BIOGEOCHEMICAL ORIENTATION SURVEY OVER THE MOUNTAIN LAKE DIATREME, ALBERTA

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Alberta Geological Survey
Open File Report 1998-06

ACKNOWLEDGMENTS

First and foremost, Monopros Limited is thanked for allowing the Alberta Geological Survey to research the Mountain Lake Diatreme, and permission to publish this paper. Mr. Gordie Jean of the Alberta Geological Survey is specifically acknowledged for his organizational skills and contributions to the sampling program. Mr. William Csanyi is thanked for preparation of the biogeochemical profiles presented in the Appendix. Special thanks to Dr. Mark Fedikow of the Manitoba Geological Services Branch for reviewing the manuscript and, being a mentor on the value of biogeochemical sampling.

CONTENTS

FIGURES

TABLES

APPENDIX

SUMMARY

A biogeochemical orientation study, using trembling aspen trees growing over and around the Mountain Lake Diatreme, will help to determine the usefulness of biogeochemistry studies for kimberlite exploration in the boreal forest regions of northern Alberta. Especially, since several kimberlites discovered in Alberta form topographic highs, which may locally be dominated by aspen vegetation. Furthermore, airborne magnetic survey highs, in association with topographic highs, have been deemed priority exploration targets and biogeochemistry may provide a quick and cost effective method for ground-testing these targets.

Bark, twig and stem samples from trembling aspen trees over the Mountain Lake Diatreme proved to be viable sampling media in their ability to up take elements indicative of ultramafic and kimberlitic sources and their analysis provided a distinctive biogeochemical signature that may be used elsewhere in Alberta. Bark, twig and stem aspen samples yielded a significant geochemical signature (up to 28 times background) directly over, or in the immediate vicinity of, the Mountain Lake Diatreme for trace elements including Co, Cr, Mg and Ni, along with incompatible elements such as La, Rb and Sm. Other notable elements that yield elevated concentrations directly over the pipe include Al, As, Au, Fe, Na, V and W. Elements that yielded an elevated concentration over the pipe, but only in selected sampling media, include: Hf, Sb and Zr from bark, Ce from twig, and Cs and Nd from stem samples. Elements that are depleted directly over the pipe include Ba, Ca, Cu, and Zn; K yields a slight depletion over the centre of the pipe; P is concentrated over the eastern slope of the pipe and in the lowlands to the west of the pipe.

Analysis from a second sampling transect, located over a similar - but non-kimberlitic - topographic high 6.5 km east of Mountain Lake, did not yield any anomalous concentrations for elements indicative of kimberlites. The geochemical variance between the second sampling transect and the Mountain Lake Diatreme transect indicate that the positive geochemical pattern obtained over the diatreme is not related to the physiographic environment and that biogeochemical sampling can detect an ultramafic signature from associated soil and bedrock.

Stem samples, followed by bark and then twig samples, provide the best overall geochemical correlation with samples from the adjacent soil and bedrock, particularly for key kimberlite indicator elements such as Ce, Co, Cr, Cu, La, Ni, Rb, Sm and Sr.

The soil layer over the diatreme is enriched with varying combinations of soluble and immobile elements, which influence the surficial expression or vegetation characteristics, and may be of importance for defining kimberlitic surficial expressions in northern Alberta.

INTRODUCTION

Recent (1990's) kimberlite discoveries in the Mountain Lake area, northwestern Alberta, and the Buffalo Head Hills area, north central Alberta, represent the early stage of kimberlite exploration in Alberta. Initial exploration techniques such as airborne magnetic surveys and aerial photo interpretation have defined an abundance of potential targets in the boreal forest regions dominating northern Alberta. To date, ground follow-up exploration techniques have mainly relied on heavy mineral diamond indicator analyses, ground magnetic surveys, seismic surveys, soil geochemical surveys and drilling.

The objective of this study is to evaluate the potential of biogeochemical prospecting as a method of ground testing targets defined by regional airborne magnetic and aerial photograph surveys to detect kimberlite, lamproite and related rocks.

Biogeochemical methods of prospecting depend on the chemical analysis of elements in vegetation. The assumption is made that elements residing in the soil or bedrock will be accumulated by the plant in a representative manner and that consequently, anomalous concentrations in the vegetation will indicate anomalies in the substrate. The Mountain Lake South Diatreme, which remains virtually undisturbed, was selected to determine if the geochemistry of the vegetation over a known kimberlitic diatreme in Alberta would show a good geochemical correlation with the underlying soils and bedrock.

PREVIOUS STUDIES

Biogeochemical techniques have been used successfully for the detection of metalliferous deposits in many parts of the world (Brooks, 1972; Levinson, 1974; Malyuga, 1964; Warren and Delavault, 1950b; Warren, 1972). Although its practical application in the exploration for kimberlites has not yet been determined, site-specific geobotanical studies above kimberlitic bodies indicate that there is some scope for developing techniques for exploration purposes.

