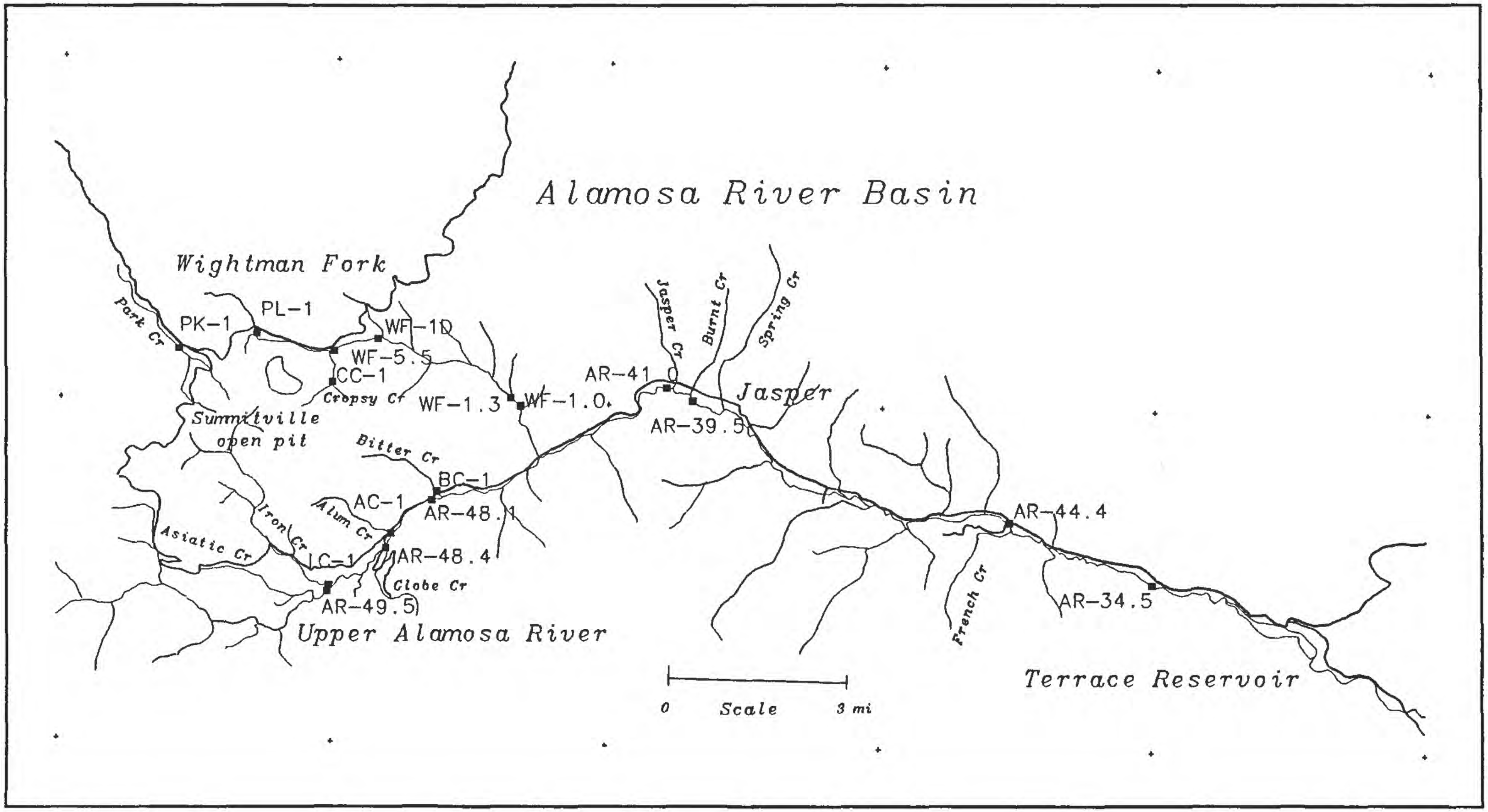


Figure 7. Sample localities for stream-sediment samples collected in Sept., 1994 by the EPA MKC, 1994). Localities indicated by the solid squares based on sample locality descriptions provided by EPA (MKC, 1994, table 2-1); analytical results are tabulated in the Appendix.

Bitter Creek, 6.4, and BC-1, a sample from lower Bitter Creek, 8.5. The EPA sample distances (mi) on the Wightman Fork traverse are: PK-1, a sample from Park Creek on the west side of the continental divide, 2.7; PL-0, a sample from Pipeline Creek, 4.0; CC-1, a sample from Cropsy Creek above the waste pile, 5.3; WF-5.5, a sample from the Wightman Fork just below the intersection with Cropsy Creek, 5.5; WF-1D, a sample on the Wightman Fork upstream from Big Hollow Creek, 6.4; WF-1.3, a sample on the Wightman Fork upstream from Whitney Gulch, 9.2; WF-1.0 a sample on the Wightman Fork upstream from Smallpox Gulch, 9.5. The EPA sample distances (mi) on the Lower Alamosa River (lower Alamosa River) are: AR41.0, sample on the lower Alamosa River just above Jasper Creek, 13.9; AR39.5, a sample from just below Burnt Creek, 14.4; AR44.4, (sample run in duplicate) a sample from the bridge crossing near the Alamosa guard station, 21.5; and AR34.5, a sample from the lower Alamosa River just above the gaging station, 25.0.

Five separate chemical digestions were performed on either the entire suite of both NURE and EPA stream-sediment samples or on a subset depending upon the availability of sample materials. The various leach procedures are briefly discussed below in order of their chemical reactivity, or their ability to extract metals bound to mineral phases based upon the bonding energy of these metals. Metals that are adsorbed to minerals are much less tightly bound than are metals that are a part of the crystalline structure of a mineral.

The weakest extraction performed was the sodium acetate extraction (EPA method 1311); the analytical results are given in tables A1a (NURE) and A1b (EPA). This extraction procedure is designed to extract weakly-bound adsorbed metals on clay minerals in soils, that is, metals that are retained on solid phase material by weak ion exchange associations or weak inorganic and organic complexation. The degree of extractability is governed by the strength of the ion exchange binding relative to sodium and the stability of acetate complex (Martell and Smith, 1989). The complexing ability of acetate also acts to keep the extracted transition metals from readsorbing to solid surfaces including container walls. Acetate extractions are used extensively in the agricultural studies to identify the fraction of trace elements available to the local plant population. (Walsh and Beaton, 1973).

The 0.25M hydroxylamine hydrochloride (NH_2OH-HCl)--0.25M HCl extraction (HYDXAMN), the next weakest extraction procedure, was performed to remove metals associated with the amorphous iron- and manganese-oxide phases (Chao and Zhou, 1983). These are the mineral phases that form in the stream environment in response to changes in pH and Eh in the stream and are presumed to be largely responsible for removal of many trace metals that are associated with the hydrous iron oxides in stream sediments. However, metals associated with the surface oxidation of the Summitville deposit, that is the crystalline hydrous oxides and sulfate minerals listed in table 1, such as goethite and jarosite, should not be dissolved. Studies by Chao (1972) indicated that this extraction procedure does not readily attack the crystalline iron oxide phases. This differentiation is important in determining the short and long term geochemical processes that take place in the stream environment. In this procedure, the acidity (pH 1-2) of the HCl and the redox properties of the hydroxylamine solubilize the iron and manganese phases which in turn, release metals that were coprecipitated at the time of deposition or adsorbed later. Analytical results are given in tables A2a (NURE) and A2b (EPA).

The 2M HCl-H_2O_2 extraction (HCl-PRX) was performed to remove metals associated with all iron- and manganese-oxide mineral phases (Gulson and others, 1992). This is a more robust

robust digestion than the HYDXAMN leach that will dissolve both the hydrous amorphous and the crystalline iron- and manganese-oxide minerals that form as a result of surface oxidation of the Summitville deposit, including the crystalline forms such as goethite and hematite (see the mineral phases listed in table 1). In addition to the increased acidity, the hydrogen peroxide produces an oxidizing environment which is capable of attacking selected organic phases present in the sample. Analytical results are given in tables A3a (NURE) and A3b (EPA).

The EPA 3050 procedure (EPA method 3050) was used to evaluate the total digestable metal content of the samples and to compare these results with the total-sample digestion procedure used routinely by the U.S. Geological Survey (Briggs, 1990). In this procedure the combination of concentrated hydrochloric acid, nitric acid, and hydrogen peroxide produce an extremely oxidizing solution. This solution is capable of dissolving most element oxides, sulfides, carbonates, and other more common mineral phases. It will not however decompose silicate minerals nor extract elements that may be occluded in the silicate phases. Selected oxides of chromium, zirconium, and titanium and selected major elements are also not attacked, but recovery levels greater than 90 percent or more are commonly observed for most environmentally significant elements (Kane and others, 1993). The analytical results from this digestion are given in the appendix in tables A4a (NURE) and A4b (EPA).

The total-sample digestion procedure (TSD) is a multi-acid decomposition using a combination of nitric, hydrochloric, hydrofluoric, and perchloric acids that ensures the decomposition of most minerals, including silicate minerals and titanium and chromium oxides (Crock and others, 1982; Briggs, 1990). Only zircon, chromite, and selected tin oxides minerals are resistant to this decomposition procedure. Previous investigations using a variety of reference materials support the completeness of this decomposition (Church, 1981; Wilson and others, 1994). The analytical results from this digestion are given in the appendix in tables A5a (NURE) and A5b (EPA).

Samples were randomized and submitted to the laboratory as blind samples. Analytical precision and accuracy of the methods was tested by the analysis of standard reference materials (SRMs) available from the National Institute of Standards and Technology (NBS, 1982; NIST, 1993a, 1993b). Three SRMs were analyzed during the course of this study. The analytical results (TSD) from these three SRMs compare well with certified values (tables A6 and A7) and the results from replicate samples are well within routine analytical error limits established by the USGS laboratories.

Lead-isotopic compositions (tables A8a and A8b) were determined from the 2M HCl-H_2O_2 extraction solutions to characterize the lead being derived from the tributary streams and transported to the Alamosa River. Analytical procedures are given in Church and others (1993). These data were used to evaluate the contribution of metals from the tributaries to the metal load in the stream sediments of the Alamosa River. Lead-isotopic analyses of water from several seeps from the Summitville open-pit (Plumlee and others, 1995a) and the sludge from the Portable Interim Treatment System (PITS) water treatment plant (Roeber and others, 1995) confirm that the previously published lead-isotopic data from base metal sulfide-bearing barite veins reported by Doe and others (1979) were representative of this phase of the mineralization in the Summitville deposit. Limited lead-isotopic data obtained from a petrologic study of the origin and evolution of the volcanic rocks of the Platoro caldera (Lipman and others, 1978) provide a basis for the interpretation of the lead-isotope data from the stream sediments.

RESULTS AND INTERPRETATION

The geochemical data from the different chemical leach studies indicate that two principal components are present in the stream sediments. The first group of elements includes those associated with the silicate mineral phases that are detrital fragments of rock eroded into the streams. The bulk of the ore-metals in the stream sediments are either contained in or associated with the second principal component which is the hydrous iron- and manganese-oxide coatings on sediment grains. This association is derived from the coprecipitation of ore-metals by iron and manganese hydroxides or from the adsorption of dissolved metals by precipitated hydrous iron- and manganese-oxide coatings. Inspection of the data from the acetate leaches (for example, see fig. 8) indicates that only a very small component of the ore-metals is weakly adsorbed on clay minerals. Concentrations of leachable iron in most samples analyzed was less than the limit of detection (< 10 ppm), zinc and copper concentrations exceed 10 ppm in only a few samples, and lead and titanium were not detected in the acetate extraction. Most elements are present in the sodium acetate extraction at or below the analytical limit of detection (tables A1a and A1b).

In contrast, the data from both the HYDXAMN and the HCl-PRX extractions contain substantially higher concentrations of iron and some ore-metals. Distribution profiles for selected metals are shown in figs. 9 and 10. Many elements show very similar distribution profiles. Large amounts of metal were present in the sediments in the 1994 EPA samples and a second HCl-PRX extraction of the samples was required. These data are summed and reported in tables A3a and A3b. We have selected three elements (iron, copper, and lead) to demonstrate the geochemical variation of metals along the river profiles. Differences between the profiles obtained for data for the two extraction methods are not significant. Higher metal concentrations were obtained in the HCl-PRX extraction but the same element profiles were obtained from both extractions.

Geochemical data from the total-sample digestions (TSD) also show similar profiles for copper, lead, and zinc (fig. 11). In contrast, yields for the HYDXAMN and HCl-PRX extractions for metals such as titanium, which are tightly bound in silicate mineral phases or magnetite, are very low. Cobalt, which is not enriched at the Summitville deposit, showed no significant enrichment in the sediments below the Summitville deposit nor is there any significant variation in the total element concentration of cobalt along the profile of the Alamosa River or Wightman Fork.

We interpret the data from the leach studies of the stream sediments to indicate that the dominant mineralogical phases for the adsorption of metals are the amorphous hydrous iron- and manganese-oxide phases. Yields from sites along the Wightman Fork downstream from the Summitville open-pit indicate that as much as 50 percent of the zinc, lead, and arsenic, and as much as 90 percent of the copper in the stream sediments are bound in the hydrous iron- and manganese-oxide phases. Generally, more than half of the ore-metal content in the iron- and manganese-oxide phases is extractable with the HYDXAMN extraction which we interpret indicates that the ore metals are adsorbed on the hydrous amorphous iron- and manganese-oxide phases.

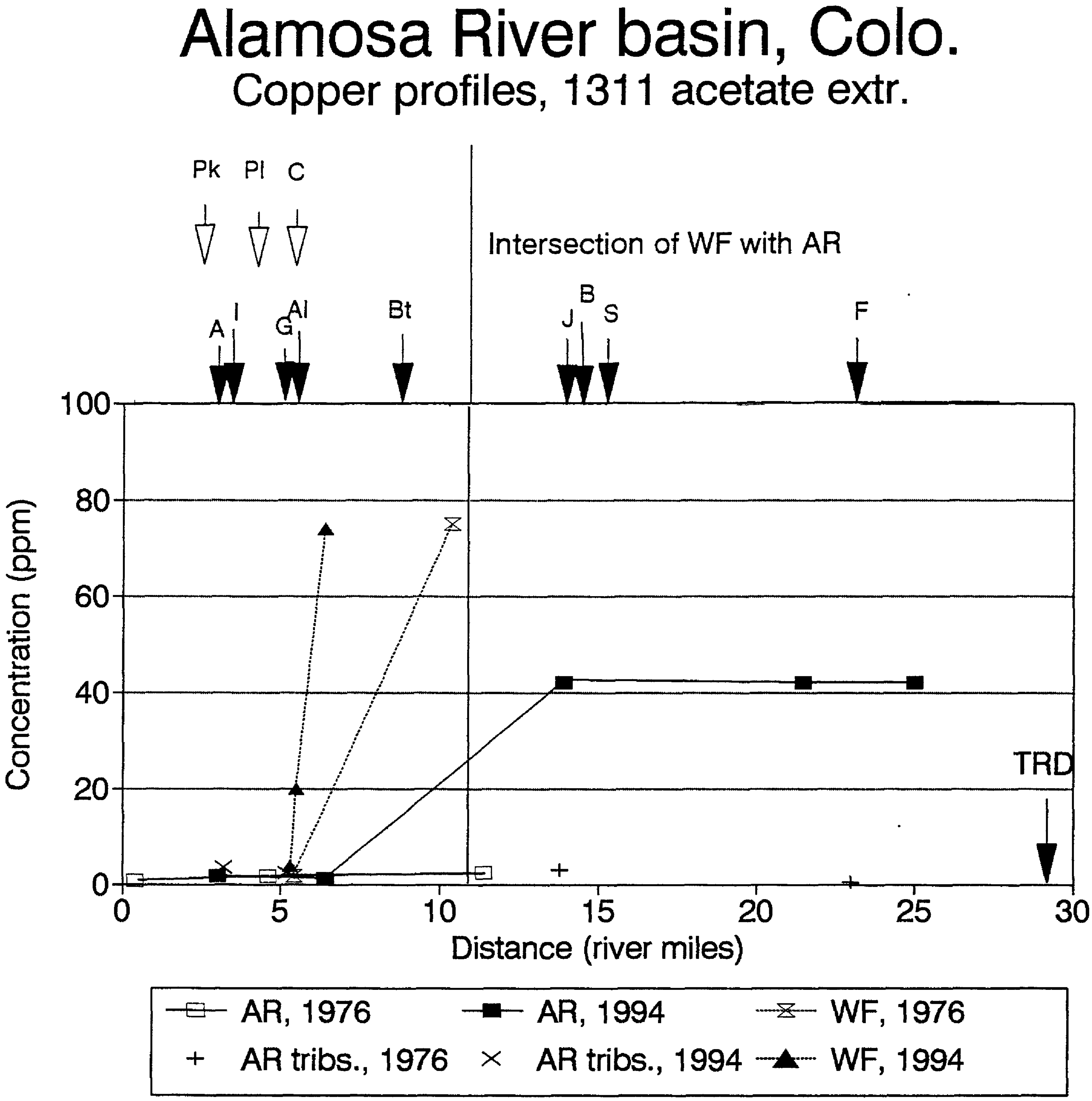


Figure 8A. Metal profiles for copper released from stream sediments using the acetate extraction procedure. Intersections of tributaries are shown at the top of the diagram: Asiatic Creek (A), Iron Creek (I), Globe Creek (G), Alum Creek (Al), and Bitter Creek (Bt) are tributaries that drain into the upper Alamosa River; Jasper Creek (J), Burnt Creek (B), Spring Creek (S), and French Creek (F) are tributaries that drain into the lower Alamosa River; Park Creek (Pk) drains away from the headwaters of the Wightman Fork to the west, Pipeline Creek (Pl) and Cropsy Creek (C) drain into the Wightman Fork. The Summitville deposit is located just above the confluence of Cropsy Creek with the Wightman Fork. The intersection of the Wightman Fork with the Alamosa River is at mile 10.5 and is indicated by the vertical line in the figure.

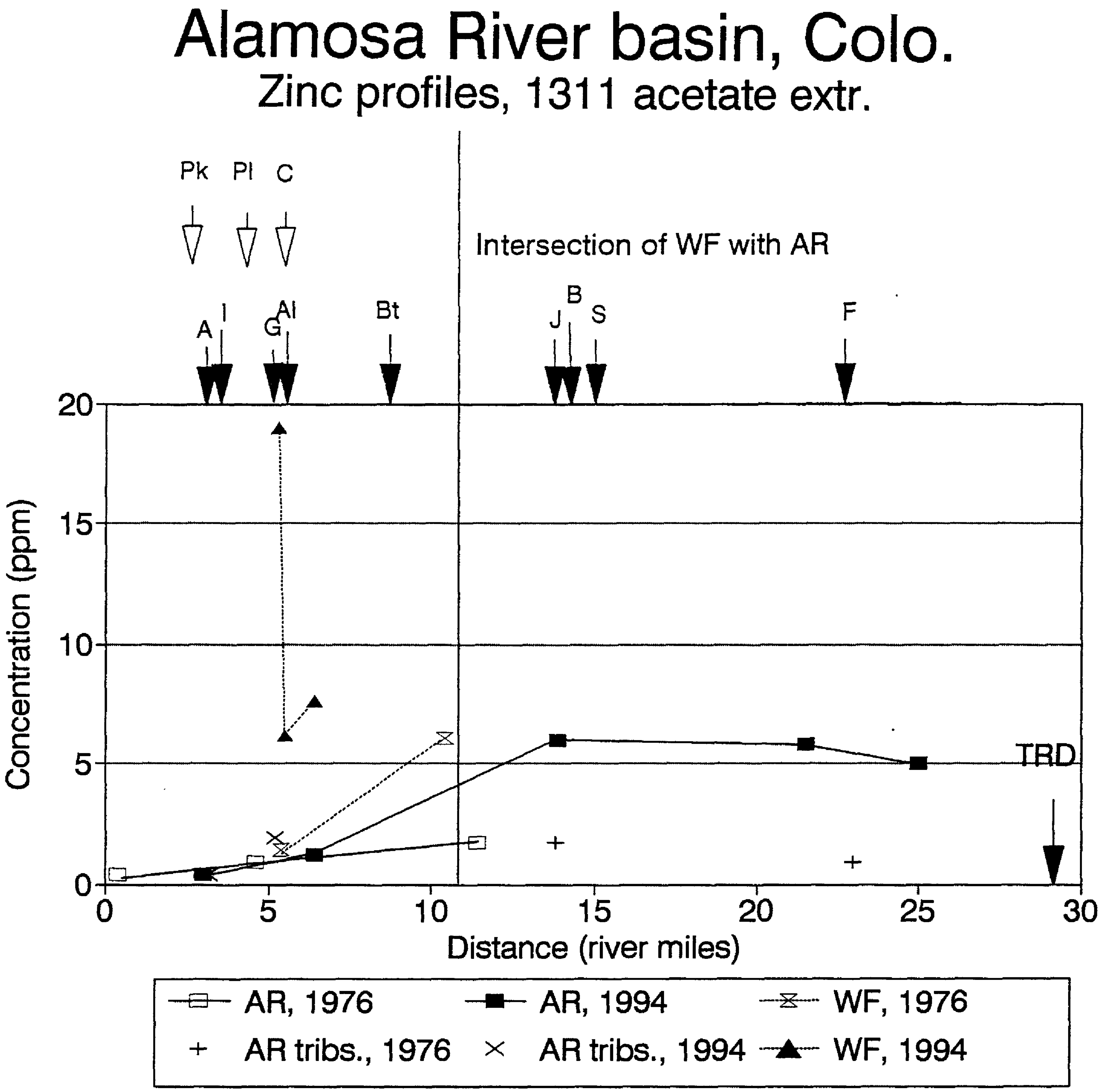


Figure 8B. Metal profiles for zinc released from stream sediments using the acetate extraction procedure. Abbreviations are the same as those used in fig. 8A.