Several kimberlites have been documented to exhibit unique surficial characteristics, including distinctive vegetation patterns, where the trees and undergrowth were found growing more profusely, or subdued as grasses and shrubs, over the kimberlite than on the host country rock (Alexander and Shrivastava, 1984; Almeida-Filho and Castelo Branco, 1992; Buks, 1965; Cole, 1980; Fipke, 1995; Kingston, 1986). A brief summary of some biogeochemical surveys over kimberlite pipes is discussed below.

A soil geochemistry study conducted by Mathur and Alexander (1983) over the Hinota Kimberlite, India, yielded elevated concentrations (up to five times background) for V, Cu, Ni and Cr. Despite a positive geobotanical correlation between larger sized vegetation and the kimberlite, preliminary analysis from the ashing of leaves and twigs from the Mahua (*Madhuca indica*), Teak (*Tectona grandis*) and Palas (*Butea monosperma*) vegetation did not yield any positive geochemical relationship with the kimberlite. The study concluded that the plants chosen for this work were not the right type for accumulating the elements of interest, and that other plant species growing over and around the pipe be tested.

Komogorova *et al.*, (1986) sampled the bark, twigs and needles from larch (*Larix daurica*) over the Udachnaya, Dal'nyaya and Zarnitsa pipes in the Daldyn kimberlite field, Yakutia, Russia. They concluded that Ti, Ni, Cr and Fe were detected in relatively high concentrations over all three pipes and the product of three elements (Ti x Cr x Ni) yielded contrasts of up to 200 times the concentrations yielded by larches growing in the carbonate host rocks. Furthermore, the study discovered that the larch growing along the ore-haulage road yielded sharply higher concentrations of Ti, Cr and Ni. Also of interest, Komogorova *et al.*, (1986) noted a relatively high ash content from samples collected over the kimberlite pipes, in the order of two to five times greater versus samples collected over the country rock.

In 1989, a biogeochemical study was completed over the southern portion of the Sturgeon Lake 01 kimberlite block, Saskatchewan (Dunn, 1993). The kimberlite represents a glacially transported megablock of crater-facies volcaniclastic kimberlite, which measures at least 200 m by 125 m in size, up to 40 m thick, and occurs within 100 m of glacial sediments that overlie Cretaceous bedrock shale (Scott Smith, 1996; Kjarsgaard, 1995). The kimberlite is overlain by a gravelly boulder till up to 10 m in thickness, which comprises a developed soil horizon consisting of 50 cm of silty brunisol representing conditions similar to those in northern Alberta. Vegetation selected for sampling included trembling aspen (*Populus tremuloides*), red-osier dogwood (*Cornus stolonifera*) and beaked hazelnut (*Corylus cornuta*). Although the geobotanical expression did not identify any features of the vegetation cover that might assist in the detection of a concealed kimberlite, tissue samples collected over the kimberlite yielded some enrichment in Ni, Rb, Sr, Cr, Nb, Mg and P and depletion in Mn and Ba.

Studies in the Kirkland Lake area, northern Ontario, yielded enrichment/depletions including an enrichment of Sr, Rb, Be, Mo and depletion of Mn from Balsam fir tissue samples collected over the Diamond Lake kimberlite and Buffonta kimberlitic dyke, and an enrichment of Sr, Rb, Au, Cr, Na, Cd, Co, Cu, Ba, Cs, REE, Zn and depletion of Mn from Spruce twigs over the C14 kimberlite (McClenaghan and Dunn, 1995).

GEOLOGICAL SETTING AND GENERAL GEOLOGY OF THE MOUNTAIN LAKE VOLCANICS

In 1995, Monopros Limited publicly announced the discovery of two ultramafic diatremes (possible kimberlites), located directly north of Mountain Lake in northwestern Alberta, approximately 75 km northeast of Grande Prairie (Wood and Williams, 1994). The volcanic/volcanogenic rocks of the Mountain Lake Diatreme form a positive-relief, ovoid feature approximately 0.5 km wide by 1.5 km long and 30 m high, and occur within the early Late Campanian to Maastrichtian Wapiti Formation sediments of the Western Canada Sedimentary Basin (Figure 1). The Wapiti Formation consists of light grey, fine- to medium-grained, argillaceous, carbonaceous sandstone with interbedded siltstone, silty shale, thin layers of bentonite and coal, and is locally conglomeritic (Dawson *et al.*, 1989). In the vicinity of Mountain Lake the thickness of the Wapiti Formation is about 150 to 200 m (Leckie *et al.*, 1996).