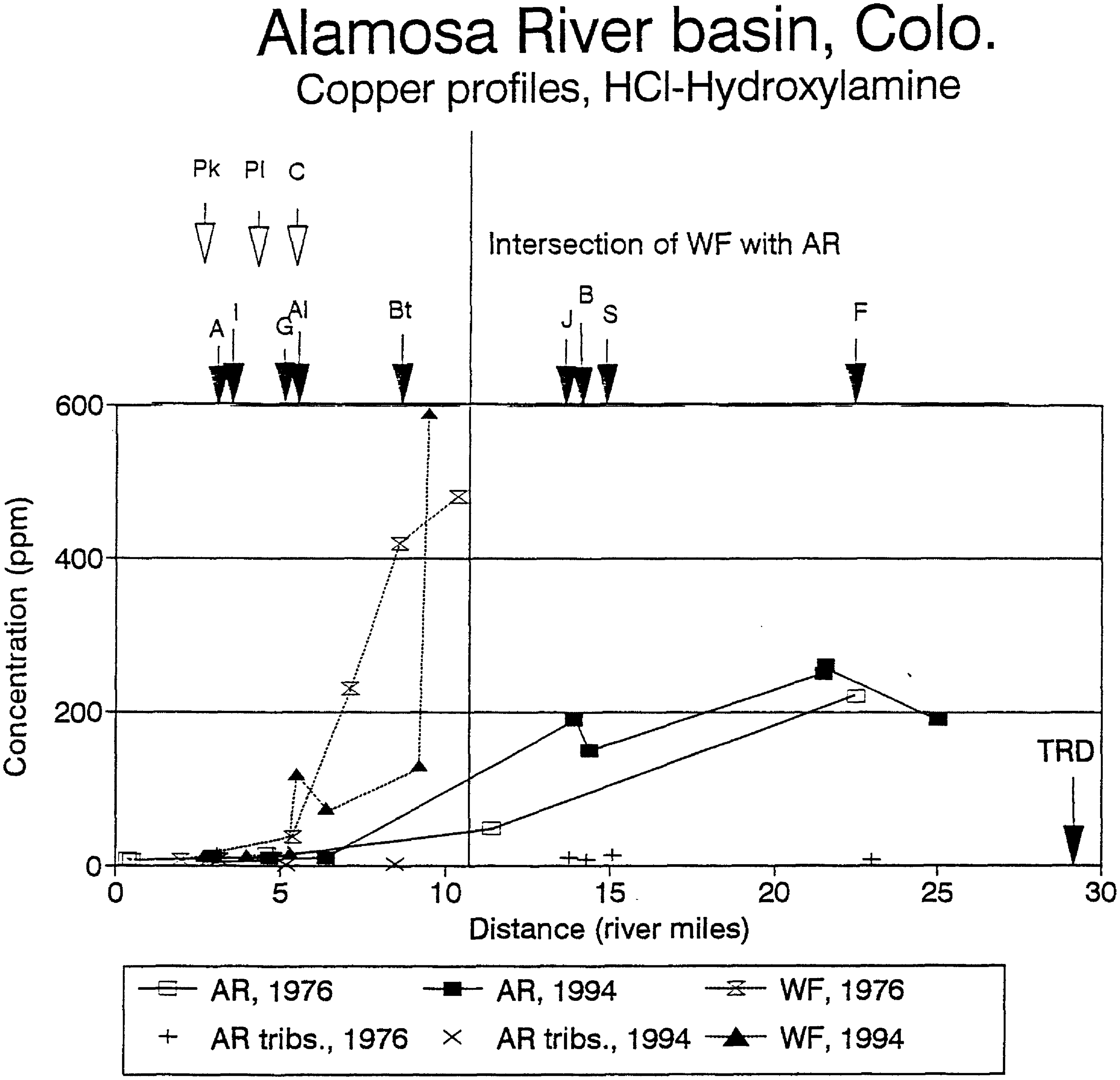


Figure 9A. Metal profiles for copper released using the HYDXAMN extraction procedure (Chao and Zhou, 1983). Abbreviations are the same as those used in fig. 8A.

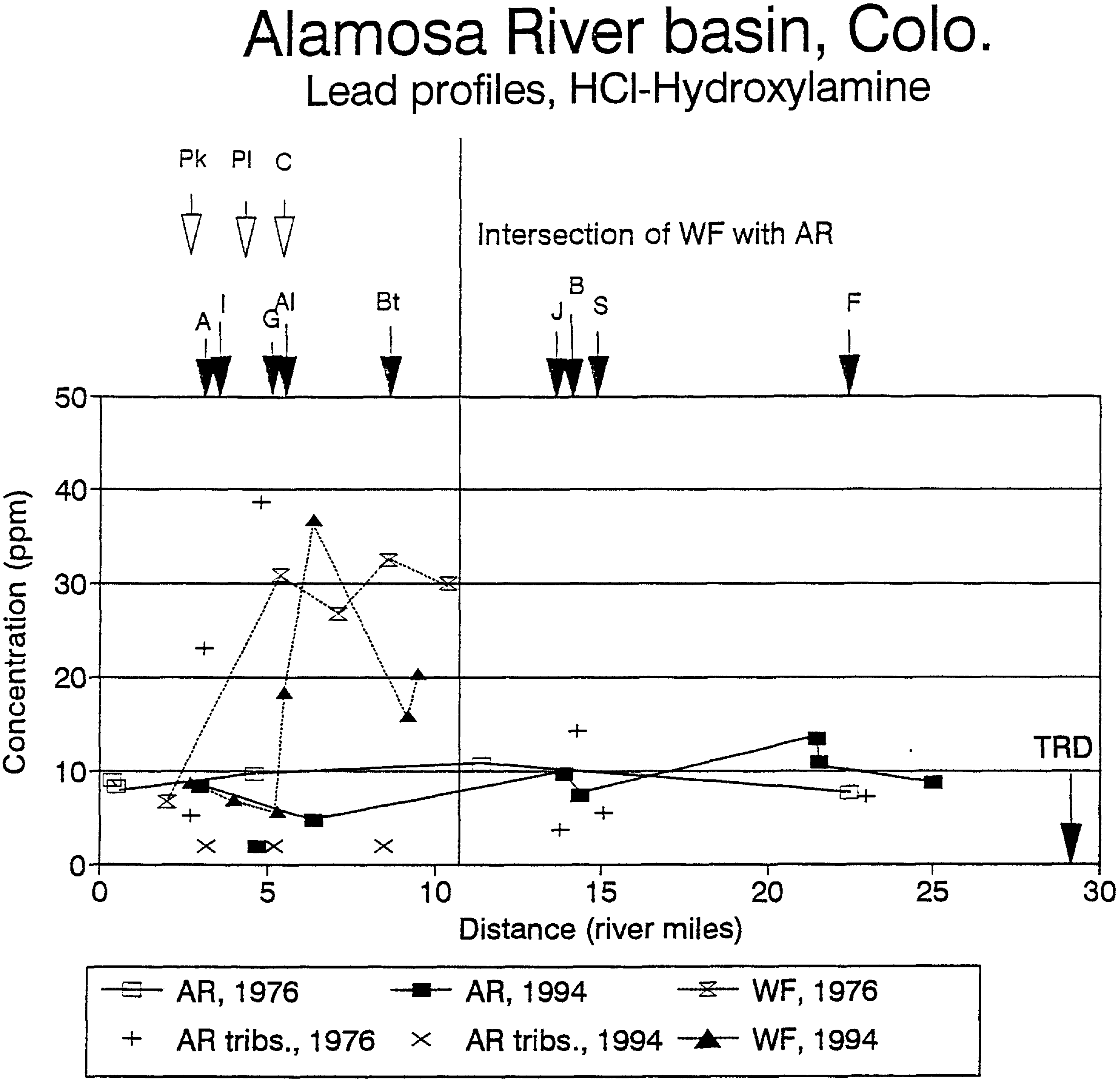


Figure 9B. Metal profiles for lead released using the HYDXAMN extraction procedure (Chao and Zhou, 1983). Abbreviations are the same as those used in fig. 8A.

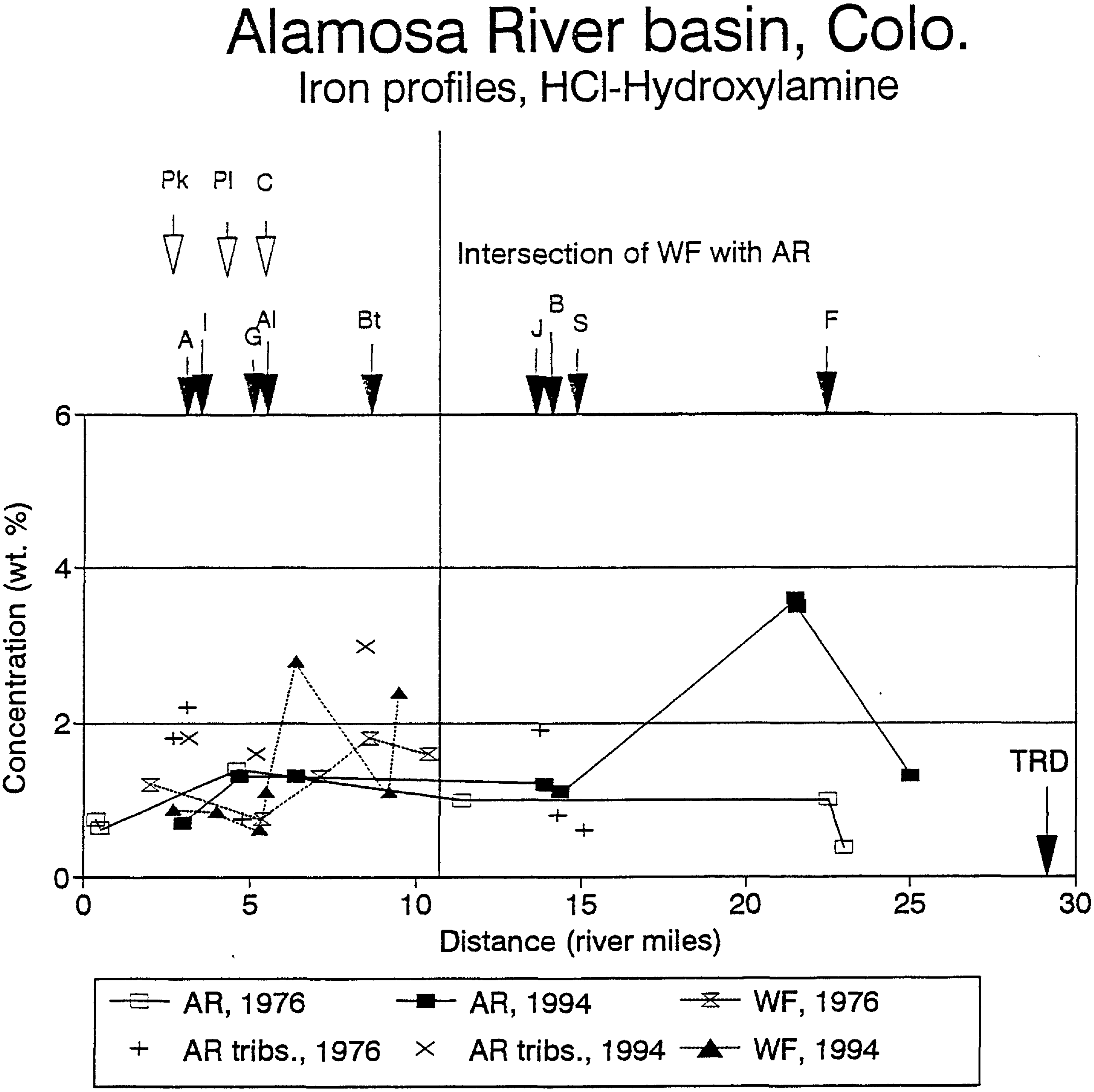


Figure 9C. Metal profiles for iron released using the HYDXAMN extraction procedure (Chao and Zhou, 1983). Abbreviations are the same as those used in fig. 8A.

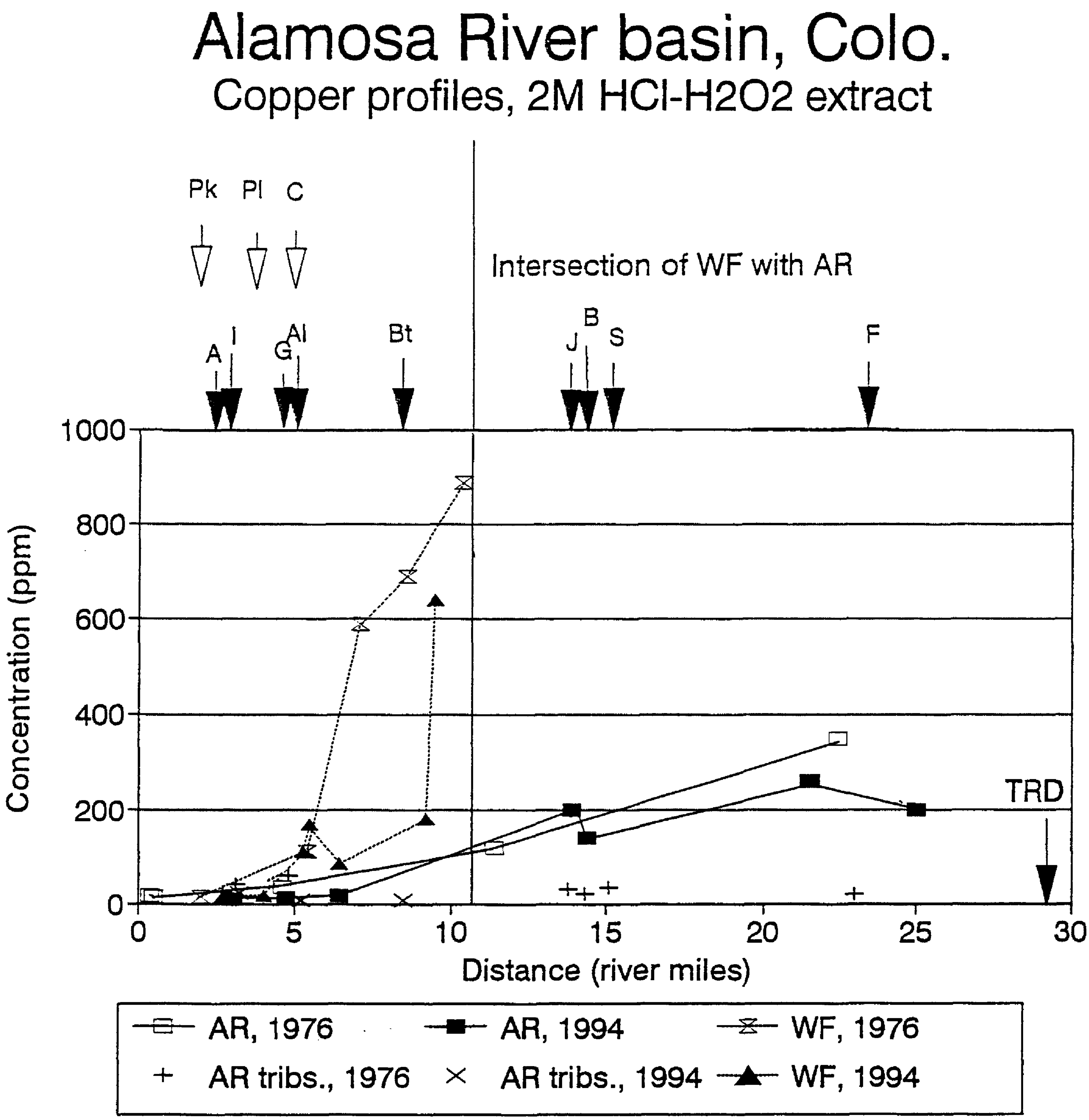


Figure 10A. Metal profiles for copper released using the HCl-PRX extraction procedure (Gulson and others, 1992). Abbreviations are the same as those used in fig. 8A.

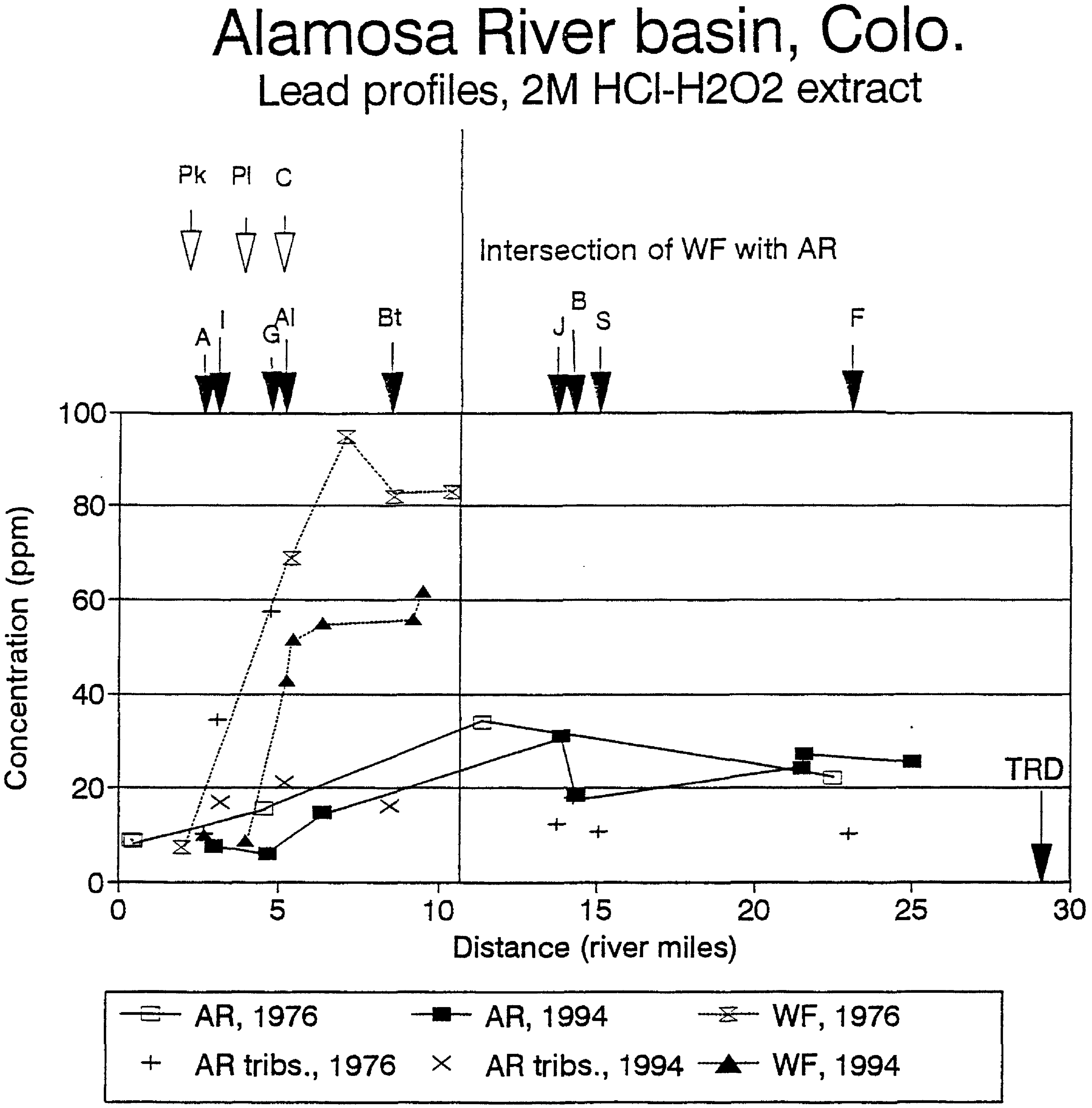


Figure 10B. Metal profiles for lead released using the HCl-PRX extraction procedure (Gulson and others, 1992). Abbreviations are the same as those used in fig. 8A.