The volcanic rocks occur in at least two separate bodies, Mountain Lake South and North. The Mountain Lake South forms a pronounced topographic high and measures 400 x 650 m (~26 ha.), while the Mountain Lake North has no topographic expression and measures about 250 x 350 m (~8 ha.). Drilling indicates that the Mountain Lake South body is a steep-sided pipe composed mainly of juvenile-rich volcaniclastics that have been dated by palynology to a maximum emplacement age

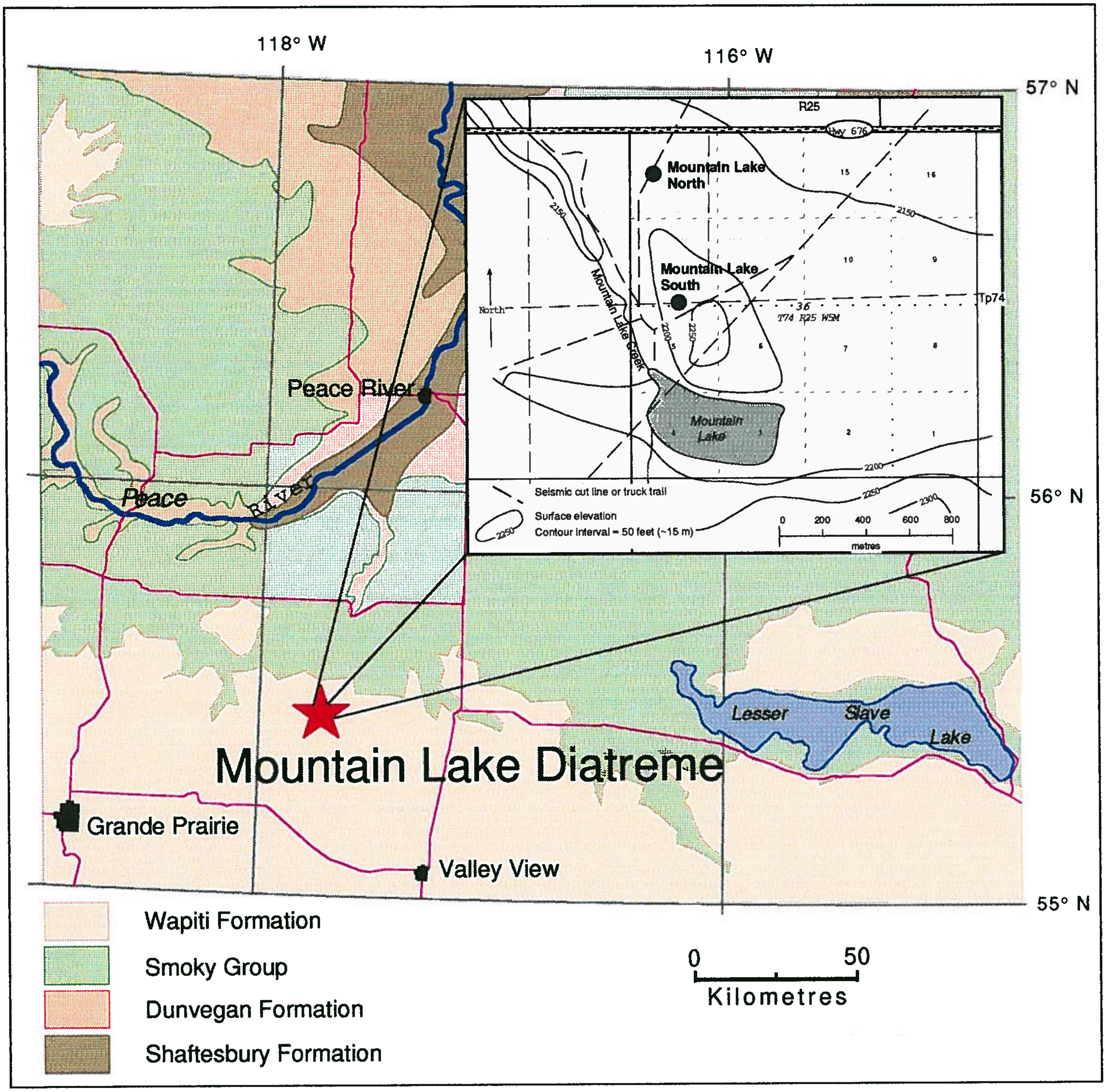


Figure 1. Regional geology of the Mountain Lake area.

of mid-Maastrichtian, probably 68 Ma (Wood *et al.*, 1998). Kjarsgaard (1996) classified the Mountain Lake body as alkaline ultrabasic volcanics. Petrographic examination of pyroclastic material from drill core consists mainly of olivine-rich juvenile lapilli tuffs with euhedral to anhedral olivine completely altered to clay minerals and serpentine. Other coarse constituents include rare ultramafic and basement xenoliths. The lapilli consist of devitrified vesicular glass (serpentine) and microcrystalline phlogopite-biotite mica, clinopyroxene, spinel, rutile, perovskite and apatite.