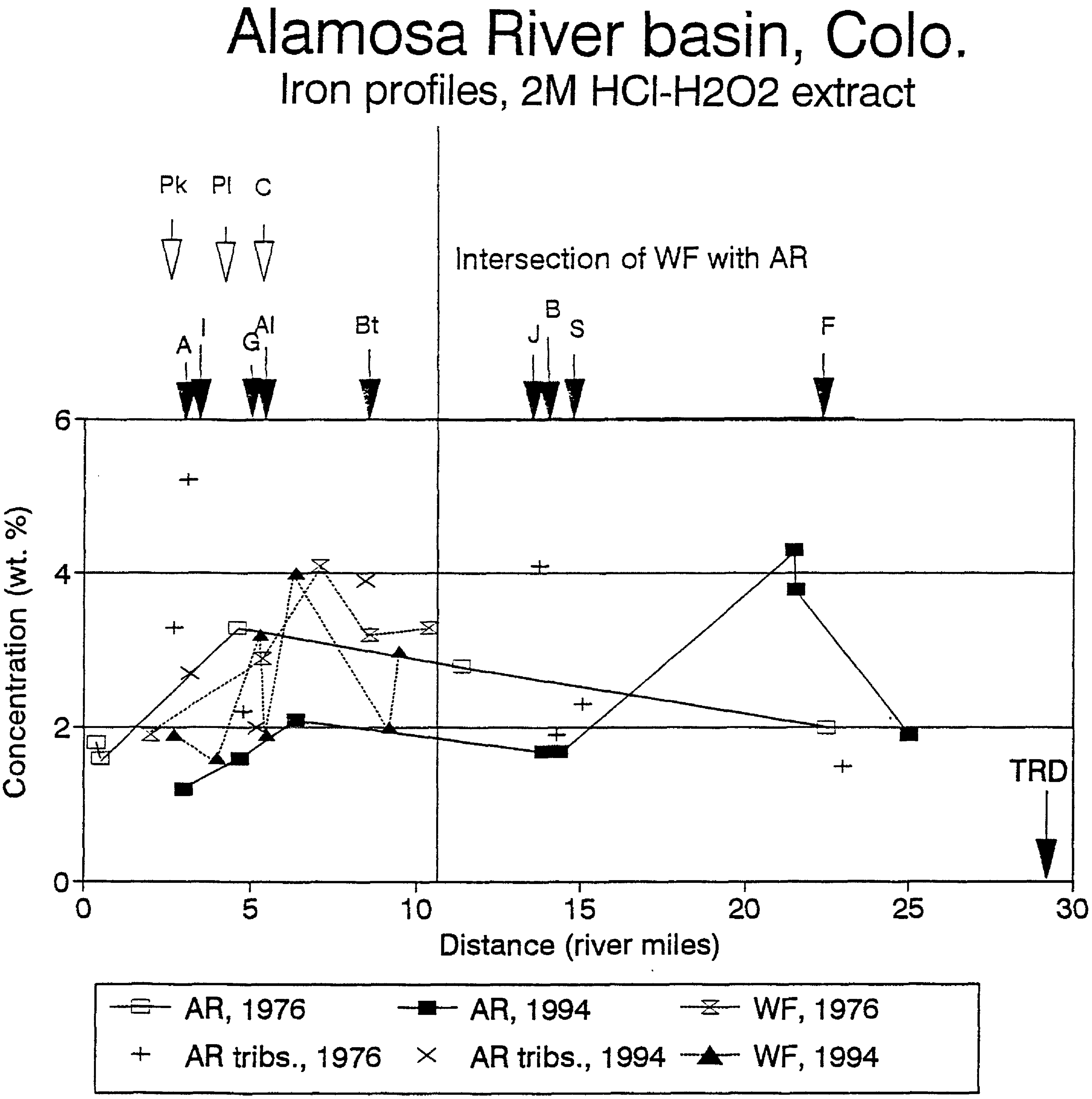


Figure 10C. Metal profiles for iron released using the HCl-PRX extraction procedure (Gulson and others, 1992). Abbreviations are the same as those used in fig. 8A.

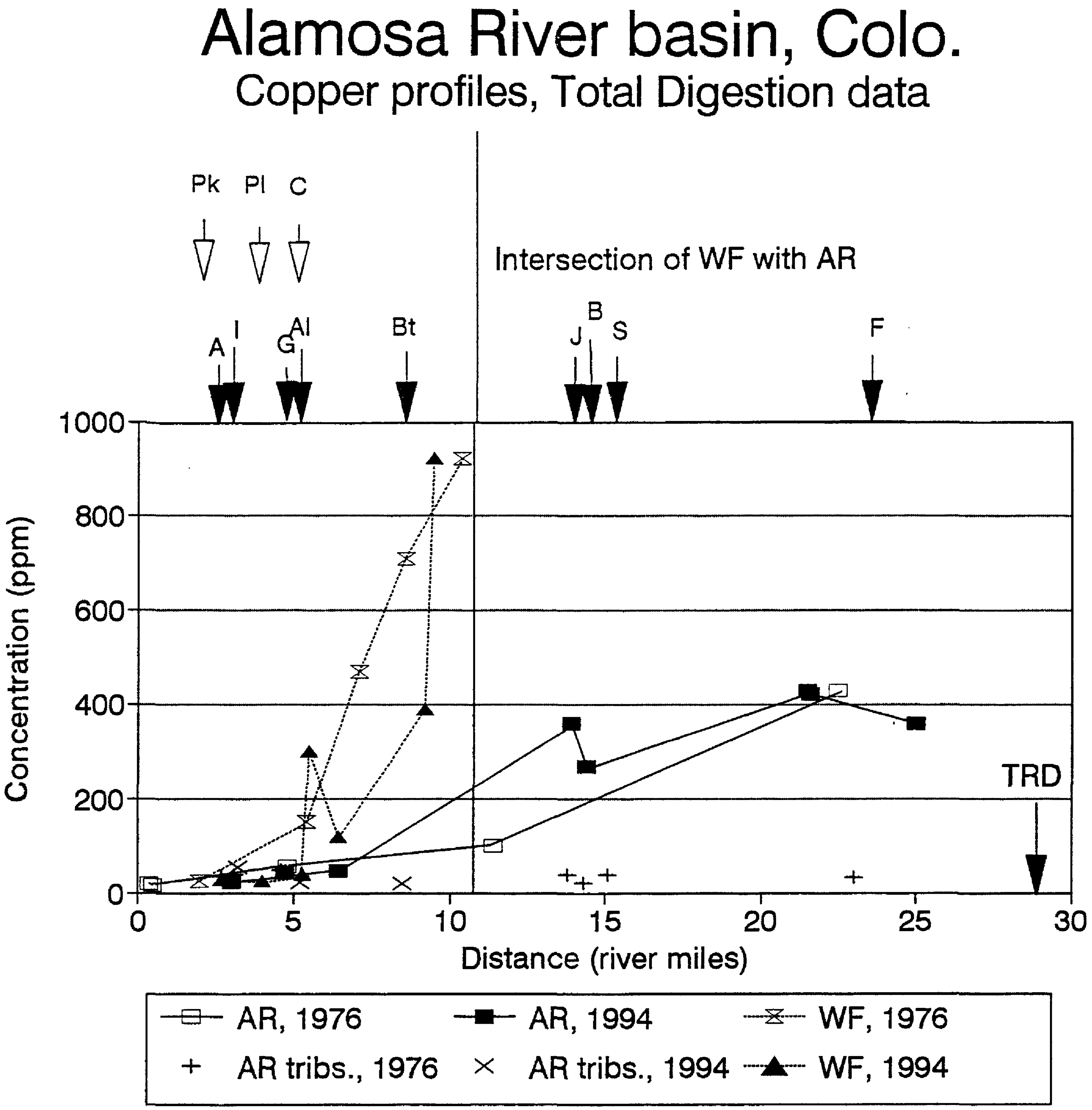


Figure 11A. Metal profiles for copper using the USGS total digestion procedure (Briggs, 1990). Abbreviations are the same as those used in fig. 8A.

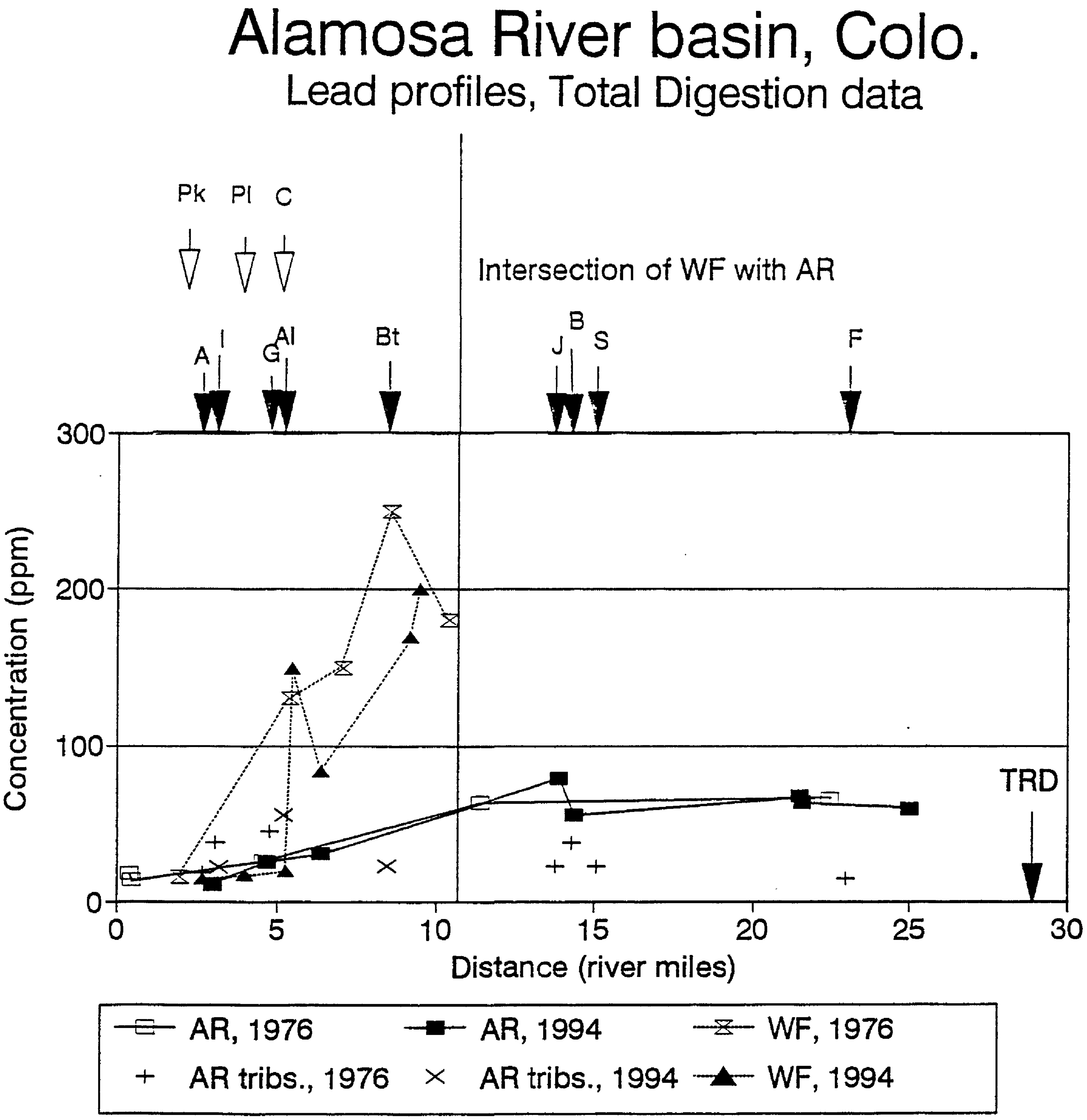


Figure 11B. Metal profiles for lead using the USGS total digestion procedure (Briggs, 1990). Abbreviations are the same as those used in fig. 8A.

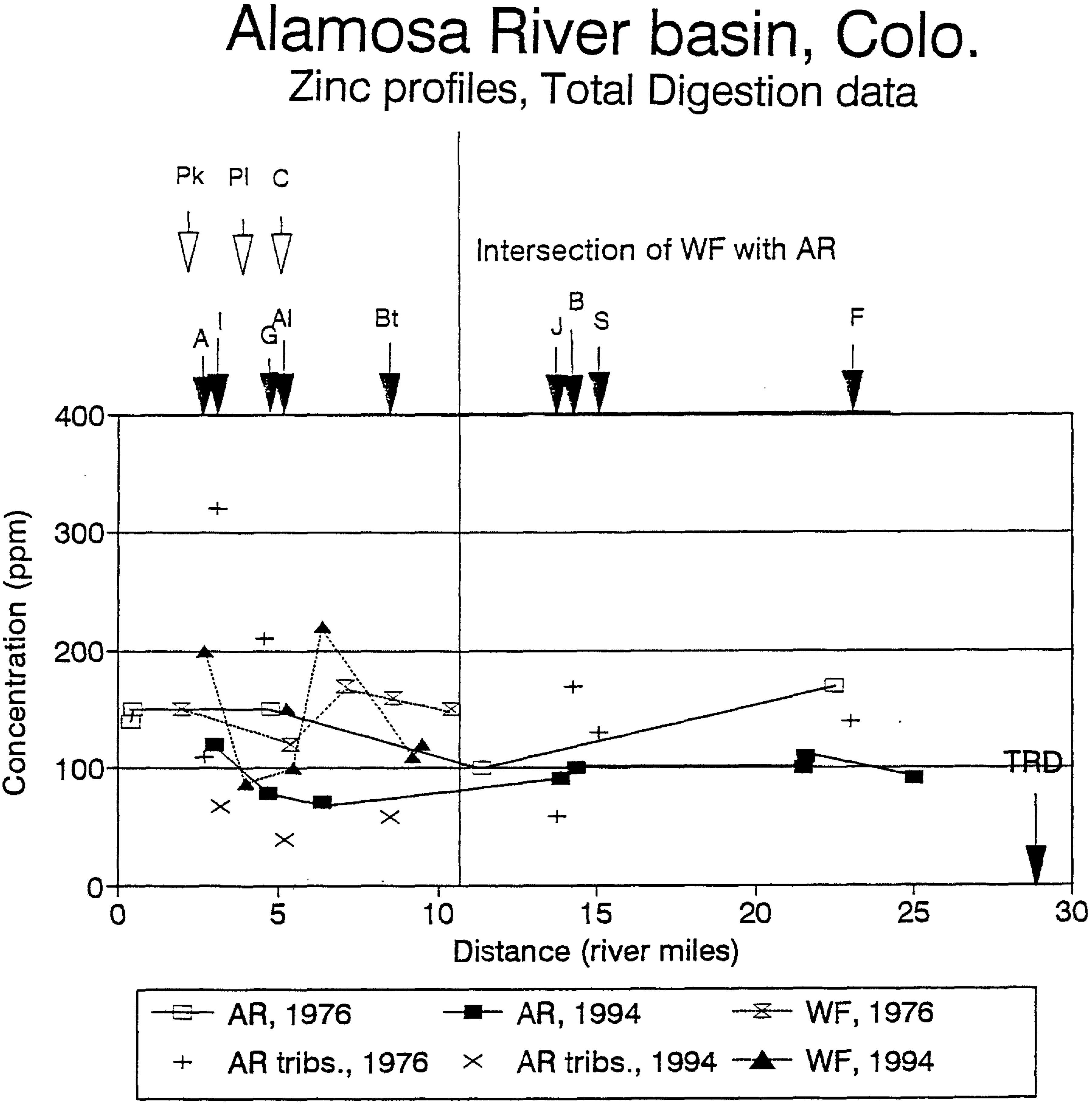


Figure 11C. Metal profiles for zinc using the USGS total digestion procedure (Briggs, 1990). Abbreviations are the same as those used in fig. 8A.

GEOCHEMICAL ENRICHMENT AND COMPARISONS OF PROFILES FROM THE 1976 NURE STREAM SEDIMENT AND 1994 EPA STREAM SEDIMENT DATA

Copper, lead, and zinc show relatively minor variations in concentration between the two geochemical baseline sample suites taken in 1976 and 1994 (fig. 11). Minor variations are due primarily to the metals introduced into the Wightman Fork from the Summitville deposit (downstream from the confluence of the Wightman Fork with Cropsy Creek at about 5.5 mi). The lead and copper profiles show that the Summitville deposit contributed large amounts of copper and lead to the Wightman Fork sediments in both 1976 and 1994. Copper concentrations in the upper Alamosa River in both baseline suites averages about 30 ppm whereas the copper concentration in the lower Alamosa River in the 1994 geochemical baseline exceeded 300 ppm. Similar high values were obtained in the 1976 geochemical baseline at site C26811. Copper concentrations in stream sediments of the Wightman Fork below Cropsy Creek exceeded 700 ppm in the 1976 geochemical baseline. The geochemical data from the 1994 sediment baseline indicate that copper concentrations are at substantially the same levels, but the data show more scatter, probably due to differences in sampling techniques.

Lead concentrations in sediments of the lower Alamosa River remained constant at about 60 ppm in both the 1976 and the 1994 baselines. Lead concentrations in the upper Alamosa River exceeded 25-30 ppm; higher concentrations were seen in the tributaries from the Stunner area. Similar values were found in the Park Creek and Pipeline Creek drainages above the Summitville deposit. Lead concentrations in stream sediments of the Wightman Fork below Cropsy Creek were about 200 ppm in both the 1976 and the 1994 geochemical baselines. Zinc concentrations in the lower Alamosa River appear to be lower in the 1994 profile (about 100 ppm) suggesting that the pH of the water has decreased sufficiently since 1976 to retard the adsorption of zinc onto the hydrous iron- and manganese-oxide phases.

Major changes in the mineralogy of the sediment loads between the two geochemical baselines are also evident from the major element data. Changes in the concentrations of iron in the sediments of the lower Alamosa River are indicated by comparisons of the two geochemical baselines (fig. 12a). These changes are rather subtle and the data are perturbed by the high iron concentrations from site AR44.4. Major changes in the concentration of aluminum (figure 12b) however indicate that erosion from the Summitville mine site has increased significantly since 1976. The concentration of aluminum at the Cropsy Creek site in the 1994 geochemical baseline exceeds 9.0 weight percent. The aluminum concentration in the lower Alamosa River increased from about 7.1 weight percent in the 1976 baseline to about 8.7 weight percent in the 1994 baseline.

Because the major elements make up the bulk of the mass of the sediments, it may be easier to see the impact of these changes by normalizing the geochemical data to an element whose concentration should not change as a result of the open-pit mining activity at Summitville. Hydrologic sorting of mineral phases on the basis of mineral density during transport in the river results in a systematic decrease in some element concentrations in the stream sediments along the river course. This phenomenon can be readily seem in several plots of metals not associated with the Summitville deposit. Profiles of the element titanium are shown as an example (fig. 13). Note in figure 13a that there is more variation in the concentration of titanium in stream sediments from the tributaries (both 1976 and 1994 samples are plotted) than there is in the river

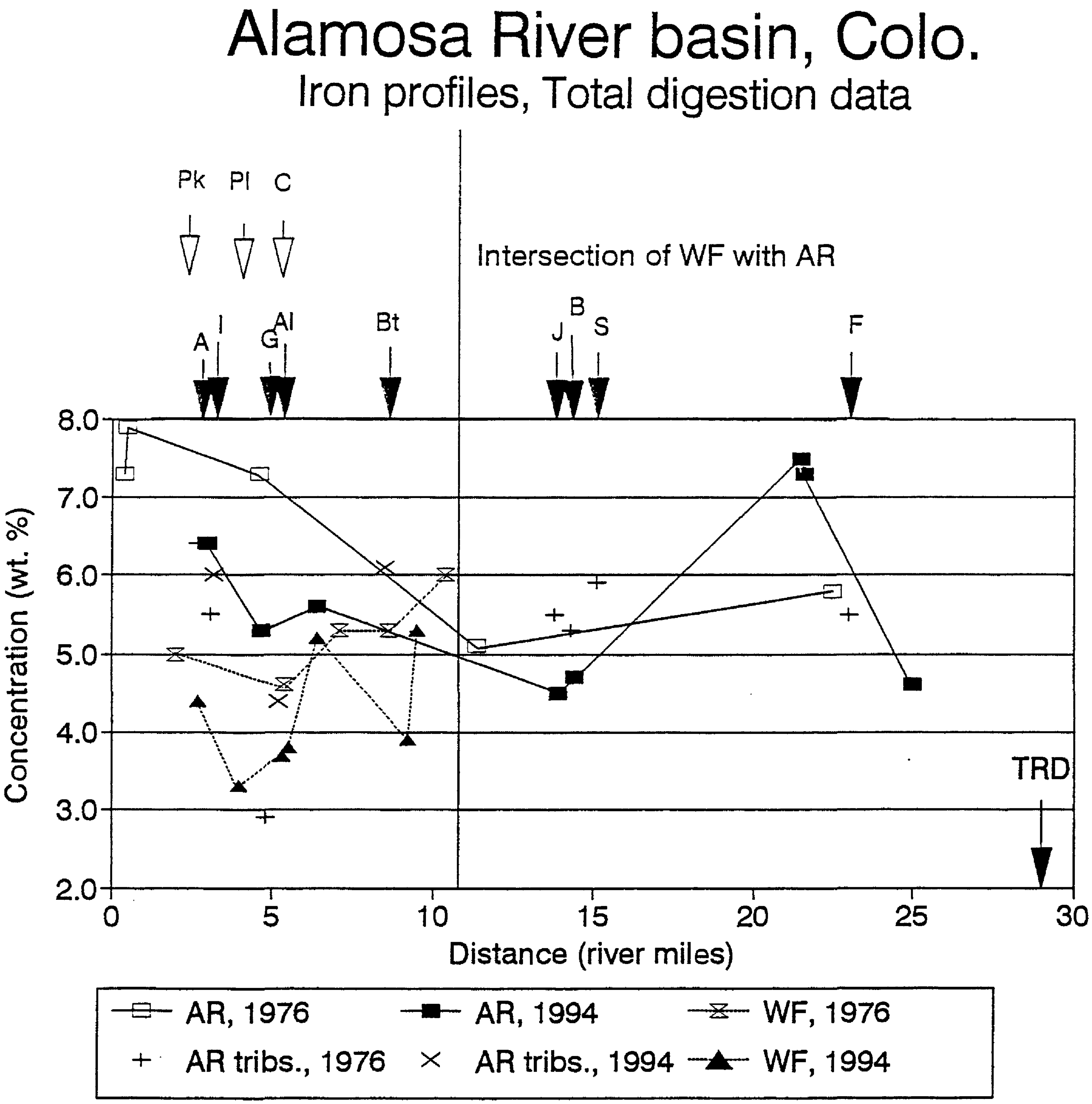


Figure 12A. Geochemical profiles for iron for both stream and river sediments from the 1976 and the 1994 geochemical baseline studies. Abbreviations are the same as those used in fig. 8A.

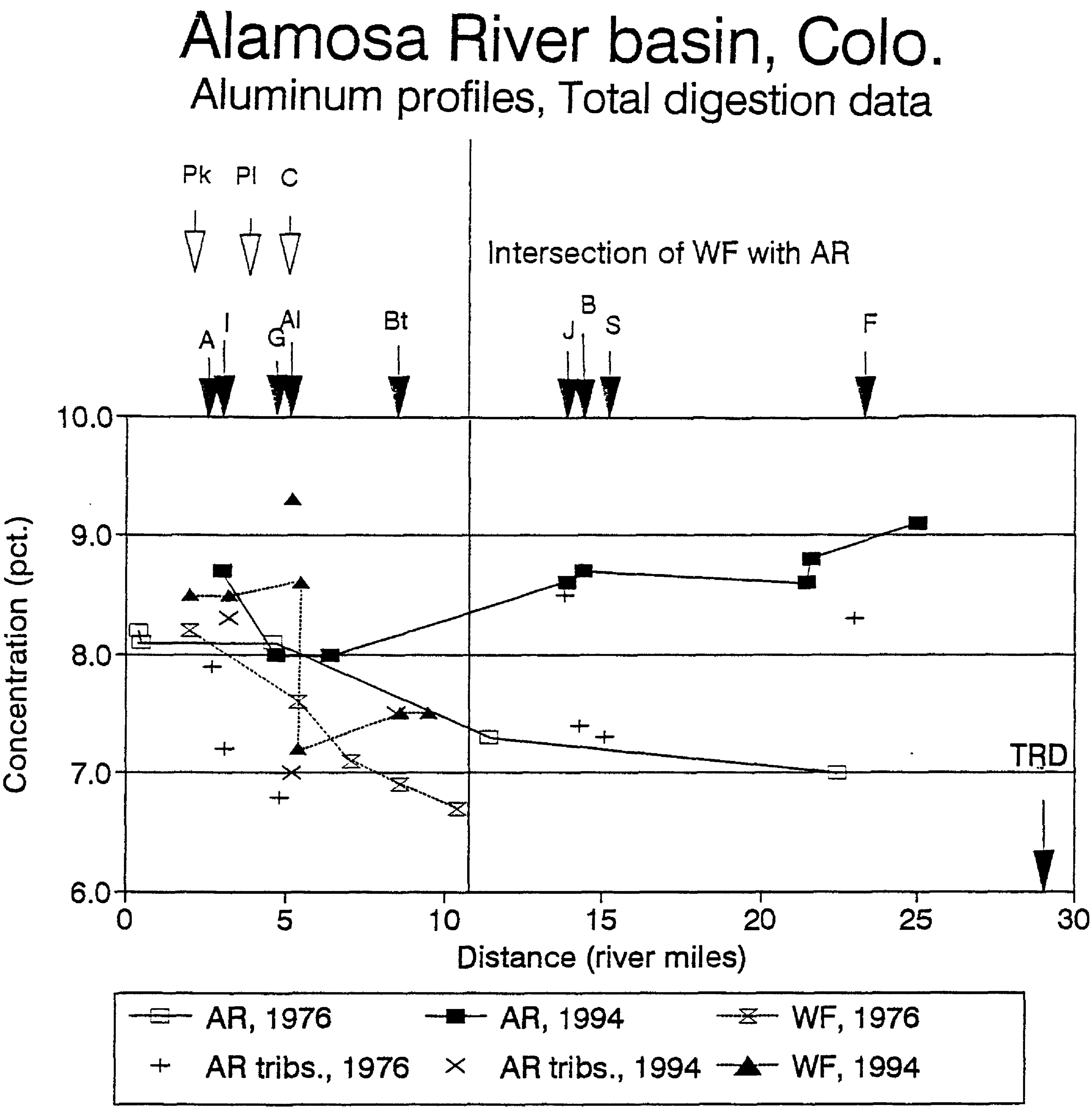


Figure 12B. Geochemical profiles for aluminum for both stream and river sediments from the 1976 and the 1994 geochemical baseline studies. Abbreviations are the same as those used in fig. 8A.

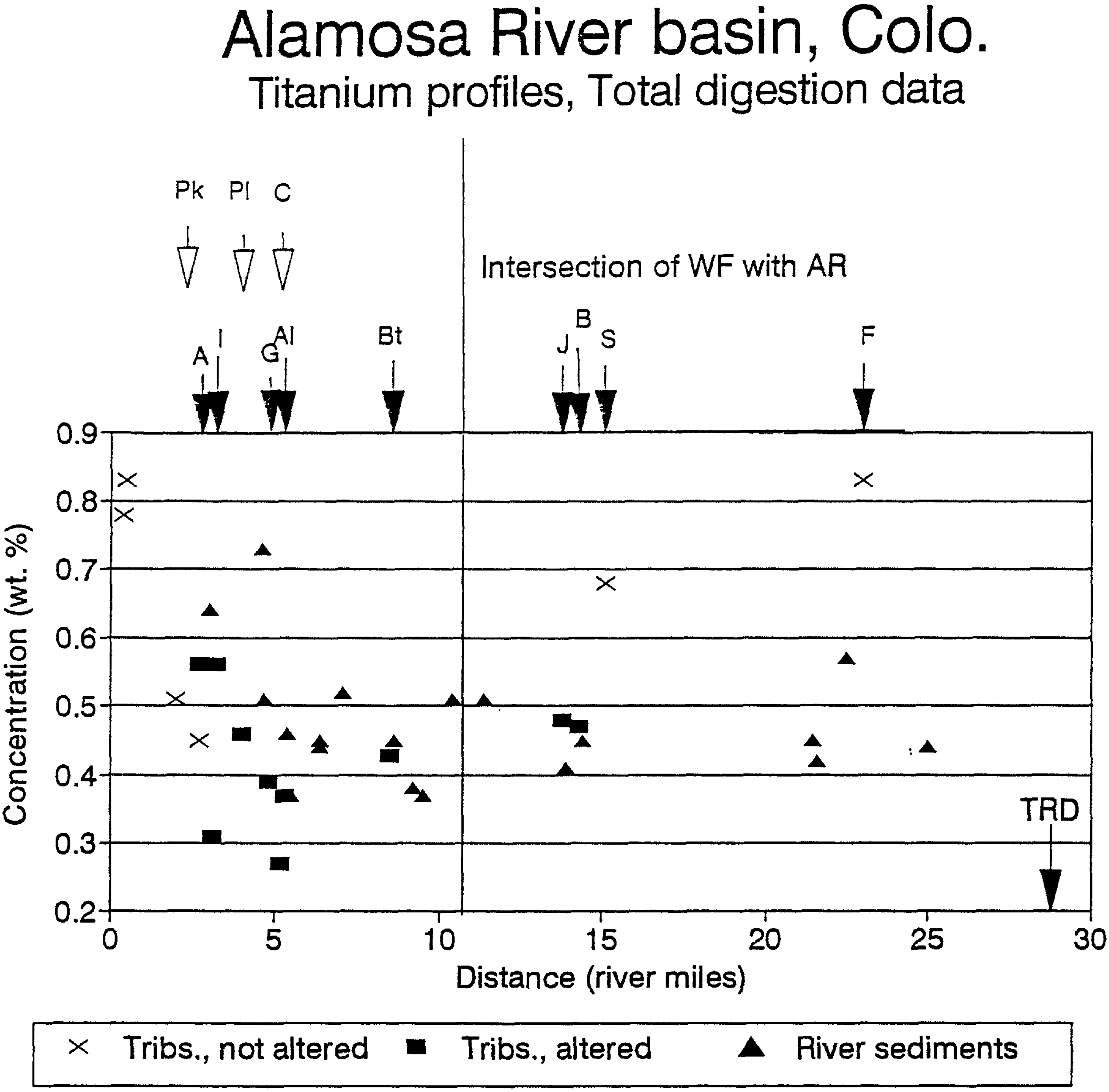


Figure 13A. Geochemical variation of titanium in stream sediments of the Alamosa River basin. Note that the data from the two geochemical baseline studies are grouped according to the alteration state of bedrock type underlying the tributary drainage basins. Abbreviations are the same as those used in fig. 8A.

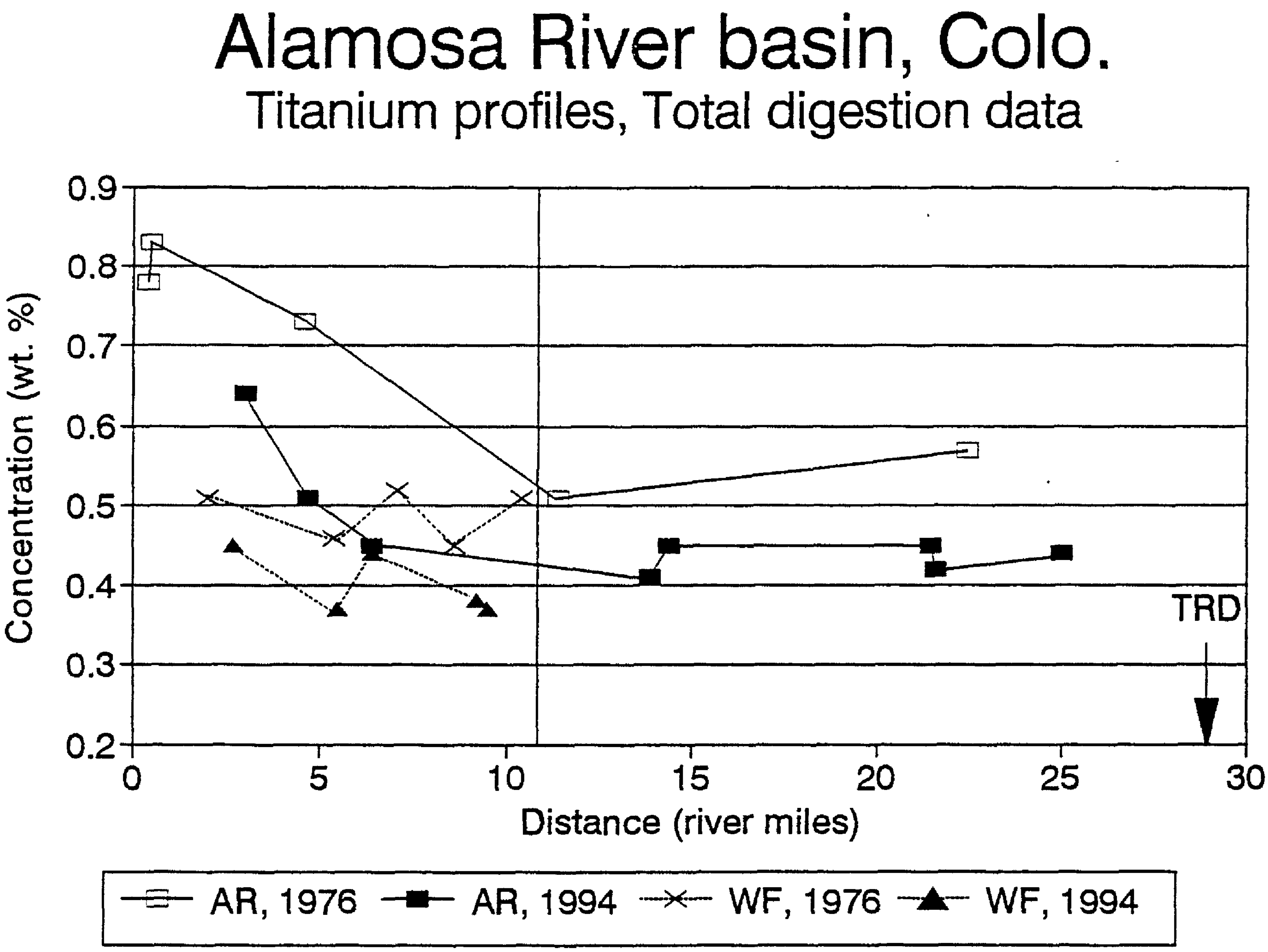


Figure 13B. Geochemical profile for titanium in river sediments of the Alamosa River basin.

sediments. Alteration of the bedrock within these tributary basins does not contribute to the variation of titanium in the stream sediments. Gray and Coolbaugh (1994) state that titanium in the acid-sulfate alteration zone of the Summitville deposit was conserved indicating that the alteration process did not move titanium into or out of the alteration zone. Furthermore, there is little variation of titanium between rock types in the Alamosa River basin (Lipman, 1975, tables 9 and 10). Although the concentration of titanium decreases downstream from the headwaters in sediments of both the Alamosa River and the Wightman Fork as a result of the hydrologic sorting process described above, titanium is present at concentration levels that are readily determined in all stream-sediment samples. The titanium profiles are relatively smooth although the 1976 profile is offset from that of the 1994 profile suggesting that sampling techniques used in the two baselines were somewhat different.

We have chosen titanium as the element against which to plot the major-element geochemical data (compare figs. 12 and 14). Element-ratio plots (fig. 14a) indicate that iron concentrations increased about ten percent in the 1994 sediment baseline of the lower Alamosa River relative to iron present in the 1976 geochemical baseline (that is the ratio increased from about 10 to 11). This trend is not readily apparent in the total element data (fig. 12a), in fact it appears that the iron content has decreased. (Note that the normalized iron concentration at site AR44.4 is extremely elevated; we conclude that this site may be non-representative of the sediment in the lower Alamosa River.) The change in iron concentrations between the 1976 and the 1994 sediments baselines is largely in response to the dramatic changes in aluminum content between the two years. Aluminum concentrations increased by thirty to forty percent (that is, from a ratioed value of about 14 to about 18-20, fig. 14b) between the 1976 and the 1994 geochemical baselines! The impact of the increased aluminum concentration is not as readily apparent in the plot showing total aluminum concentrations (fig. 13b). Since there is substantially no difference in the aluminum contents of the HYDXAMN and the HCl-PRX extraction data between the two baselines, we conclude that the increase in aluminum reflects a substantial increase in clay minerals being eroded and deposited in the lower Alamosa River following open-pit mining at Summitville. Removal of a large amount of material from the Summitville deposit to the waste piles has exposed a substantial amount of material containing large amounts of kaolinite to rapid erosion (Plumlee and others, 1995b; Gray and others, 1994). Elevated concentrations of aluminum in the sediments from Cropsy Creek corroborate this interpretation.

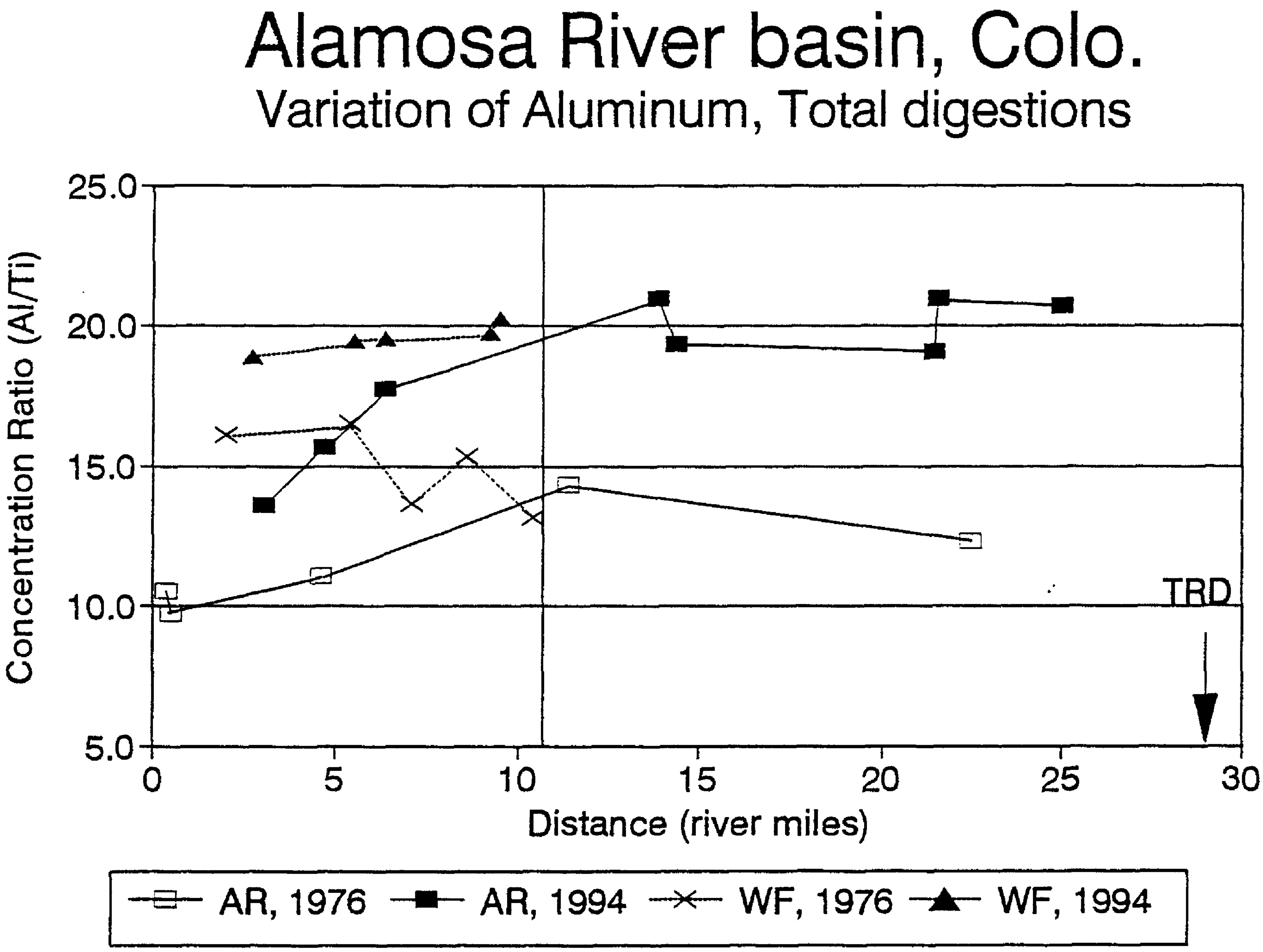


Figure 14A. Geochemical variation of aluminum in river sediments only (ratioed to titanium) from the 1976 and the 1994 geochemical baselines. Abbreviations are the same as those used in fig. 8A.