OVERBURDEN AND SOIL PROFILE

The Mountain Lake area is covered by luvisolic, gleysolic, brunisolic and organic soils that were developed on coarse outwash and shoreline material, and on alluvial and aeolian material (Odynsky, 1956). An enzyme leach soil geochemical study (Eccles, 1998), completed using the same east-west sampling transect as the present study, characterized the following weakly defined soil profiles. At the local scale, the parent material is likely till, based on the presence of rounded, siliceous pebbles observed in layers and dispersed within the matrix throughout the soil profile. Organic-rich A horizons are very dark brown to black and 5 to 13 cm thick, except in the low lying areas directly east of Mountain Creek, where they are up to 25 cm thick. The A horizons are underlain by silty clay loam to silty loam soils, which are interpreted to be the B horizon. These soils occur on top of the diatreme, on the slopes of the diatreme and to the west of Mountain Creek on relatively low-lying topography. The B horizon soils are characterized by their grey- to yellow-brown colour, amorphous to weakly fine-granular structure and common iron stains. The B horizon colour is distinctly browner in the low lying areas directly east of Mountain Creek. The B-C horizon contact was not observed, except at the centre of the sampling transect directly over the diatreme, where altered ultrabasic rocks were contacted at a depth of approximately 1.8 m with a Dutch soil auger. Brown to yellowish-brown loamy sand to sand and gravel were observed at the extreme eastern end of the sampling transect.

VEGETATION

The native vegetation in the vicinity of Mountain Lake is characterized by a mixed tree cover, where deciduous and spruce trees may occur either in mixtures or separately as the dominant cover of local areas. The larger trees include trembling aspen (*Populus tremuloides*), black spruce (*Picea mariana*), balsam popular (*Populus balsamifera*), mountain alder (*Alnus tenuifolia*) and white birch (*Betula papyrifera*). Trembling aspen was selected as a sampling medium due to its widespread distribution and relatively high density, especially over the topographic high formed by the Mountain Lake Diatreme, where the aspen totally dominates (Figure 2). Black spruce, albeit sparse, was the only other tree species observed on top of the diatreme.

It is not known whether aspen represents a reliable sampling medium for the uptake of elements important in kimberlite exploration such as Co, Cr and Ni. Wolfe (1971) noted the ability of trembling aspen growing on glacially transported till over the relatively small Nipissing diabase sills in the Elk Lake - Gowganda region, Ontario, which host Ag-Co-Ni-bearing veins, to concentrate dispersed Co with anomaly contrasts of up to 8 times. However, Dunn (1993) concluded that the elemental concentrations in aspen over the Sturgeon Lake Kimberlite were low in comparison to

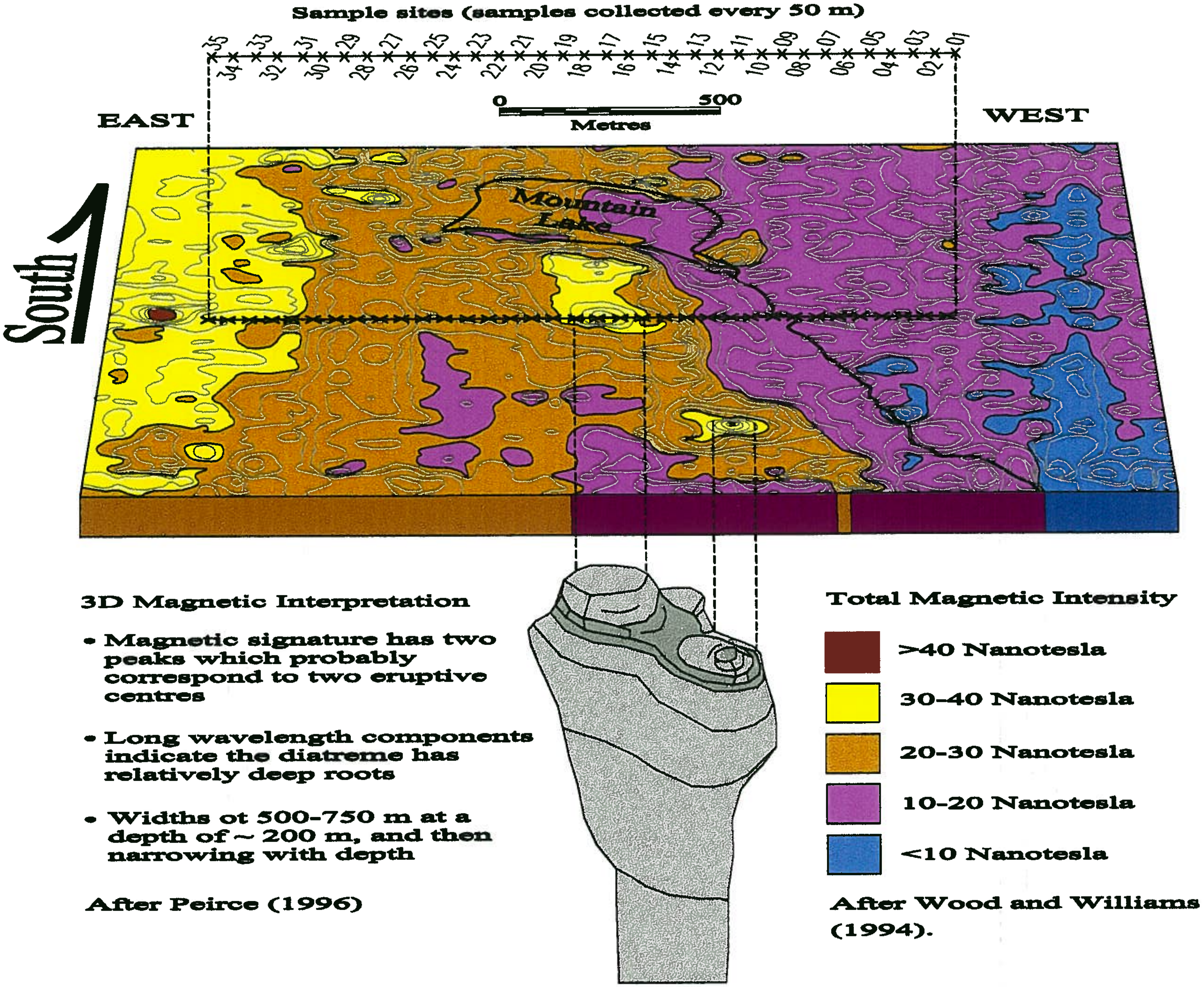
Figure 2. Trembling aspen (Populus tremuloides) growing on top of the Mountain Lake Diatreme.

those of aspen from an area of Precambrian metavolcanics in northern Saskatchewan. A biogeochemical orientation study using aspen trees growing over and around the Mountain Lake Diatreme will help to determine the usefulness of biogeochemistry studies for kimberlite exploration in the boreal forest regions of northern Alberta. Especially, since several kimberlites discovered in Alberta form topographic highs, which may locally be dominated by aspen. Furthermore, airborne magnetic survey highs, in association with topographic highs, have been deemed priority exploration targets and biogeochemistry may provide a quick and cost effective method for ground-testing these targets.

Aspen average about 12 m in height and 25-30 cm in diameter, but sometimes reach a height of 30 m and a diameter of 60 cm. Aspen grow best on well-drained loam, but also occur on a wide variety of other soils, and are supported by a shallow root system of widely spread lateral roots. The trembling aspen, like all poplars, reproduce quickly and easily by means of root suckers and therefore, grow rapidly in newly burned areas. The more or less coarsely toothed leaves are usually a reliable means of identifying the various species of poplars. A summer observation at the Mountain Lake Diatreme is that the aspen foliage over the diatreme does not show any noticeable discolouration of foliage, which could result from the morphological and mutational changes in plants caused by elements such as Ni and Cr: chlorosis and necrosis of leaves; Fe: darkening of leaves; and Co: increase of chlorophyll in some species and chlorosis in others (Brookes, 1972). Aspen are readily distinguishable from closely related willows by their winter buds, which are characterized by their scales and slender, shiny twigs that bear a reddish-brown, sharp-pointed terminal bud. The bark on young poplars is generally greenish to yellowish-brown and smooth; on older trees it tends to become greyish, rough and more or less furrowed.

SAMPLE COLLECTION AND PREPARATION

Field work was conducted in February, 1998 when the trembling aspen were barren of leaves. Thirty-five sample sites were established, one every 50 m on a single east-west transect oriented roughly perpendicular to the larger of two positive magnetic anomalies interpreted to be possible kimberlites (Figure 3). Bark, twigs and stems were sampled at every sample site, and analyzed to determine metal distribution throughout the tree. Stems are defined as the main leader from the crown, or tree top. Approximately 1 kg of material was collected from each sample media, including trembling aspen bark, twig and stem, by: (1) using a knife to remove the bark in 3-10 cm strips at knee to waist level; (2) using pruning shears to sample the last five years of growth from the twigs; and (3) bending smaller trees over by hand, cutting off the top 1 m from the tree top and removing all twigs, sampling only the stem. The sample size for any vegetation geochemical sample is dictated by the weight loss on ashing, which for most species varies between 93-99%; the sample collection should ensure that 1 g of ashed material is available for analysis. Five duplicate samples, including bark, twig and stem material, were collected at various points along the sampling transect for duplicate analysis. Parameters recorded over a 10 m^2 area at each sample site include: the percentage of aspen and other tree species; average aspen circumference; and the physiographical terrain present (Table 1). To enable data comparison, the sample locations are identical to the locations of a soil sampling survey completed by the Alberta Geological Survey in 1997 (Eccles, 1998).



3D Magnetic Interpretation

- Magnetic signature has two peaks which probably correspond to two eruptive centres
- Long wavelength components indicate the diatreme has relatively deep roots
- Widths ot 500-750 m at a depth of ~ 200 m, and then narrowing with depth

After Peirce (1996)

Total Magnetic Intensity

🟫 >40 Nanotesla
🟨 30-40 Nanotesla
🟧 20-30 Nanotesla
🟪 10-20 Nanotesla
🟦 <10 Nanotesla

After Wood and Williams (1994).

Figure 3. Biogeochemistry sample locations over the Mountain Lake Diatreme. The sampling transect is plotted on a rotated ground magnetic survey (view from the north), with a 3D magnetic interpretation of the pipe.

Table 1. Sample site (10x10 m^2) measurements: observations along the sampling transect.