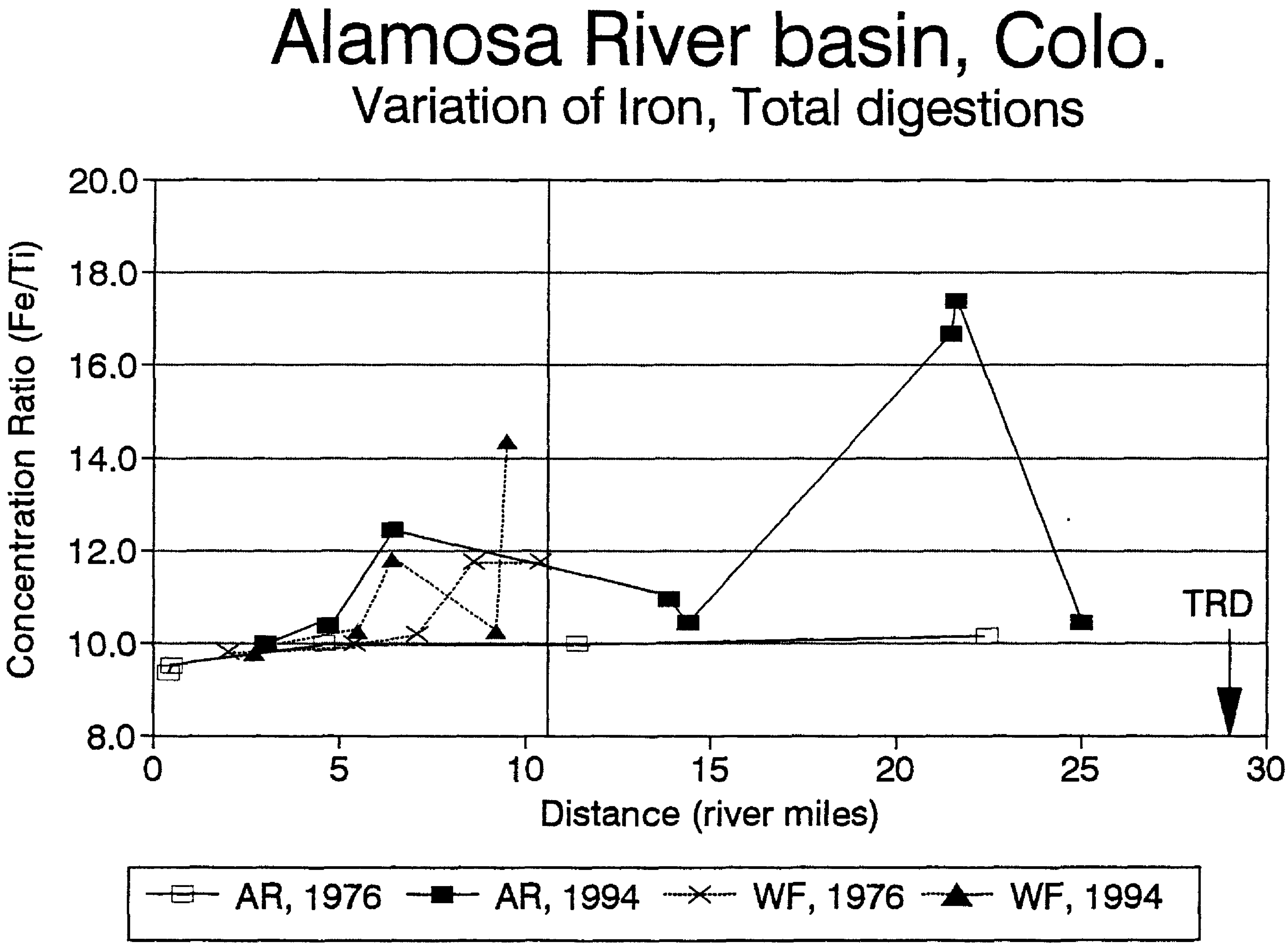


Figure 14B. Geochemical variation of iron in river sediments only (ratioed to titanium) from the 1976 and the 1994 geochemical baselines. Abbreviations are the same as those used in fig. 8A.

LEAD-ISOTOPIC DATA AND INTERPRETATION

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 (for example see Gulson, 1986). 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-100-mesh fraction of the stream sediments (that is, the 2M $HCl-H_2O_2$ leachates) to "fingerprint" and quantify the contribution from the mineral deposits in the headwaters.

Lipman and others (1978) developed isotopic and chemical data and interpreted the evolutionary history of the rocks of the San Juan volcanic field. They argued that the magmas were formed by partial melting of previously existing crustal rocks ranging in age from 1.8 to 1.45 billion years. Because these pre-existing crustal rocks contained variable amounts of uranium, thorium, and lead, the radiogenic growth of lead in these individual source regions resulted in a heterogeneous lower crust. Partial melting of this lower crustal source in Oligocene time produced magmas that had different lead-isotopic ratios. Hydrothermal fluids leached sources in the crust that also had variable lead-isotopic compositions and resulted in ore deposits in the Alamosa River basin that have discrete lead-isotopic compositions. This evolutionary process is common in silicic volcanic fields in large cratonic masses such as the San Juan volcanic field.

The lead-isotopic data from stream sediments collected from the tributaries, like the geochemical data, reflect the rocks being eroded within the drainage basin. Published lead-isotopic analyses of these different rock units are plotted in figure 15. There are substantial differences in lead-isotopic compositions between the individual rock units. The isotopic composition of lead from tributaries underlain by both fresh and altered rock reflect the isotopic composition of lead in the rocks that underlie their respective drainage basins.

The lead-isotopic composition of sediments from the Wightman Fork below the Summitville deposit and on the lower Alamosa River have a uniform lead-isotopic composition in the 1976 geochemical baseline at an average $^{206}Pb/^{204}Pb$ value of about 18.05 (fig. 16). We interpret this lead-isotopic signature to be dominated by lead derived from the weathering of the South Mountain quartz latite that hosts the Summitville deposit. This is not a surprising result because the Summitville deposit is a low-lead and low-zinc deposit (Gray and Coolbaugh, 1994) and has produced acid-mine-drainage in the Wightman Fork for many years. The lead-isotopic composition in the 1976 stream sediments does not match the composition of water draining from the Chandler and Reynolds adits and seeps within the open-pit (table 2) nor that of the base metal

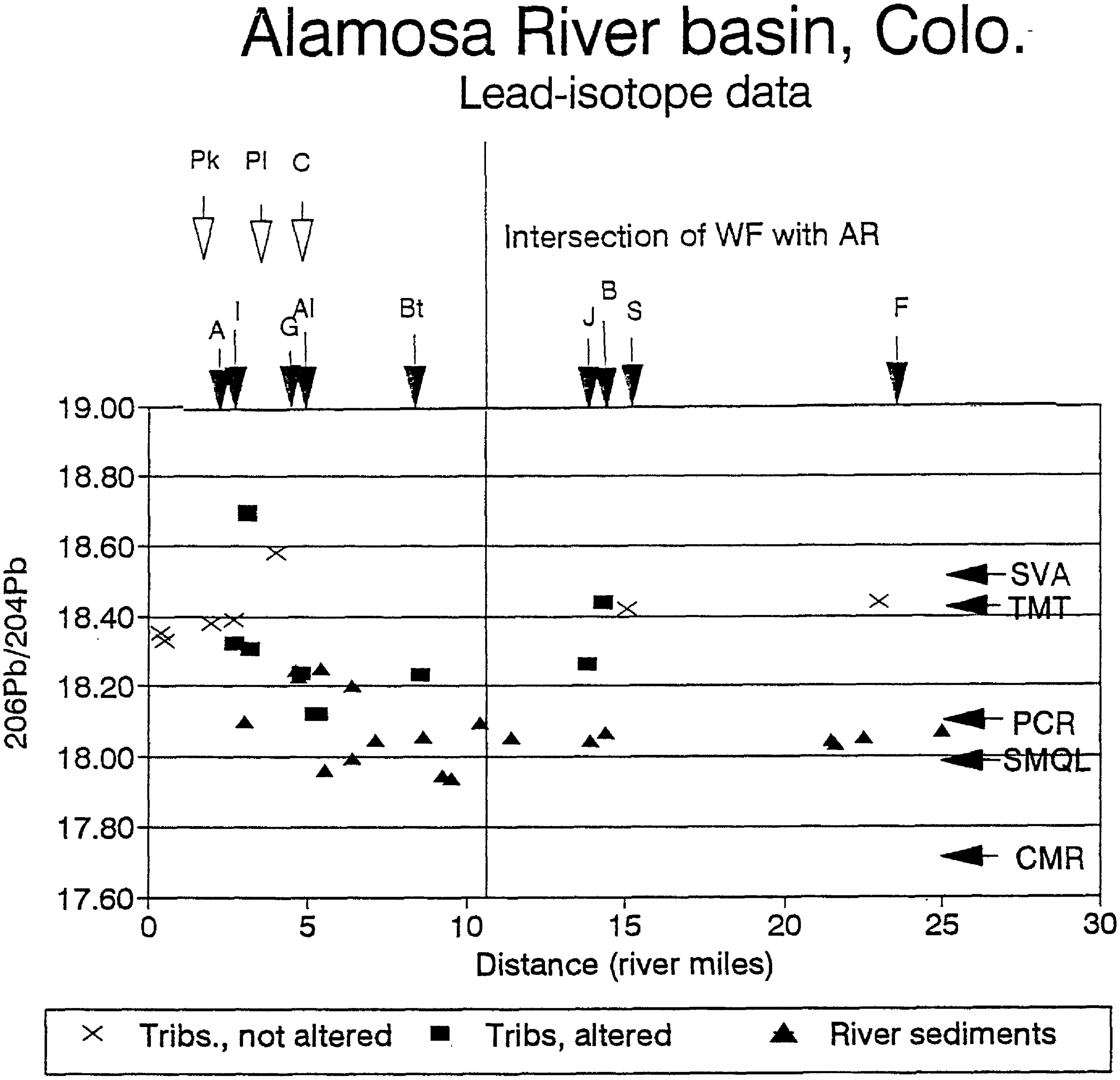


Figure 15A. $^{206}Pb/^{204}Pb$ isotopic profile showing the variation of lead-isotopic composition in stream sediments from tributary drainage basins containing both hydrothermally altered and fresh bedrock compared with the lead-isotopic compositions determined in river sediments. Also shown by the arrows on the right-hand side of the diagrams are the lead-isotopic compositions of the individual rock units present in the Alamosa River basin (CMR, Cropsy Mountain rhyolite; SMQL, South Mountain quartz latite; PCR, Park Creek rhyolite; TMT, Treasure Mountain tuff; and SVA, Summitville andesite. There are two analyses of SVA, the upper one plots where it is shown on the figure, the lower one is approximately equivalent to the analysis plotted for PCR (data from table 3). Analytical error for the lead-isotopic ratios plotted is smaller than the size of the symbol (see tables A8a and A8b). Abbreviations at the top of the figure are the same as those used in fig. 8A.

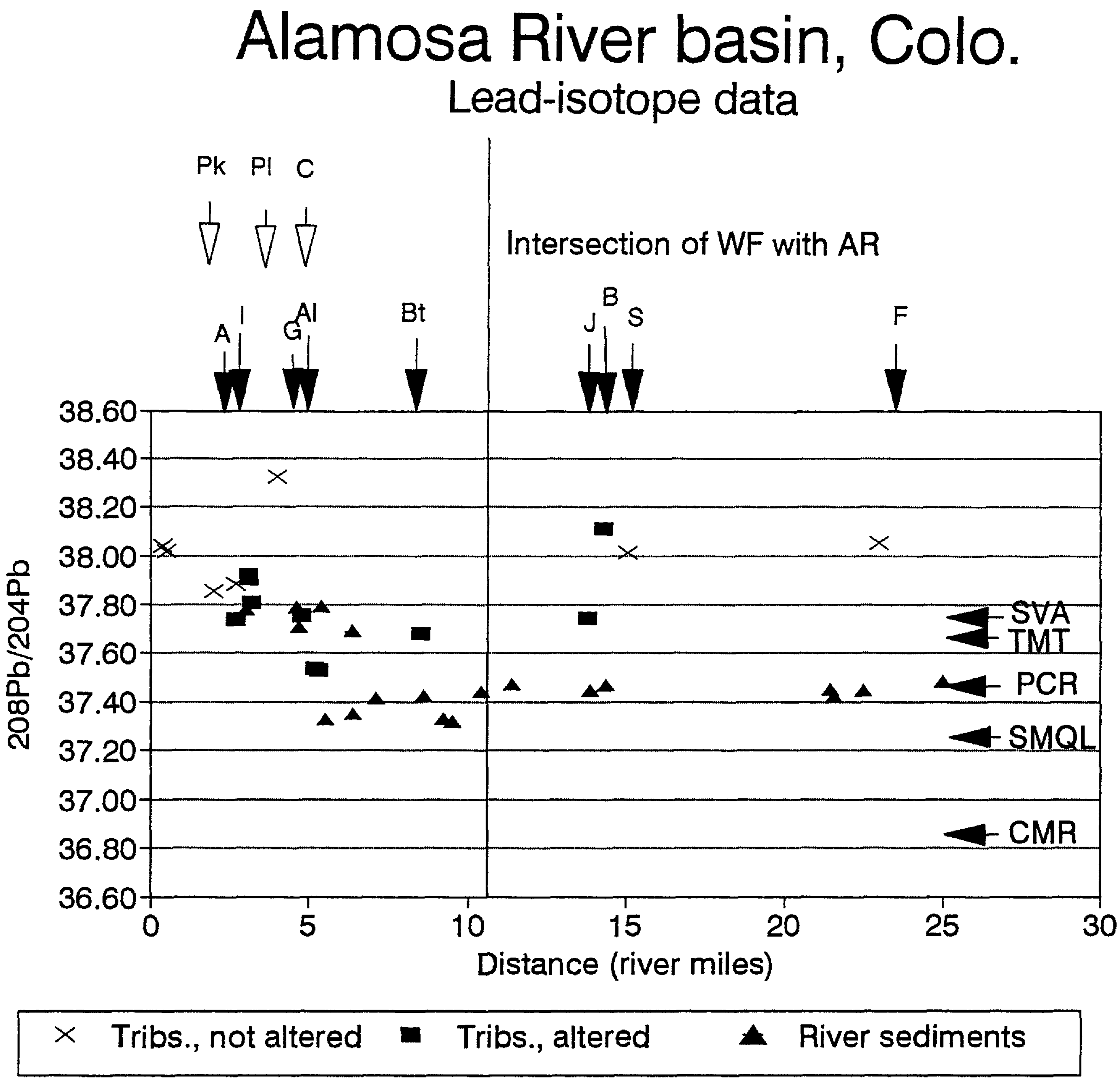


Figure 15B. $^{208}Pb/^{204}Pb$ isotopic profile showing the variation of lead-isotopic composition in stream sediments from tributary drainage basins containing both hydrothermally altered and fresh bedrock compared with the lead-isotopic compositions determined in river sediments. Also shown by the arrows on the right-hand side of the diagrams are the lead-isotopic compositions of the individual rock units present in the Alamosa River basin (CMR, Cropsy Mountain rhyolite; SMQL, South Mountain quartz latite; PCR, Park Creek rhyolite; TMT, Treasure Mountain tuff; and SVA, Summitville andesite. There are two analyses of SVA, the upper one plots where it is shown on the figure, the lower one is approximately equivalent to the analysis plotted for PCR (data from table 3). Analytical error for the lead-isotopic ratios plotted is smaller than the size of the symbol (see tables A8a and A8b). Abbreviations at the top of the figure are the same as those used in fig. 8A.

Table 2. Lead-isotopic data from aqueous sources in the Summitville open-pit, Colorado

Location	Date	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$
Portable Interim Treatment System[1]	Jan. 24, 1995	17.818	15.504	37.168
Chandler adit[2]	July 20, 1994	17.828	15.510	37.190
	August 29, 1994	17.818	15.498	37.181
Ch Seeps	August 30, 1994	17.821	15.509	37.189
Missionary seep east	July 20, 1994	17.820	15.508	38.181
Reynolds adit	July 20, 1994	17.805	15.492	37.131

[1] Sample provided by M.M. Roeber, Jr.; lead-isotopic analysis by Branch of Isotope Geology, U.S. Geological Survey.

[2] Samples from G.L. Plumlee (see fig. 3 for sample localities); lead-isotopic analyses by R.B. Vaughn.

Table 3. Published lead-isotopic data for rocks and ores from the Platoro Caldera, Colorado

Formation	Age (Ma)	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{207}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{208}\text{Pb}}{^{204}\text{Pb}}$
Rock data[1]				
Treasure Mountain Tuff, La Jara Canyon Member	29.8	18.42	15.55	37.66
Summitville Andesite	~29.5	18.52	15.57	37.75
		18.11	15.54	37.59
Rhyodacite of Park Creek	~29	18.11	15.48	37.47
Quartz Latite of South Mountain	22.8	18.00	15.52	37.22
		17.97	15.51	37.28
		17.95	15.52	37.28
Rhyolite of Cropsy Mountain	20.2	17.69	15.44	36.90
		17.68	15.41	36.80
Ore data[2]				
Summitville deposit				
Reynolds adit		17.810	15.523	37.213
		17.821	15.521	37.209
Narrow Gauge		17.79	15.46	37.00
Jasper Creek area				
Miser mine		18.112	15.546	37.574
Crater Creek area		18.925	15.625	37.853

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[1] Data from Lipman and others (1978, table 3, p. 68).

[2] Data from Doe and others (1979, table 2, p. 6).

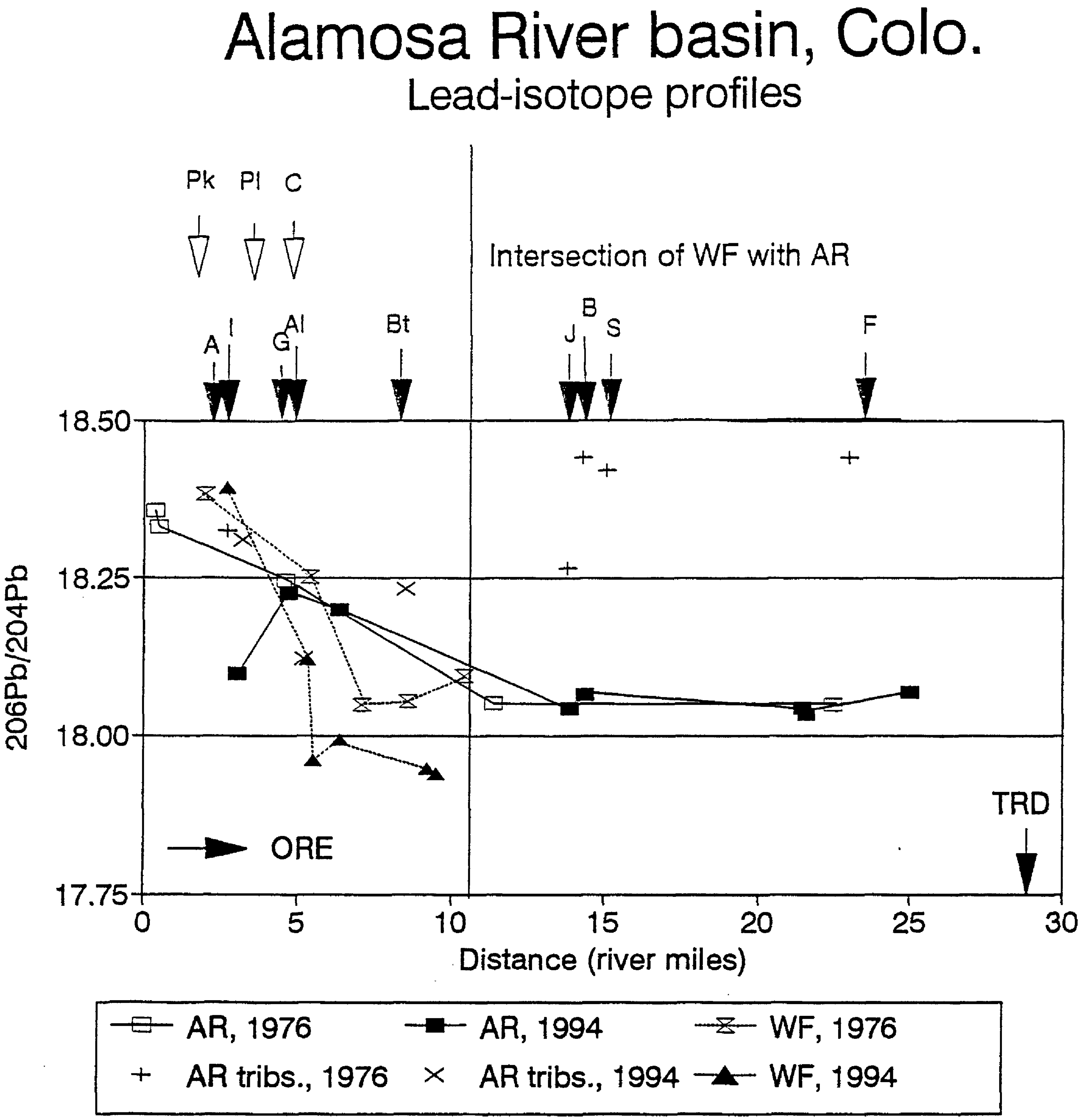

Figure 16A. $^{206}Pb/^{204}Pb$ isotope profiles showing the change in lead-isotopic composition in river sediments from the Alamosa River and the Wightman Fork. River-sediment samples from the different geochemical baselines are connected by different line types. The composition of the Summitville base metal sulfide-bearing barite veins and the aqueous seeps in the Summitville open-pit are indicated by the arrow labeled ORE. The composition of galena from the Miser Mine near Jasper (fig. 4) is indicated by the arrow on the river profile. Analytical error for the lead-isotopic ratios plotted is smaller than the size of the symbol (see tables A8a and A8b). Abbreviations at the top of the figure are the same as those used in fig. 8A.