Sample Number	Trees Species Present (%) *	T.A. Circumference (cm)	Physiography
RE-ML98-T01	T.A. = 30; S = 60; A = 7; B = 3	85	Flat; low-lying
RE-ML98-T02	T.A. = 35; S = 60; A = 5	85	Flat; low-lying
RE-ML98-T03	T.A. = 25; S = 65; A = 10	85	Flat; low-lying
RE-ML98-T04	T.A. = 20; S = 80; A = 5	80	Flat; low-lying
RE-ML98-T05	T.A. = 25; S = 75	120	Flat; low-lying
RE-ML98-T06	T.A. = 40; S = 60	130	Flat; low-lying
RE-ML98-T07	T.A. = 40; S = 60	130	West side of Creek; slightly elevated bank
RE-ML98-T08	T.A. = 70; S = 5; A = 5; B = 5; B.P. = 15	15	East side of Creek; lowest terrain
RE-ML98-T09	T.A. = 80; S = 10; A = 10	90	Flat; low-lying
RE-ML98-T10	T.A. = 90; S = 10	100	West slope: 5°
RE-ML98-T11	T.A. = 90; S = 10	90	West slope: 20°
RE-ML98-T12	T.A. = 95; S = 5	90	West slope: 30°
RE-ML98-T13	T.A. = 95; S = 5	75	West slope: 30°
RE-ML98-T14	T.A. = 95; S = 5	50	Flat; 2nd highest platform
RE-ML98-T15	T.A. = 90; S = 10	45	Flat; centre and top of the topo. high
RE-ML98-T16	T.A. = 95; S = 5	50	Flat; top of the topographic high
RE-ML98-T17	T.A. = 97; S = 3	50	East slope: 20° - 30°
RE-ML98-T18	T.A. = 99; S = 1	75	East slope: 30°
RE-ML98-T19	T.A. = 99; S = 1	75	East slope: 20° - 30°
RE-ML98-T20	T.A. = 97; S = 3	80	East slope: 15° - 20°
RE-ML98-T21	T.A. = 98; S = 1; A = 1	100	East slope: 10°
RE-ML98-T22	T.A. = 87; S = 3; A = 10	110	Flat; low-lying
RE-ML98-T23	T.A. = 80; S = 5; A = 10; B.P. = 5	130	Flat; low-lying
RE-ML98-T24	T.A. = 80; S = 5; A = 10; B.P. = 5	115	Flat; low-lying
RE-ML98-T25	T.A. = 80; S = 5; A = 10; B.P. = 5	115	Flat; low-lying; fen deposits
RE-ML98-T26	T.A. = 75; S = 10; A = 15	110	Flat; low-lying
RE-ML98-T27	T.A. = 75; S = 10; A = 15	110	Flat; low-lying
RE-ML98-T28	T.A. = 75; S = 10; A = 15	110	Flat; low-lying
RE-ML98-T29	T.A. = 55; S = 40; A = 5	110	Flat; low-lying
RE-ML98-T30	T.A. = 70; S = 20; A = 10	120	Flat; low-lying
RE-ML98-T31	T.A. = 60; S = 10; A = 30	100	Flat; low-lying
RE-ML98-T32	T.A. = 65; S = 10; A = 25	105	Flat; low-lying
RE-ML98-T33	T.A. = 70; S = 10; A = 20	110	Flat; low-lying
RE-ML98-T34	T.A. = 65; S = 10; A = 25	105	Flat; low-lying
RE-ML98-T35	T.A. = 75; S = 5; A = 20	105	Flat; low-lying

* T.A. = Trembling Aspen S = Spruce A = Alder B = Birch B.P. = Balsam Poplar

A noticeable change in the type of vegetation may be observed in aerial photographs over many "hills" in northern Alberta. Therefore, a second sampling transect was selected over a topographic high located 6.5 km east of the Mountain Lake Diatreme in order to compare the trace element concentrations obtained over the Mountain Lake Diatreme with concentrations from an area with a similar physiographic environment. The site was selected because of its proximity and similar dimensions to the Mountain Lake Diatreme, both in terms of areal extent and height. Five samples were collected with the intention of mirroring the sampling transect over the Mountain Lake Diatreme, and include bark, twig and stem samples from on top of the hill, on the slopes and in the lowlands adjacent to the hill.

The bark, twig and stem samples were air dried on paper plates for three weeks and then ashed in a kiln at 470°C for 24 hours. Approximately 1 g of each ash sample was analyzed at Activation Laboratories Ltd. for: (1) 35 elements by instrumental neutron activation analysis (INAA) with enhanced detection limits; and (2) 30 elements by inductively-coupled plasma emission spectrometry (ICP), following aqua regia digestion. A total of 48 elements were analyzed, since some elements were included in both the INAA and the ICP analysis.

ANOMALY PROFILES AND GEOCHEMICAL RESULTS

Five duplicate samples (one bark, two twig and two stem samples), were collected at various sites along the sampling transect. On average, the concentrations from the duplicate samples were within 10% of the original sample. This includes elements indicative of kimberlites. For example, a comparison between the geochemistry from the original and duplicate samples yielded concentration differences of < 10% for Cr, < 20% for Ni, < 15% for Co, < 10% for Rb, < 10% for Zn and < 5% for P.

Element profiles of the geochemical analysis from bark, twigs and stem samples collected over the Mountain Lake Diatreme are presented in Appendix 1. Four significant profiles were observed including: (1) concentrations that are elevated directly over the surficial expression of the pipe (e.g. Ni); (2) concentrations elevated above background which occur at the edges of the pipe or in the lowlands directly adjacent to the pipe (e.g. Ag); (3) a combination of 1 and 2 (e.g. Co); and (4) a depletion in concentrations directly over, or slightly shifted over, the pipe (e.g. Ba). Elements with concentrations below the detection limit of the analyses, which therefore, do not yield a geochemical signature include Be, Eu, Hg, Ir, Lu, Sn, Tb, Ti and Yb.

The trembling aspen proved to be a viable sampling medium in its ability to up take elements indicative of ultramafic and kimberlitic sources. Bark, twig and stem aspen samples yielded a significant geochemical signature (up to 28 times background) directly over, or in the immediate vicinity of, the Mountain Lake Diatreme for trace elements including Co, Cr, Mg and Ni, along with incompatible elements such as La, Rb and Sm (Table 2). Nickel may be singled out as the most diagnostic element of the survey, with concentrations of up to 28 times background from a stem sample occurring directly over the pipe. Other notable elements that yield elevated concentrations directly over the pipe include Al, As, Au, Fe, Na, V and W. Elements that yielded an elevated concentration over the pipe, but only in selected sampling media, include: Hf, Sb and Zr from bark,

Table 2. Biogeochemical summary of selected elements.

Element	**Dominant Profile ***	**Element Uptake Ranking**	**Maximum Concentration Times Background**		
			(Bark)	**(Twig)**	**(Stem)**
Au	3	Stems>Twigs>Bark	4	2	4.5
Ba	4	Stems>Bark>Twigs	5.5	3.5	5.5
Co	3	Stems=Bark>Twigs	3.25	3	3.25
Cr	1	Bark=Stems>Twigs	6	2	5
Cs	1	Stems	/	/	4
Cu	4	Stems>Twigs>Bark	1.25	1.75	2
Fe	1	Stems>Bark>Twigs	2.75	1.5	8
Hf	1	Bark	2	/	/
K	4?	Stems>Twigs>Bark	1.5	1.5	1.75
La	3	Stems=Twigs>Bark	4	4.5	5
Mg	1	Stems=Twigs=Bark	2.25	2.5	3
Nd	1	Stems	/	/	1.2
Ni	1	Stems>Twigs>Bark	10	10	28
P	2 or 4	Stems=Twigs>Bark	2.25	3.75	4.5
Rb	3	Bark>Twigs>Stems	3.5	5.25	3.5
Sm	3	Stems=Twigs>Bark	3	3	4
Sr	3	Bark=Twigs=Stems	2.25	2.25	2.25
V	3 or 1	Bark>Stems>Twigs	3	2	2
Zn	4	Stems>Twigs>Bark	1.5	1.5	2
Zr	1	Bark	2	/	/

* Dominant Profiles:
1 - concentration elevated directly over the surficial expression of the diatreme
2 - concentration elevated at the edges of the diatreme
3 - combination of 1 and 2
4 - depleted concentration directly over the surficial expression of the diatreme

Ce from twig, and Cs and Nd from stem samples. The stem and twig samples yielded elevated distinct P concentrations over the eastern slope of the pipe and in the lowlands to the west of the pipe. Elements that are depleted directly over the pipe include Ba, Ca, Cu, and Zn. Potassium yields a slight depletion over the centre of the pipe, which is enhanced by a slight elevation in the K concentration at the edges of the pipe.

Analysis from a second sampling transect, located over a topographic high 6.5 km east of Mountain Lake did not yield anomalous concentrations for elements indicative of kimberlites. For example, Figure 4 compares the concentrations of Ni yielded by the analyses of bark, twig and stem samples collected over the diatreme with similar samples collected over the second site. The Mountain Lake Diatreme yields Ni concentrations of up to 141 ppm Ni directly over the pipe, while the maximum Ni concentration over the second sampling transect is only 35 ppm Ni, and comparable to background Ni concentrations in the vicinity of Mountain Lake. Other elements indicative of kimberlite such as Cr and La yielded similar results. However, it is interesting to note that the second sampling transect did yield elevated concentrations of Co and Rb from bark and stem samples directly over the top of the hill, which may warrant further investigation of the biogeochemical method and discrete selection of elements for interpretation. The geochemical variance between the second sampling transect and the Mountain Lake Diatreme transect indicate that the positive geochemical pattern obtained over the diatreme is not related to the physiographic environment and that biogeochemical sampling can detect an ultramafic signature from associated soil and bedrock.

Anomalous geochemical patterns are evident in analyses from all three trembling aspen sampling medium including bark, twig and stem samples. However, it would appear that the stems provide the best overall relative element abundance association. This is evident in the majority of key kimberlite indicator elements outlined in Table 2, where stem samples represent either the best uptake of metals in terms of element concentrations and signatures, or are equivalent to the bark and twig samples. The stem samples also returned the highest number of elements to yield concentrations above the minimum detection limits of the analyses.