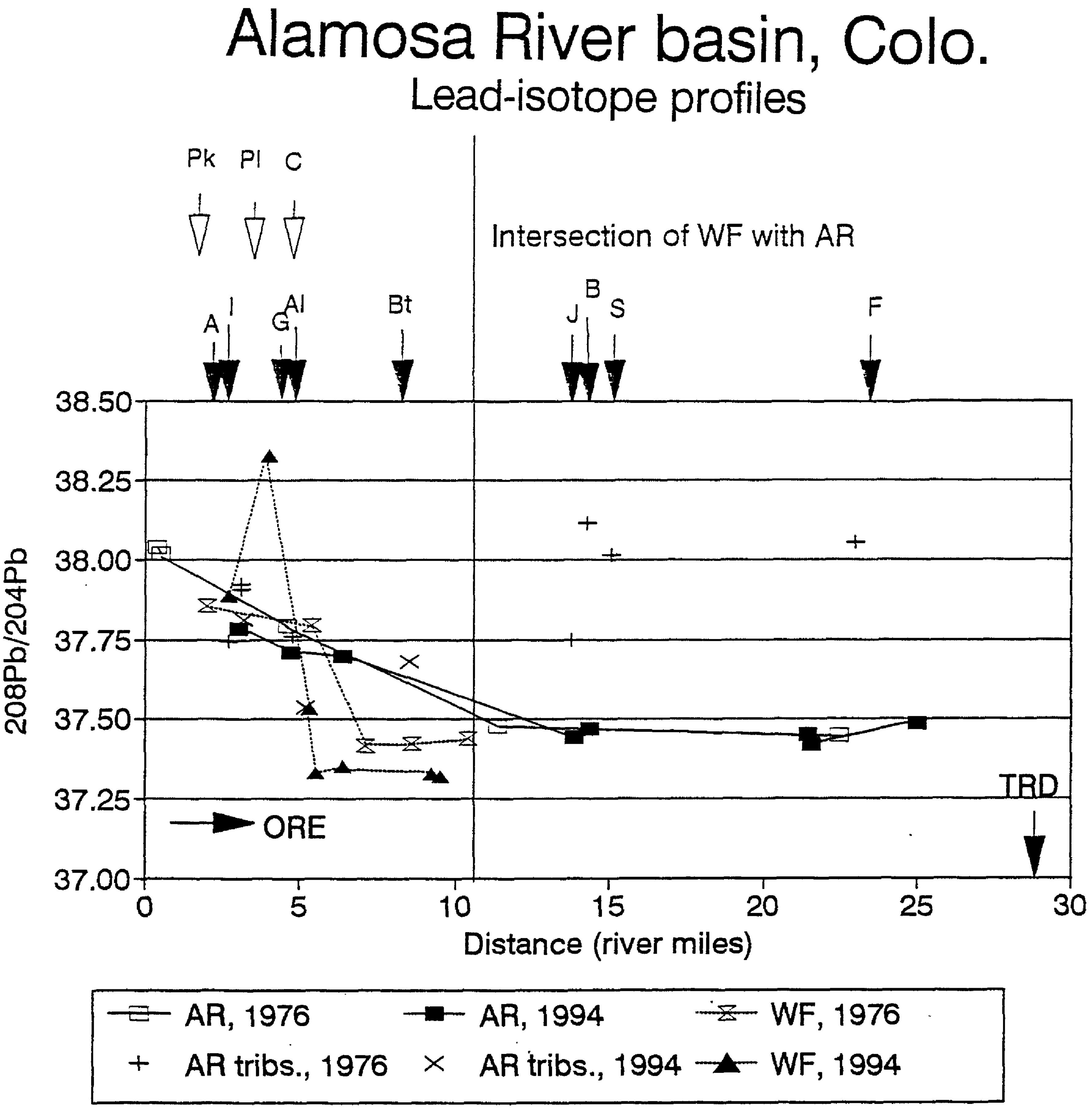

Figure 16B. $^{208}Pb/^{204}Pb$ isotope profiles showing the change in lead-isotopic composition in river sediments from the Alamosa River and the Wightman Fork. River-sediment samples from the different geochemical baselines are connected by different line types. The composition of the Summitville base metal sulfide-bearing barite veins and the aqueous seeps in the Summitville open-pit are indicated by the arrow labeled ORE. The composition of galena from the Miser Mine near Jasper (fig. 4) is indicated by the arrow on the river profile. Analytical error for the lead-isotopic ratios plotted is smaller than the size of the symbol (see tables A8a and A8b). Abbreviations at the top of the figure are the same as those used in fig. 8A.

sulfide-bearing barite veins present in the Summitville deposit (table 3). Both the acidic waters sampled from the open pit and the galenas analyzed have a $^{206}Pb/^{204}Pb$ value of about 17.82. This is a surprising result that indicates that the bulk of the lead load in the Wightman Fork comes from erosion of altered material in the Summitville deposit in the South Mountain quartz latite rather than from the acid-mine drainage caused by flow from the Reynolds adit.

The isotopic composition of lead in sediments in the Wightman Fork in the 1994 geochemical baseline has a different, less radiogenic lead-isotopic composition than that from the 1976 geochemical baseline. The average value of lead in the sediments collected in the Wightman Fork below the Summitville open pit had a $^{206}Pb/^{204}Pb$ value of about 17.95. We interpret the lead-isotopic compositions measured in the stream sediments of the Wightman Fork in the two different baselines to reflect mixtures of rock lead derived from sulfuric acid attack of the South Mountain quartz latite and lead derived from the base metal sulfide-bearing barite veins of the Summitville deposit. The isotopic composition of lead in the stream sediments from the Lower Wightman Fork in the 1976 geochemical baseline can be accounted for largely by the isotopic composition and variation of lead in the South Mountain quartz latite. However, the change in the isotopic composition of lead in the 1994 geochemical baseline reflects a substantial addition of lead from the base-metal ores in the Summitville deposit.

One of the powerful uses of lead isotopes in environmental geochemistry is the leverage they provide to calculate the contribution of a point-source of metal contamination to the total metal load in the sediments of the Alamosa River. We can calculate the contribution of sediments from the Summitville open-pit mine to the sediment load of the Wightman Fork by the two sets of isotopic data. The lever rule calculation is shown in the following equation:

$$Pb_{PS} = \{[R_{76} - R_{94}] / [R_{76} - R_{ore}]\} \times 100$$

Where: Pb_{PS} is the percent of the lead load attributed to a specific point-source of lead contamination,

R_{76} is the lead isotope ratio of the stream sediments of the Wightman Fork from 1976 geochemical baseline,

R_{94} is the lead isotope ratio of the stream sediments of the Wightman Fork from 1994 geochemical baseline, and

R_{ore} is the lead isotope ratio of the ore lead from the Summitville deposit.

We use an average value of $^{206}Pb/^{204}Pb = 18.05$ and $^{208}Pb/^{204}Pb = 37.42$ for the composition of lead from the sediments of the Wightman Fork below the Summitville deposit in the 1976 geochemical baseline, we use an average value of $^{206}Pb/^{204}Pb = 17.95$ and $^{208}Pb/^{204}Pb = 37.33$ for the composition of lead from the sediments of the Wightman Fork below the Summitville deposit in the 1994 geochemical baseline, and we use an average value of $^{206}Pb/^{204}Pb = 17.82$ and $^{208}Pb/^{204}Pb = 37.18$ for the composition of lead from the ore from the Summitville deposit to calculate the contribution of lead to the Wightman Fork resulting from the open-pit mining operation of SCMCI. We calculate that about 40 percent (that is, 43 percent using the $^{206}Pb/^{204}Pb$ data and 38 percent using the $^{208}Pb/^{204}Pb$ data) more of the lead in the 1994 stream sediments

sediments from the lower Wightman Fork was from the base metal sulfide-bearing barite veins. Since the composition of lead measured in the sediments of the Wightman Fork was not reflected in the 1994 sediments sampled from the lower Alamosa River, this change in lead-isotopic composition in the sediments of the Wightman Fork may represent a relatively recent event such as the increased release of metals and erosion at the site following the cessation of open-pit mining at the end of 1991, thus reducing the amount of rock lead derived from erosion of material from the waste dumps. If a sample had been collected from just below the intersection of the Wightman Fork with the Alamosa River during the 1994 geochemical baseline, this change should have been detected. However, because the nearest sediment-sample site analyzed is about 4 miles downstream, we were unable to detect this change in lead-isotopic composition in the lower Alamosa River sediments.

The lead-isotopic data from the two geochemical baselines also shows that the contribution of lead from the Wightman Fork totally dominates the lead budget of the lower Alamosa River in both the 1976 and the 1994 geochemical baselines. A baseline geochemical study of stream-sediment cores, accompanied by ^{210}Pb dating would be required to determine the pre-mining geochemical and lead-isotopic baselines of the Wightman Fork. Given that the oxidized ore deposit was exposed at the surface in 1870 (Raymond, 1877) we would expect that the isotopic composition of lead in the Wightman Fork would have been the same prior to mining. However, the metal load being added to the lower Alamosa River prior to mining remains to be determined.

COMPARISONS BETWEEN THE GEOCHEMICAL BASELINES DETERMINED USING STREAM-SEDIMENT AND WATER DATA

Environmental regulations governing impact of mining sites are based, in part, upon water quality (for example, see table 2 for the regulatory requirement for the Summitville mine site, Hutchinson and Cameron, 1995, p. 113). Although numerous studies of water quality of streams in the Alamosa River basin have been conducted in the recent past, neither complete sets of water data nor water samples are available from the past to assess either the impact of mining activity on water quality or to evaluate the geochemical baseline prior to the onset of mining (Miller and McHugh, 1994; Bove and others, 1995; Brown, 1995; Cain, 1995; Hutchinson and Cameron, 1995; Kirkham and others, 1995; Logsdon and Mudder, 1995; Miller and Van Zyl, 1995; Mueller and Mueller, 1995; Ortiz and others, 1995; Roeber and others, 1995; Walton-Day and others, 1995; Ward and Walton-Day, 1995). Furthermore, because water chemistry changes in response to spring runoff and storm events, the water chemistry represents an instantaneous measure of the state of the environment. If the relationship between annual variations in stream chemistry and the concentration of metals trapped in the fine-grained sediment in the stream bed could be established, perhaps a better measure of the long-term change in conditions resulting from mining activities could be defined.

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APPENDIX--Tables of analytical results

Table A1a. Analytical results for 1311 extraction of selected NURE samples from the Alamosa River basin, Colo.

Sample No.	K ppm	Mg ppm	Ca ppm	Al ppm	Fe ppm	As ppm	B ppm	Ba ppm
Alamosa River samples								
Composite	270	390	2300	<20	<20	<4	<2	21
C26456	200	240	1500	53	41	<4	<2	21
C26805	92	180	1700	<20	29	<4	<2	14
C26803	48	36	350	<20	<20	<4	<2	3.1
C26812	230	510	5100	<20	<20	<4	<2	22
Wightman Fork samples								
C26793	130	170	1400	<20	<20	<4	<2	12
C26796	39	45	350	42	<20	<4	<2	5.8
NIST Standard Reference Material								
SRM 2704	85	290	18000	<20	<20	<4	<2	16
SRM 2709	720	1600	13000	<20	<20	<4	8.2	43
SRM 2711	1000	1000	24000	<20	29	3.9	2.5	32

Sample No.	Cd ppm	Co ppm	Cu ppm	Mn ppm	Ni ppm	Pb ppm	Si ppm	Sr ppm	Zn ppm
Alamosa River samples									
Composite	<0.8	<0.4	0.7	110	<0.8	<2	290	23	<0.8
C26456	<0.8	<0.4	1.7	48	<0.8	<2	130	14	0.9
C26805	<0.8	0.4	2.5	47	<0.8	<2	110	15	1.7
C26803	<0.8	1.1	3.0	29	<0.8	<2	34	2.9	1.7
C26812	<0.8	<0.4	0.4	140	<0.8	<2	260	23	0.9
Wightman Fork samples									
C26793	<0.8	<0.4	1.7	55	<0.8	<2	64	12	1.4
C26796	<0.8	0.4	75	69	<0.8	<2	47	2.9	6.1
NIST Standard Reference Material									
SRM 2704	1.3	1.5	0.9	140	2.8	<2	44	26	100
SRM 2709	<0.8	0.4	0.9	86	1.1	<2	720	60	<0.8
SRM 2711	16	0.8	0.5	120	<0.8	5.8	520	35	3.8

Table A1b. Analytical results for 1311 extraction of selected EPA samples from the Alamosa River basin, Colo.

Sample No.	K ppm	Mg ppm	Ca ppm	Al ppm	Fe ppm	As ppm	Ba ppm
Alamosa River samples							
AR-49.5	54	380	2600	<20	<20	<4	22
IC-1	<20	<20	<20	<20	<20	<4	<0.4
AC-1	<20	20	<20	<20	28	<4	<0.4
AR-48.1	<20	118	600	<20	<20	<4	0.9
AR-41.0	<20	44	580	<20	<20	<4	0.6
AR-44.4	<20	40	320	<20	<20	<4	<0.4
AR-34.5	<20	68	540	<20	<20	<4	2.8
Wightman Fork samples							
CC-1	<20	<20	240	<20	<20	<4	4.2
WF-5.5	<20	<20	90	<20	48	<4	1.3
WF-1.0	<20	<20	106	<20	36	<4	<0.4
NIST Standard Reference Material							
SRM 2711	820	1000	25000	<20	30	5	29

Sample No.	Co ppm	Cu ppm	Mn ppm	Pb ppm	Si ppm	Sr ppm	Zn ppm
Alamosa River samples							
AR-49.5	1.2	1.7	360	<2	240	26	<0.8
IC-1	2.6	3.4	140	<2	36	<0.8	<0.8
AC-1	<0.8	2.4	8	<2	28	<0.8	1.9
AR-48.1	1.0	1.2	44	<2	76	5	1.2
AR-41.0	2.8	42	88	<2	110	2.4	6.0
AR-44.4	4.2	42	120	<2	144	2.2	5.8
AR-34.5	1.5	42	70	<2	102	4.2	5.0
Wightman Fork samples							
CC-1	1.3	3.6	220	<2	<20	2.2	19
WF-5.5	2.0	20	68	<2	36	<0.8	6.2
WF-1.0	3.0	74	40	<2	42	<0.8	7.6
NIST Standard Reference Material							
SRM 2711	1.2	2.6	110	9.8	460	34	3

Table A2a. Analytical results from 0.25M HCl-0.25M hydroxylamine hydrochloride extracts from NURE stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Latitude	Longitude	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm
Alamosa River samples												
Composite	37.3631	106.6200	160	600	2400	6500	7500	4000	120	27	6	2
Duplicate	37.3631	106.6200	110	360	2100	5900	6300	3200	98	26	5	<1
C26777	37.3697	106.5889	82	350	630	7200	22000	7700	140	41	36	2
C26776	37.3717	106.5844	53	430	530	1800	18000	3800	110	16	6	1
C26467	37.3778	106.5678	140	700	1700	6000	7500	4400	130	25	5	7
C26456	37.3817	106.5681	87	430	1300	4500	14000	4100	140	35	24	1
C26805	37.4089	106.5050	63	390	730	5900	9800	4500	110	18	3	2
C26803	37.4228	106.4794	73	460	370	1000	19000	2900	140	10	4	3
C26804	37.4211	106.4739	130	470	1400	6600	8000	3700	85	25	5	2
C26806	37.4189	106.4656	100	500	1100	7100	6000	4100	180	24	10	4
C26811	37.3897	106.3781	72	310	570	3000	10000	2300	110	14	7	2
C26812	37.3875	106.3767	100	580	1600	9600	3800	1900	110	35	5	1
Park Creek sample												
C26788	37.4347	106.6372	92	530	1000	5800	12000	2500	190	23	11	1
Wightman Fork samples												
C26793	37.4292	106.5850	70	550	500	2800	7500	3800	240	22	6	3
C26794	37.4297	106.5606	78	400	350	2400	13000	2300	180	22	8	3
C26795	37.4247	106.5378	49	300	300	2400	18000	3100	180	27	11	2
C26796	37.4044	106.5217	65	280	220	2000	16000	3400	160	25	8	3
NIST Standard Reference Materials												
SRM 2704			74	190	5400	25000	8300	1700	64	13	5	40
SRM 2709			480	1200	3700	14000	4500	4600	330	17	6	12
SRM 2711			110	1300	2300	21000	2200	2400	150	22	5	2

Table A2a. Analytical results from 0.25M HCl-0.25M hydroxylamine hydrochloride extracts from NURE stream-sediment samples, Alamosa River basin, Colo.--continued

Sample No.	Cu ppm	La ppm	Mn ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm
Alamosa River samples										
Composite	9	13	600	2.0	1300	9	50	9	11	20
Duplicate	8	12	590	<2.0	1200	8	47	8	11	16
C26777	15	25	2200	17.0	630	23	87	9	34	130
C26776	9	7	480	1.9	730	5	14	10	6	19
C26467	17	15	450	3.5	600	39	47	17	11	42
C26456	14	14	2300	6.3	1100	10	35	10	13	32
C26805	49	9	150	2.0	780	11	45	6	6	17
C26803	11	4	120	<2.0	680	4	12	7	2	7
C26804	8	15	760	2.4	1000	14	52	9	12	29
C26806	13	11	660	5.0	910	6	71	8	8	18
C26811	220	7	230	<2.0	670	8	24	6	5	43
C26812	8	18	630	2.4	1300	7	44	8	12	21
Park Creek sample										
C26788	7	11	1300	2.4	970	7	58	13	10	53
Wightman Fork samples										
C26793	38	9	450	<2.0	450	31	33	7	6	16
C26794	230	11	580	2.4	680	27	18	5	6	35
C26795	420	12	780	1.9	830	33	18	6	8	41
C26796	480	12	500	2.0	850	30	12	6	7	28
NIST Standard Reference Materials										
SRM 2704	69	5	340	11.0	740	150	32	5	8	310
SRM 2709	13	8	310	26.0	420	7	83	16	8	21
SRM 2711	59	12	400	5.4	640	1100	35	7	11	170

Table A2b. Analytical results from 0.25M HCl-0.25M hydroxylamine hydrochloride extracts from EPA stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	As ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm
Alamosa River samples											
AR-49.5	51	360	3300	6900	6900	3000	<10	88	26	7	<2
IC-1	<50	<50	270	680	18000	1900	<10	9	8	6	<2
AR-48.4	<50	97	820	3300	13000	2100	<10	40	14	5	<2
AC-1	<50	<50	150	440	16000	660	<10	8	4	<2	<2
AR-48.1	<50	73	790	2000	13000	2200	<10	22	10	4	<2
BC-1	<50	<50	260	650	30000	1100	<10	3	5	<2	<2
AR-41.0	<50	120	260	3000	12000	3400	<10	46	18	3	<2
AR-39.5	<50	140	350	2600	11000	4000	<10	38	18	5	<2
AR-44.4	<50	<50	320	2000	36000	6900	<10	49	23	11	<2
AR-44.4D	<50	<50	290	2000	35000	7400	<10	32	16	11	<2
AR-34.5	<50	180	420	2300	13000	3900	<10	75	18	5	<2
Park Creek sample											
PK-1	<50	200	920	6300	8700	1800	<10	170	24	16	<2
Wightman Fork samples											
PL-0	<50	270	1200	5300	8500	2200	<10	140	24	10	<2
CC-1	<50	76	180	2500	6200	4100	<10	43	31	9	<2
WF-1D	<50	150	440	2300	28000	6000	<10	91	40	15	4
WF-5.5	<50	<50	97	700	11000	1600	44	41	10	3	<2
WF-1.3	<50	<50	110	1200	11000	1400	37	25	9	2	2
WF-1.0	<50	<50	87	730	24000	2900	80	39	10	9	8

Table A2b. Analytical results from 0.25M HCl-0.25M hydroxylamine hydrochloride extracts from EPA stream-sediment samples, Alamosa River basin, Colo.--(continued)

Sample No.	Cu ppm	La ppm	Mn ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm
Alamosa River samples										
AR-49.5	12	12	650	<2	1300	8	56	8	13	22
IC-1	7	<4	360	<2	920	<4	2	11	<2	4
AR-48.4	10	6	220	<2	970	<4	28	11	4	11
AC-1	<2	<4	26	<2	620	<4	<2	12	<2	5
AR-48.1	10	<4	160	<2	790	5	13	8	4	8
BC-1	2	<4	60	<2	1100	<4	<2	10	<2	3
AR-41.0	190	9	120	<2	850	10	15	7	5	19
AR-39.5	150	8	150	<2	910	7	14	6	5	22
AR-44.4	250	<4	290	<2	960	13	12	7	6	23
AR-44.4D	260	7	310	<2	830	11	12	7	6	21
AR-34.5	190	7	180	<2	880	9	18	7	6	19
Park Creek sample										
PK-1	12	10	2200	5	870	9	58	13	10	150
Wightman Fork samples										
PL-0	14	11	1000	4	590	7	69	20	9	25
CC-1	15	17	1200	3	1200	6	14	3	6	62
WF-5.5	120	4	170	<2	540	18	4	5	<2	18
WF-1D	75	18	1200	<2	1500	37	25	10	9	120
WF-1.3	130	<4	100	<2	480	16	7	6	<2	15
WF-1.0	590	<4	120	<2	800	20	5	11	<2	20

Table A3a. Analytical results from 2M HCl-H_2O_2 extracts from NURE stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Latitude	Longitude	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	As ppm	Ba ppm	Ce ppm	Cd ppm	Co ppm
Alamosa River samples													
Composite	37.3631	106.6200	640	1000	3900	7600	18000	10000	<2	150	36	<1	8
Duplicate	37.3631	106.6200	390	640	3700	7700	16000	8200	<2	140	35	<1	7
C26777	37.3697	106.5889	160	830	2600	9400	52000	20000	2	290	73	1	66
C26776	37.3717	106.5844	88	750	1400	1800	33000	6700	2	160	24	<1	9
C26467	37.3778	106.5678	370	1800	6000	10000	22000	19000	<2	260	57	<1	13
C26456	37.3817	106.5681	360	1000	3000	6300	33000	11000	2	260	57	<1	32
C26805	37.4089	106.5050	250	1000	3300	8200	28000	11000	10	250	33	<1	8
C26803	37.4228	106.4794	190	1400	1900	1100	41000	6800	4	170	20	<1	7
C26804	37.4211	106.4739	460	1400	3200	9600	19000	11000	2	150	46	<1	8
C26806	37.4189	106.4656	220	1100	4300	7900	23000	11000	<2	350	40	<1	14
C26811	37.3897	106.3781	170	580	1600	3200	20000	5200	7	240	20	<1	8
C26812	37.3875	106.3767	410	1200	3500	14000	15000	7600	<2	190	60	<1	10
Park Creek sample													
C26788	37.4347	106.6372	170	910	1600	5000	19000	6000	<2	260	32	<1	11
Wightman Fork samples													
C26793	37.4292	106.5850	180	1400	1500	3300	29000	9800	38	530	38	<1	9
C26794	37.4297	106.5606	240	1200	1600	3600	41000	9200	58	450	49	<1	16
C26795	37.4247	106.5378	100	600	1100	2400	32000	6400	51	250	34	<1	12
C26796	37.4044	106.5217	120	600	1400	2000	33000	7500	47	250	34	<1	11
NIST Standard Reference Materials													
SRM 2704			110	440	7900	28000	26000	9100	13	90	16	4	12
SRM 2709			1000	3500	13000	21000	31000	20000	13	590	37	<1	17
SRM 2711			320	4000	8200	36000	15000	12000	110	290	49	61	11

Table A3a. Analytical results from 2M HCl-H_2O_2 extracts from NURE stream-sediment samples, Alamosa River basin, Colo.--(continued)

Sample No.	Cr ppm	Cu ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm
Alamosa River samples														
C26777	7	42	44	8.0	2800	1.2	36	1700	35	130	170	22	49	250
C26776	3	24	12	1.3	510	0.2	3	1200	10	24	21	20	7	40
C26467	19	59	32	11	840	1.1	12	1300	58	92	590	40	21	120
C26456	3	36	25	2.9	2800	0.8	10	1800	16	65	340	29	20	68
C26805	6	120	17	3.1	340	2.3	7	1500	34	78	350	22	10	53
C26803	6	31	11	2.1	210	2.1	3	1300	12	40	85	19	4	25
C26804	13	20	28	5.4	1100	1.4	9	1800	18	87	830	21	20	56
C26806	10	34	20	4.4	900	0.7	12	1700	11	100	650	23	11	49
C26811	3	350	11	1.3	290	1.7	4	950	22	38	200	15	6	74
C26812	6	20	30	3.9	940	<0.2	7	1800	10	79	800	31	18	49
Park Creek sample														
C26788	3	14	15	1.4	1100	0.4	4	1100	7	56	300	19	11	69
Wightman Fork samples														
C26793	7	110	19	2.8	580	1.1	5	1300	69	66	180	20	8	60
C26794	7	590	26	2.5	990	1.3	7	1700	95	48	140	21	13	120
C26795	4	690	17	1.7	800	0.5	4	1100	82	29	130	14	9	81
C26796	5	890	17	2.0	620	0.8	4	1300	83	24	87	14	9	69
NIST Standard Reference Materials														
SRM 2704	92	130	8	21	500	1.3	31	1100	170	43	53	16	11	430
SRM 2709	65	47	19	38	640	0.7	92	850	15	150	430	61	15	100
SRM 2711	14	170	27	12	770	<0.2	18	1200	1200	71	630	28	21	400

Table A3b. Analytical results from 2M $HCl-H_2O_2$ extracts from NURE stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	As ppm	Ba ppm	Ce ppm	Cd ppm	Co ppm
Alamosa River samples											
AR-49.5	360	690	3700	6900	12000	6700	<2	110	34	<1	5
IC-1	49	480	1200	690	27000	3700	5	97	16	<1	4
AR-48.4	47	350	1200	2800	16000	3700	<2	88	23	<1	3
AC-1	30	690	460	410	20000	1500	5	72	6	<1	1
AR-48.1	96	590	1500	2100	21000	4100	<2	73	22	<1	3
BC-1	50	340	1300	640	39000	2700	<2	95	18	<1	1
AR-41.0	74	720	780	2300	17000	4300	18	110	23	<1	2
AR-39.5	89	580	1000	1900	17000	4900	7	100	24	<1	3
AR-44.4	75	580	1500	1800	43000	9300	7	82	26	<1	8
AR-44.4D	90	610	900	1800	38000	8300	12	120	23	<1	7
AR-34.5	120	700	1000	1900	19000	5400	12	150	23	<1	4
Park Creek sample											
PK-1	110	800	1600	6100	19000	5100	<2	220	39	<1	14
Wightman Fork samples											
PL-0	120	770	2200	5700	16000	11000	<2	160	41	<1	13
CC-1	170	1200	3000	2700	32000	10000	10	240	57	<1	10
WF-1D	59	1200	1700	2600	40000	14000	<2	190	62	<1	18
WF-5.5	65	450	290	660	19000	3100	110	140	20	<1	3
WF-1.3	53	470	300	1200	20000	3000	110	170	19	<1	2
WF-1.0	69	480	270	830	30000	4600	160	150	20	<1	5
Water treatment plant sample											
PITS	11000	35	11000	16000	24000	87000	630	6	84	110	340

Table A3b. Analytical results from 2M $HCl-H_2O_2$ extracts from NURE stream-sediment samples, Alamosa River basin, Colo.--(continued)

Sample No.	Cr ppm	Cu ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm
Alamosa River samples														
AR-49.5	<1	11	16	1.7	560	<0.2	1	1200	8	60	600	17	13	32
IC-1	2	24	8	<0.5	340	2.0	2	1300	17	12	70	19	3	14
AR-48.4	1	13	11	0.7	190	<0.2	1	970	6	31	51	13	5	17
AC-1	1	6	4	<0.5	36	8.4	1	730	21	8	38	13	1	9
AR-48.1	2	17	11	0.5	180	2.3	1	1100	15	23	67	15	5	16
BC-1	1	7	9	<0.5	120	1.5	<1	1700	16	11	22	20	4	11
AR-41.0	2	200	12	<0.5	120	5.1	2	990	31	20	96	9	5	22
AR-39.5	1	140	12	0.6	170	1.7	2	1000	18	19	76	12	6	25
AR-44.4	2	260	12	0.8	340	1.2	2	1200	24	20	31	18	7	30
AR-44.4D	2	260	11	0.7	280	3.5	2	1100	27	23	83	12	7	27
AR-34.5	2	200	11	1.2	170	3.7	2	1100	26	26	95	11	6	25
Park Creek sample														
PK-1	2	16	18	<0.5	2000	<0.2	6	1200	10	66	200	19	13	150
Wightman Fork samples														
PL-0	4	18	21	2.4	980	1.2	6	840	9	79	320	29	13	44
CC-1	4	110	31	1.2	1300	3.9	7	1900	43	49	130	18	10	96
WF-1D	8	85	33	2.6	1200	1.4	7	2000	55	50	290	20	11	180
WF-5.5	2	170	10	0.5	180	3.1	2	820	52	12	60	8	3	29
WF-1.3	2	180	10	0.7	130	3.7	1	850	56	16	59	9	3	31
WF-1.0	7	640	10	0.5	140	10.2	2	940	62	14	54	13	4	31
Water treatment plant sample														
PITS	28	55000	46	4.9	9200	2.7	410	1900	92	58	<10	45	73	11000

Table A4a. Analytical results for 3050 extraction of selected NURE samples from the Alamosa River basin, Colo.

Sample No.	Latitude	Longitude	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	Ag ppm	As ppm	B ppm
Alamosa River samples											
Composite	37.3631	106.6200	1700	2600	7900	12000	70000	27000	<4	< 20	29
C26456	37.3717	106.5681	990	2200	6200	7700	65000	22000	<4	< 20	26
C26805	37.4089	106.5050	560	2300	6800	8000	50000	19000	<4	< 20	22
C26803	37.4228	106.4794	320	3100	4200	1500	61000	15000	<4	< 20	27
C26812	37.3875	106.3767	690	2000	6200	12000	46000	18000	<4	< 20	22
Wightman Fork samples											
C26793	37.4292	106.5850	280	2900	3300	3400	49000	21000	<4	56	23
C26796	37.4044	106.5217	200	1700	3700	2700	60000	16000	<4	82	24
NIST Standard Reference Materials											
SRM 2704			220	2700	11000	28000	41000	17000	<4	< 20	29
SRM 2709			860	4400	15000	17000	36000	31000	<4	< 20	58
SRM 2711			350	5000	9100	25000	27000	22000	4	78	22

Sample No.	Latitude	Longitude	Ba ppm	Ce ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm	Li ppm	Mn ppm
Alamosa River samples											
Composite	37.3631	106.6200	200	50	<4	24	17	17	26	11	1200
C26456	37.3717	106.5681	270	70	<4	39	11	35	33	9	2900
C26805	37.4089	106.5050	310	47	<4	15	16	89	25	7	500
C26803	37.4228	106.4794	530	47	<4	11	11	32	24	5	320
C26812	37.3875	106.3767	200	60	<4	20	19	20	32	9	1100
Wightman Fork samples											
C26793	37.4292	106.5850	540	64	<4	15	14	120	34	8	650
C26796	37.4044	106.5217	420	51	<4	19	11	850	27	6	770
NIST Standard Reference Materials											
SRM 2704			110	30	<4	18	110	98	15	35	580
SRM 2709			450	37	<4	17	100	38	21	43	550
SRM 2711			220	59	42	13	31	110	33	18	590

Table A4a. Analytical results for 3050 extraction of selected NURE samples from the Alamosa River basin, Colo. --(continued)

Sample No.	Latitude	Longitude	Ni ppm	P ppm	Pb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm	Zr ppm
Alamosa River samples												
Composite	37.3631	106.6200	11	1500	15	1600	140	3300	180	15	150	20
C26456	37.3717	106.5681	15	1600	19	1200	100	1500	110	20	150	14
C26805	37.4089	106.5050	14	1300	49	1500	94	1200	80	10	99	11
C26803	37.4228	106.4794	7	1500	16	1800	82	120	42	6	53	5
C26812	37.3875	106.3767	14	1500	10	2200	92	2600	150	16	110	24
Wightman Fork samples												
C26793	37.4292	106.5850	11	1600	100	1800	99	250	48	11	130	<4
C26796	37.4044	106.5217	9	1600	160	1300	51	320	54	11	150	4
NIST Standard Reference Materials												
SRM 2704			47	1100	170	1500	45	180	32	15	500	6
SRM 2709			91	670	15	1700	120	690	86	13	110	11
SRM 2711			19	900	1100	1400	55	790	57	21	390	14

Table A4b. Analytical results for 3050 extraction of selected EPA samples from the Alamosa River basin, Colo.

Sample No.	Na ppm	K ppm	Mg ppm	Ca ppm	Al ppm	Fe ppm	Ag ppm	As ppm
Alamosa River samples								
AR-49.5	1300	1400	7300	11000	20000	46000	<4	<20
IC-1	<100	1300	8600	630	13000	60000	<4	<20
AC-1	<100	1800	2600	390	4400	45000	<4	<20
AR-48.1	<100	1300	6400	2900	13000	53000	<4	<20
AR-41.0	<100	2100	5800	3300	14000	44000	<4	25
AR-44.4	220	2500	5200	2500	19000	69000	<4	23
AR-44.4D	<100	2100	5100	2400	18000	67000	<4	<20
AR-34.5	110	2600	5200	2700	16000	43000	<4	<20
Wightman Fork samples								
CC-1	<100	890	1600	2100	9900	23000	<4	<20
WF-5.5	<100	1400	1200	530	6900	37000	<4	130
WF-1.0	<100	1800	1400	870	9600	53000	<4	160
NIST Standard Reference Material								
SRM 2711	<100	3800	8300	22000	18300	25000	3	67

Sample No.	B ppm	Ba ppm	Ce ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	La ppm
Alamosa River samples								
AR-49.5	15	160	46	<4	18	6.0	16	22
IC-1	11	170	37	<4	12	6.5	30	19
AC-1	<10	240	21	<4	6.4	4.6	18	12
AR-48.1	<10	210	37	<4	12	6.1	32	19
AR-41.0	<10	290	50	<4	8.7	12	300	27
AR-44.4	18	390	46	<4	19	10	360	23
AR-44.4D	17	370	47	<4	17	9.1	350	22
AR-34.5	15	320	49	<4	11	7.2	300	25
Wightman Fork samples								
CC-1	<10	210	62	<4	10	7.5	21	34
WF-5.5	<10	280	42	<4	6.9	5.6	280	24
WF-1.0	11	360	44	<4	15	14	750	25
NIST Standard Reference material								
SRM 2711	11	200	46	37	11	25	100	26

Table A4b. Analytical results for 3050 extraction of selected EPA samples from the Alamosa River basin, Colo.--(continued)

Sample No.	Li ppm	Mn ppm	Mo ppm	Ni ppm	P ppm	Pb ppm	Si ppm
Alamosa River samples							
AR-49.5	<8	960	<4	4.3	1300	11	1900
IC-1	<8	830	<4	6.2	1700	13	2000
AC-1	<8	120	16	<4	1000	42	1200
AR-48.1	<8	440	<4	5.6	1400	24	2100
AR-41.0	<8	320	6	9.2	1500	60	2400
AR-44.4	<8	540	<4	9.2	1400	54	2200
AR-44.4D	<8	520	4	8.4	1400	49	2500
AR-34.5	<8	400	4	7.3	1500	52	2400
Wightman Fork samples							
CC-1	<8	1200	<4	6.4	1400	7.8	2500
WF-5.5	<8	210	<4	6	1200	100	2100
WF-1.0	<8	180	10	4.1	1500	140	2200
NIST Standard Reference Material							
SRM 2711	17	540	<4	18	820	1200	2700

Sample No.	Sr ppm	Th ppm	Ti ppm	V ppm	Y ppm	Zn ppm	Zr ppm
Alamosa River samples							
AR-49.5	130	<8	1900	100	15	65	26
IC-1	24	<8	<100	55	4.8	34	<4
AC-1	22	<8	<100	29	<4	16	<4
AR-48.1	45	<8	140	52	6.7	35	3.9
AR-41.0	57	<8	170	45	7.3	51	<4
AR-44.4	64	<8	290	50	8.7	57	6.8
AR-44.4D	60	<8	210	47	8.2	54	4.9
AR-34.5	69	<8	150	40	8.6	50	<4
Wightman Fork samples							
CC-1	63	<8	<100	23	7.9	67	<4
WF-5.5	44	<8	<100	21	0	71	<4
WF-1.0	57	<8	<100	28	4.9	71	<4
NIST Standard Reference Material							
SRM 2711	47	8	600	50	17	310	12

Table A5a. Analytical results from total digestions of NURE stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Latitude	Longitude	Na pct.	K pct.	Mg pct.	Ca pct.	Fe pct.	Al pct.	Ti pct.	P pct.
Alamosa River samples										
Composite	37.3631	106.6200	1.60	1.60	1.40	3.10	7.30	8.20	0.78	0.14
Duplicate	37.3631	106.6200	1.70	1.50	1.50	3.10	7.90	8.10	0.83	0.14
C26777	37.3697	106.5889	0.91	1.50	0.75	1.10	5.50	7.20	0.31	0.16
C26776	37.3717	106.5844	0.76	2.00	0.69	0.51	6.40	7.90	0.56	0.16
C26467	37.3778	106.5678	1.10	1.80	0.88	1.30	2.90	6.80	0.39	0.11
C26456	37.3817	106.5681	1.20	1.80	1.20	2.10	7.30	8.10	0.73	0.22
C26805	37.4089	106.5050	1.10	1.90	1.10	1.60	5.10	7.30	0.51	0.13
C26803	37.4228	106.4794	1.10	2.40	0.67	0.32	5.50	8.50	0.48	0.18
C26804	37.4211	106.4739	1.80	1.60	1.20	2.80	5.30	7.40	0.47	0.16
C26806	37.4189	106.4656	1.40	1.90	1.00	1.30	5.90	7.30	0.68	0.16
C26811	37.3897	106.3781	1.20	1.90	0.88	1.30	5.80	7.00	0.57	0.12
C26812	37.3875	106.3767	1.70	2.30	1.20	3.20	5.50	8.30	0.83	0.16
Park Creek sample										
C26788	37.4347	106.6372	1.30	1.80	0.62	1.60	5.00	8.20	0.51	0.15
Wightman Fork samples										
C26793	37.4292	106.5850	1.10	2.20	0.51	0.66	4.60	7.60	0.46	0.17
C26794	37.4297	106.5606	1.50	2.10	0.44	0.89	5.30	7.10	0.52	0.14
C26795	37.4247	106.5378	1.30	1.90	0.48	0.79	5.30	6.90	0.45	0.14
C26796	37.4044	106.5217	1.40	1.80	0.53	0.74	6.00	6.70	0.51	0.14
NIST Standard Reference Materials										
SRM 2704			0.59	1.90	1.30	2.70	4.10	5.90	0.32	0.10
SRM 2709			1.20	1.90	1.60	1.90	3.50	7.20	0.34	0.07
SRM 2711			1.30	2.50	1.20	3.00	3.00	6.70	0.30	0.09

Table A5a. Analytical results from total digestions of NURE stream-sediment samples, Alamosa River basin, Colo.--(continued)

Sample No.	As ppm	Ba ppm	Be ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Mn ppm	Mo ppm
Alamosa River samples													
Composite	<10	650	4	<2	51	22	25	20	25	27	17	1300	<2
Duplicate	<10	630	4	<2	52	26	20	18	21	28	16	1400	<2
C26777	<10	530	3	<2	78	69	21	38	15	44	30	2500	<2
C26776	<10	400	2	<2	59	17	17	37	20	32	11	750	<2
C26467	10	570	2	<2	64	12	32	58	19	36	26	720	3
C26456	11	670	4	2	71	46	29	49	40	35	16	2800	3
C26805	21	750	3	<2	60	15	32	100	17	33	14	600	3
C26803	<10	940	2	<2	62	11	29	38	24	33	10	350	3
C26804	<10	650	2	<2	64	17	29	22	22	37	23	1400	3
C26806	<10	730	3	<2	69	18	60	40	36	37	14	1100	<2
C26811	22	1000	3	<2	55	17	22	430	19	30	12	660	3
C26812	25	870	4	<2	78	26	30	34	18	43	20	1300	<2
Park Creek sample													
C26788	<10	660	2	<2	67	22	20	26	19	33	11	1400	3
Wightman Fork samples													
C26793	80	1000	2	<2	72	12	31	150	26	40	19	640	3
C26794	88	840	2	<2	66	19	20	470	16	37	15	830	2
C26795	120	980	2	<2	63	18	19	710	19	35	15	950	2
C26796	98	210	2	<2	61	14	23	920	21	33	13	760	2
NIST Standard Reference Materials													
SRM 2704	17	400	2	<2	56	16	140	120	15	29	49	600	3
SRM 2709	21	900	4	<2	41	14	120	33	18	22	57	550	<2
SRM 2711	89	710	2	30	70	11	46	130	17	39	31	680	2

Table A5a. Analytical results from total digestions of NURE stream-sediment samples, Alamosa River basin, Colo. --(continued)

Sample No.	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Alamosa River samples											
Composite	9	29	13	18	17	480	5	210	23	3	140
Duplicate	9	26	12	14	18	500	5	240	23	3	150
C26777	9	48	47	38	10	260	7	88	44	3	320
C26776	8	29	9	19	13	290	7	140	19	2	110
C26467	7	33	14	45	11	260	9	92	24	2	150
C26456	6	33	24	26	16	370	6	200	25	4	210
C26805	6	28	14	64	14	380	8	150	17	2	100
C26803	6	29	8	23	12	480	8	140	13	1	59
C26804	8	33	14	38	11	530	6	120	25	3	170
C26806	10	38	24	23	12	450	6	170	20	2	130
C26811	8	26	11	66	12	410	7	170	15	2	170
C26812	10	35	20	15	13	610	7	220	26	3	140
Park Creek sample											
C26788	8	32	14	16	10	420	8	110	21	2	150
Wightman Fork samples											
C26793	8	29	12	130	11	420	10	110	16	2	120
C26794	8	29	11	150	9	430	8	120	15	2	170
C26795	7	28	10	250	9	420	8	110	16	2	160
C26796	7	29	10	180	10	400	8	120	16	2	150
NIST Standard Reference Materials											
SRM 2704	7	28	45	160	12	140	8	97	21	2	410
SRM 2709	6	18	79	18	12	230	9	120	16	2	100
SRM 2711	12	32	21	1100	10	250	12	90	28	2	350

Table A5b. Analytical results from total digestions of EPA stream-sediment samples, Alamosa River basin, Colo.

Sample No.	Na pct.	K pct.	Mg pct.	Ca pct.	Fe pct.	Al pct.	Ti pct.	P pct.	As ppm	Ba ppm	Be ppm
Alamosa River samples											
AR-49.5	1.70	1.70	1.40	3.40	6.40	8.70	0.64	0.14	<10	650	3
IC-1	0.66	2.10	1.10	0.27	6.00	8.30	0.56	0.18	12	660	2
AR-48.4	0.90	2.30	1.10	0.93	5.30	8.00	0.51	0.17	<10	770	2
AC-1	0.44	2.40	0.62	0.17	4.40	7.00	0.27	0.15	10	720	1
AR-48.1	0.84	2.20	0.96	0.89	5.60	8.00	0.45	0.16	<10	830	2
BC-1	1.20	2.10	0.88	0.31	6.10	7.50	0.43	0.19	13	1000	2
AR-41.0	0.78	2.50	0.98	0.64	4.50	8.60	0.41	0.16	32	850	2
AR-39.5	1.10	2.50	1.00	0.61	4.70	8.70	0.45	0.17	19	810	2
AR-44.4	0.96	2.40	0.88	0.56	7.50	8.60	0.45	0.16	19	790	2
AR-44.4D	0.98	2.40	0.90	0.55	7.30	8.80	0.42	0.16	22	900	2
AR-34.5	1.00	2.50	0.90	0.59	4.60	9.10	0.44	0.17	29	820	2
Park Creek sample											
PK-1	1.40	1.90	0.59	1.60	4.40	8.50	0.45	0.14	<10	620	2
Wightman Fork samples											
PL-O	1.40	1.80	0.62	1.50	3.30	8.50	0.46	0.10	<10	710	2
CC-1	2.40	2.80	0.57	1.00	3.70	9.30	0.37	0.17	<10	950	3
WF-5.5	1.20	2.60	0.40	0.28	3.80	7.20	0.37	0.14	180	930	2
WF-1D	1.20	2.10	0.58	0.76	5.20	8.60	0.44	0.22	13	710	2
WF-1.3	1.20	2.70	0.40	0.36	3.90	7.50	0.38	0.14	190	940	2
WF-1.0	1.10	2.50	0.41	0.29	5.30	7.50	0.37	0.17	250	900	2

Table A5b. Analytical results from total digestions of EPA stream-sediment samples, Alamosa River basin, Colo. --(continued)

Sample No.	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Nb ppm
Alamosa River samples											
AR-49.5	<2	58	24	10	23	20	31	15	1100	<2	11
IC-1	<2	57	13	16	56	21	30	9	810	2	9
AR-48.4	<2	60	13	16	43	20	32	10	550	2	10
AC-1	<2	74	7	14	22	17	38	5	180	15	5
AR-48.1	<2	62	14	16	46	20	33	10	500	5	7
BC-1	<2	50	9	7	21	17	27	12	400	2	9
AR-41.0	<2	83	10	32	360	21	45	11	390	13	9
AR-39.5	<2	73	15	24	270	21	39	11	440	5	9
AR-44.4	<2	64	20	22	430	19	34	12	570	6	10
AR-44.4D	<2	64	19	20	420	18	34	11	560	6	9
AR-34.5	<2	75	13	19	360	23	41	12	420	6	10
Park Creek sample											
PK-1	<2	73	25	15	29	18	37	11	2000	<2	9
Wightman Fork samples											
PL-0	<2	74	17	23	25	21	40	14	990	5	12
CC-1	<2	61	13	24	38	28	35	15	1300	2	12
WF-5.5	<2	61	9	23	300	22	35	14	260	6	11
WF-1D	<3	97	21	35	120	20	52	16	1200	<3	11
WF-1.3	<2	64	9	21	390	21	37	15	210	5	11
WF-1.0	<2	68	24	31	920	24	39	14	240	14	11

Table A5b. Analytical results from total digestions of EPA stream-sediment samples, Alamosa River basin, Colo.--(continued)

Sample No.	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Alamosa River samples										
AR-49.5	28	8	11	16	540	4	180	23	3	120
IC-1	24	8	22	17	210	7	180	18	2	68
AR-48.4	26	9	25	15	290	8	160	14	1	79
AC-1	30	6	56	9	300	13	100	10	1	39
AR-48.1	27	10	31	14	300	9	140	16	2	71
BC-1	21	4	23	11	230	9	140	10	1	58
AR-41.0	37	12	79	13	330	11	130	19	2	91
AR-39.5	32	13	56	12	380	9	130	13	1	100
AR-44.4	28	12	68	12	360	9	140	13	1	100
AR-44.4D	28	12	64	12	350	8	140	13	1	110
AR-34.5	33	10	60	13	400	10	130	16	2	91
Park Creek sample										
PK-1	32	14	15	11	450	10	97	21	2	200
Wightman Fork samples										
PL-0	32	12	17	12	430	10	110	19	2	87
CC-1	26	15	20	7	520	9	78	10	1	150
WF-5.5	24	8	150	7	410	9	82	8	<1	100
WF-1D	42	15	84	12	390	14	97	20	2	220
WF-1.3	24	8	170	7	440	10	86	9	1	110
WF-1.0	26	9	200	8	420	11	90	10	1	120

Table A6a. Replicate analysis of samples extracted using EPA 1311 procedure, Alamosa River basin, Colo.

Sample No.	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Bi ppm	Ca ppm	Cd ppm	Ce ppm
C26812	<20	<4	<2	22	<0.4	<4	4900	<0.8	<2
C26812	<20	<4	<2	23	<0.4	<4	5200	<0.8	<2
SRM 2711	<20	<4	2.2	32	<0.4	<4	23900	16	<2
SRM 2711	<20	<4	2.8	32	<0.4	<4	24500	17	<2
AR-44.4	<20	<4	<2	<0.4	<0.4	<4	320	<0.8	<2
AR-44.4	<20	<4	<2	<0.4	<0.4	<4	320	<0.8	<2

Sample No.	Co ppm	Cr ppm	Cu ppm	Fe ppm	K ppm	La ppm	Li ppm	Mg ppm	Mn ppm
C26812	<0.4	<0.4	0.4	<20	220	<0.8	<0.8	494	130
C26812	<0.4	<0.4	0.5	<20	230	<0.8	<0.8	535	140
SRM 2711	0.7	<0.4	0.8	41	1000	1.2	0.9	1010	120
SRM 2711	1.0	<0.4	0.1	17	1000	0.4	0.7	1030	120
AR-44.4	<0.4	<0.4	42	<20	<20	<1.6	<1.6	40	120
AR-44.4	<0.4	<0.4	40	<20	<20	<1.6	<1.6	40	130

Sample No.	Ni ppm	P ppm	Pb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm
C26812	<0.8	<20	<2	250	22	<20	<0.8	<0.8	0.9
C26812	<0.8	<20	<2	270	24	<20	<0.8	<0.8	0.9
SRM 2711	<0.8	<20	5.6	510	35	<20	<0.8	<0.8	3.9
SRM 2711	<0.8	<20	6.1	520	36	<20	<0.8	<0.8	3.7
AR-44.4	<0.8	<20	<2	140	2.2	<20	<0.8	<0.8	5.8
AR-44.4	<0.8	<20	<2	150	2.2	<20	<0.8	<0.8	6.4

Table A6b. Replicate analysis of samples extracted using 0.25M HCl-0.25M hydroxylamine-hydrochloride, Alamosa River basin, Colo.

Sample No.	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	Ba ppm	Ce ppm	Co ppm	Cr ppm
AR-44.4	<50	<50	320	2000	36000	6900	49	23	11	<2
AR-44.4D	<50	<50	290	2000	35000	7400	32	16	11	<2
Composite	160	600	2400	6500	7500	4000	120	27	6	2
Duplicate	110	360	2100	5900	6300	3200	98	26	5	<1

Sample No.	Cu ppm	La ppm	Mn ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm
AR-44.4	250	<4	290	<2	960	13	12	7	6	23
AR-44.4	260	7	310	<2	830	11	12	7	6	21
Composite	9	13	600	2	1300	9	50	9	11	20
Duplicate	8	12	590	<2	1200	8	47	8	11	16

Table A6c. Replicate analysis of samples extracted using 2M HCl-H_2O_2 extraction procedure, Alamosa River basin, Colo.

Sample No.	Latitude	Longitude	Na ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Al ppm	As ppm	Ba ppm	Ce ppm	Cd ppm	Co ppm
Composite	37.3631	106.6200	640	1000	3900	7600	18000	10000	<2	150	36	<1	8
Duplicate	37.3631	106.6200	390	640	3700	7700	16000	8200	<2	140	35	<1	7
AR-44.4			75	580	1500	1800	43000	9300	7	82	26	<1	8
AR-44.4D			90	610	900	1800	38000	8300	12	120	23	<1	7

Sample No.	Cr ppm	Cu ppm	La ppm	Li ppm	Mn ppm	Mo ppm	Ni ppm	P ppm	Pb ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm
Composite	5	18	17	3.6	700	<0.2	4	1500	9	74	630	30	13	43
Duplicate	3	15	17	3.1	690	<0.2	3	1500	9	74	320	22	13	38
AR-44.4	2	260	12	0.8	340	1.2	2	1200	24	20	31	18	7	30
AR-44.4D	2	260	11	0.7	280	3.5	2	1100	27	23	83	12	7	27

Table A6d. Replicate analysis of samples extracted using EPA 3050 procedure, Alamosa River basin, Colo.

Sample No.	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Bi ppm	Ca ppm	Cd ppm	Ce ppm
C26812	<20	<4	<2	22	<0.4	<4	4900	<0.8	<2
C26812	<20	<4	<2	23	<0.4	<4	5200	<0.8	<2
SRM 2711	<20	<4	2.2	32	<0.4	<4	23900	16	<2
SRM 2711	<20	<4	2.8	32	<0.4	<4	24500	17	<2
AR-44.4	<20	<4	<2	<0.4	<0.4	<4	320	<0.8	<2
AR-44.4	<20	<4	<2	<0.4	<0.4	<4	320	<0.8	<2

Sample No.	Co ppm	Cr ppm	Cu ppm	Fe ppm	K ppm	La ppm	Li ppm	Mg ppm	Mn ppm
C26812	<0.4	<0.4	0.4	<20	220	<0.8	<0.8	494	130
C26812	<0.4	<0.4	0.5	<20	230	<0.8	<0.8	535	140
SRM 2711	0.7	<0.4	0.8	41	1000	1.2	0.9	1010	120
SRM 2711	1.0	<0.4	0.1	17	1000	0.4	0.7	1030	120
AR-44.4	<0.4	<0.4	42	<20	<20	<1.6	<1.6	40	120
AR-44.4	<0.4	<0.4	40	<20	<20	<1.6	<1.6	40	130

Sample No.	Ni ppm	P ppm	Pb ppm	Si ppm	Sr ppm	Ti ppm	V ppm	Y ppm	Zn ppm
C26812	<0.8	<20	<2	250	22	<20	<0.8	<0.8	0.9
C26812	<0.8	<20	<2	270	24	<20	<0.8	<0.8	0.9
SRM 2711	<0.8	<20	5.6	510	35	<20	<0.8	<0.8	3.9
SRM 2711	<0.8	<20	6.1	520	36	<20	<0.8	<0.8	3.7
AR-44.4	<0.8	<20	<2	140	2.2	<20	<0.8	<0.8	5.8
AR-44.4	<0.8	<20	<2	150	2.2	<20	<0.8	<0.8	6.4

Table A7. Results from duplicate samples using total element digestion procedure, NURE and EPA samples, Alamosa River basin, Colo.

Sample No.	Na pct.	K pct.	Mg pct.	Ca pct.	Fe pct.	Al pct.	Ti pct.	P pct.
Composite	1.60	1.60	1.40	3.10	7.30	8.20	0.78	0.14
Duplicate	1.70	1.50	1.50	3.10	7.90	8.10	0.83	0.14
AR-44.4	0.96	2.40	0.88	0.56	7.50	8.60	0.45	0.16
AR-44.4D	0.98	2.40	0.90	0.55	7.30	8.80	0.42	0.16

Sample No.	As ppm	Ba ppm	Be ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Ga ppm	La ppm	Li ppm	Mn ppm	Mo ppm
Composite	<10	650	4	<2	51	22	25	20	25	27	17	1300	<2
Duplicate	<10	630	4	<2	52	26	20	18	21	28	16	1400	<2
AR-44.4	19	790	2	<2	64	20	22	430	19	34	12	570	6
AR-44.4D	22	900	2	<2	64	19	20	420	18	34	11	560	6

Sample No.	Nb ppm	Nd ppm	Ni ppm	Pb ppm	Sc ppm	Sr ppm	Th ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Composite	9	29	13	18	17	480	5	210	23	3	140
Duplicate	9	26	12	14	18	500	5	240	23	3	150
AR-44.4	10	28	12	68	12	360	9	140	13	1	100
AR-44.4D	9	28	12	64	12	350	8	140	13	1	110

Table A8a. Pb-isotopic data from 2M HCl-H_2O_2 extracts of NURE stream-sediment samples, Alamosa river basin, Colo.

Sample No.	Latitude	Longitude	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$
Alamosa River Samples					
Composite	37.3631	106.6200	18.356	15.575	38.042
Duplicate	37.3631	106.6200	18.331	15.569	38.021
C26777	37.3697	106.5889	18.698	15.590	37.925
C26777D[1]			18.693	15.593	37.910
C26776	37.3717	106.5844	18.325	15.555	37.744
C26467	37.3778	106.5678	18.237	15.549	37.760
C26456	37.3817	106.5681	18.247	15.559	37.792
C26805	37.4089	106.5050	18.052	15.523	37.475
C26803	37.4228	106.4794	18.266	15.549	37.748
C26804	37.4211	106.4739	18.441	15.597	38.115
C26806	37.4189	106.4656	18.421	15.580	38.015
C26811	37.3897	106.3781	18.050	15.524	37.449
C26812	37.3875	106.3767	18.441	15.574	38.058
Wightman Fork Samples					
C26788	37.4347	106.6372	18.382	15.568	37.858
C26793	37.4292	106.5850	18.253	15.578	37.796
C26794	37.4297	106.5606	18.049	15.533	37.415
C26795	37.4247	106.5378	18.055	15.538	37.424
C26796	37.4044	106.5217	18.095	15.539	37.440
NIST Standard Samples					
SRM 2704			18.747	15.630	38.413
SRM 2704D			18.756	15.644	38.450
SRM 2709			19.067	15.675	38.959
SRM 2709D			19.066	15.674	38.955
SRM 2711			17.089	15.446	36.980

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[1] All samples analyzed in Branch of Isotope Geology, USGS; suffix D indicates analyst ran sample twice as an analytical duplicate. Analytical errors are ± 0.012, ± 0.015, and ± 0.04 for the three ratios given; data normalized to certified values for NIST standards SRM 981 and SRM 982 to correct for thermal fractionation.

Table A8b. Pb-isotopic data from 2M HCl-H_2O_2 extracts of EPA stream-sediment samples, Alamosa River basin, Colo.

Sample No.	EPA No.	$\frac{^{206}Pb}{^{204}Pb}$	$\frac{^{207}Pb}{^{204}Pb}$	$\frac{^{208}Pb}{^{204}Pb}$
Alamosa River samples[1]				
AR-49.5	8-118157	18.100	15.539	37.784
IC-1	8-118152	18.310	15.565	37.813
AR-48.4	8-117293	18.226	15.537	37.708
AC-1	8-117287	18.124	15.530	37.536
AR-48.1	8-117282	18.201	15.549	37.694
BC-1	8-117275	18.235	15.551	37.681
AR-41.0	8-116845	18.043	15.531	37.445
AR-39.5	8-116831	18.066	15.530	37.467
AR-44.4	8-116826	18.044	15.529	37.452
AR-44.4D	8-116826	18.034	15.523	37.420
AR-34.5	8-116820	18.070	15.533	37.483
Park Creek sample				
PK-1	8-118210	18.392	15.583	37.888
Wightman Fork samples[1]				
PL-0	8-118908	18.584	15.645	38.324
CC-1	8-118230	18.121	15.540	37.532
WF-5.5	8-118204	17.961	15.525	37.329
WF-1D	8-118903	17.994	15.518	37.349
WF-1.3	8-118180	17.948	15.531	37.328
WF-1.0	8-118204	17.939	15.526	37.319
NIST Standard Reference Materials[1]				
SRM 2704		18.778	15.649	38.476
SRM 2711		17.097	15.436	36.943

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[1] Samples analyzed in Branch of Isotope Geology, USGS; suffix D indicates analyst ran sample twice as an analytical duplicate. Analytical errors are ± 0.012, ± 0.015, and ± 0.04 for the three ratios given; data normalized to certified values for NIST standards SRM 981 and SRM 982 to correct for thermal fractionation.