The biogeochemical signature of bark, twig and stem samples collected over the Mountain Lake Diatreme is similar to that of a soil geochemistry survey completed in 1997 (Eccles, 1998). Although completed during different years, an identical sampling transect was used for vegetation and soil sample collection and hence, sample site locations are within 10 m of one another. Using Ni as an example (Figure 5), it is easy to correlate the three distinguishable peaks displayed by the soil geochemical profile with the elevated Ni concentrations displayed by the vegetation geochemical profile. A strong correlation is also evident for elements Ce, Co, Cr, Cu, La, Rb, Sm and Sr, and a moderate correlation exists for As, Au, Mo, Sb, V and W. A reversed correlation occurs between elements Ba and Zn, where the vegetation profiles exhibit a depletion over the diatreme as apposed to the elevated profile exhibited in the soil geochemistry. This illustrates that while the aspen is not absorbing all of the elements present in the soil, it is duplicating the anomalous soil concentration levels of elements considered important for diamond exploration.

Figure 4. Nickel profile comparison: Mountain Lake Diatreme versus a second sampling transect (similar topographic high and located 6.5 km east).

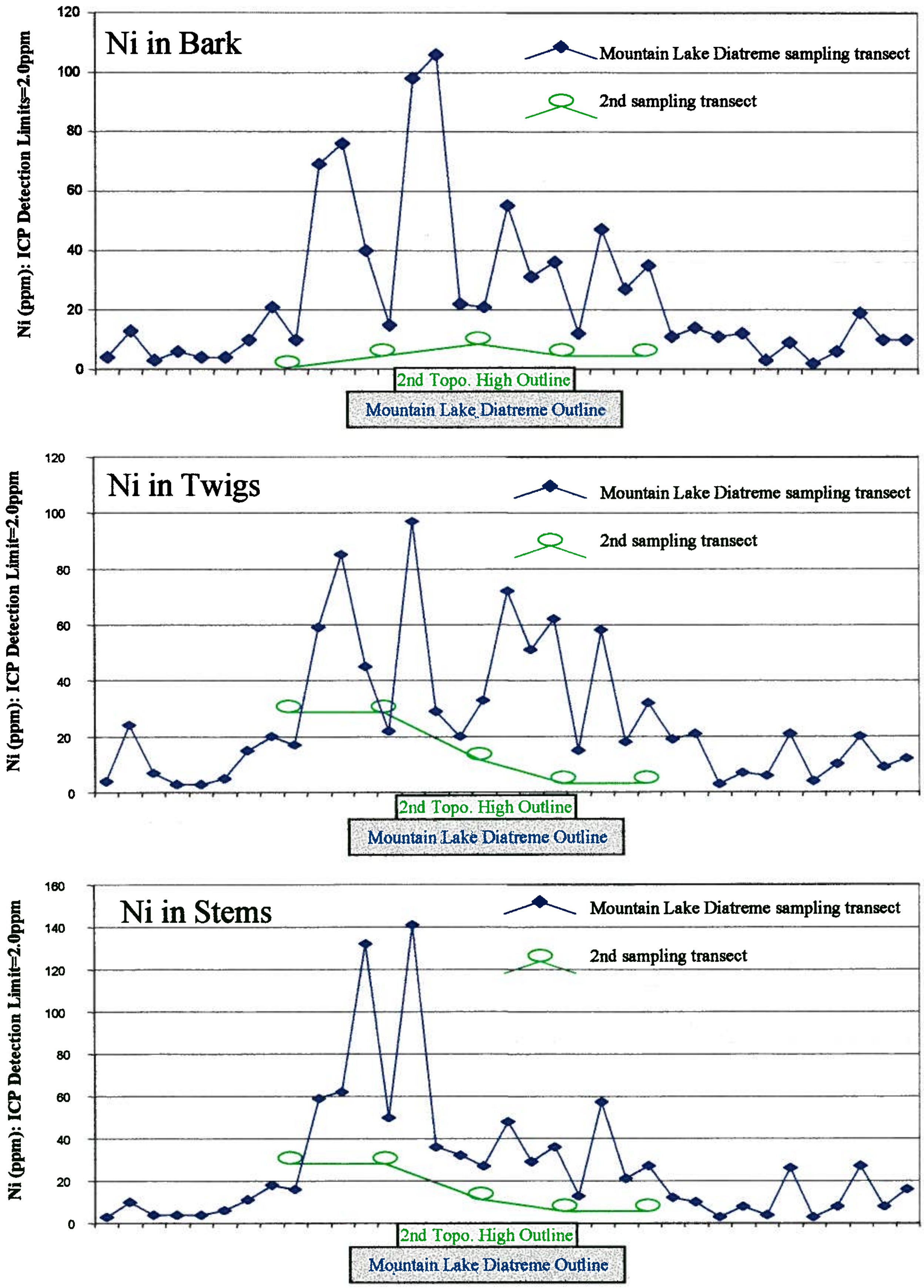
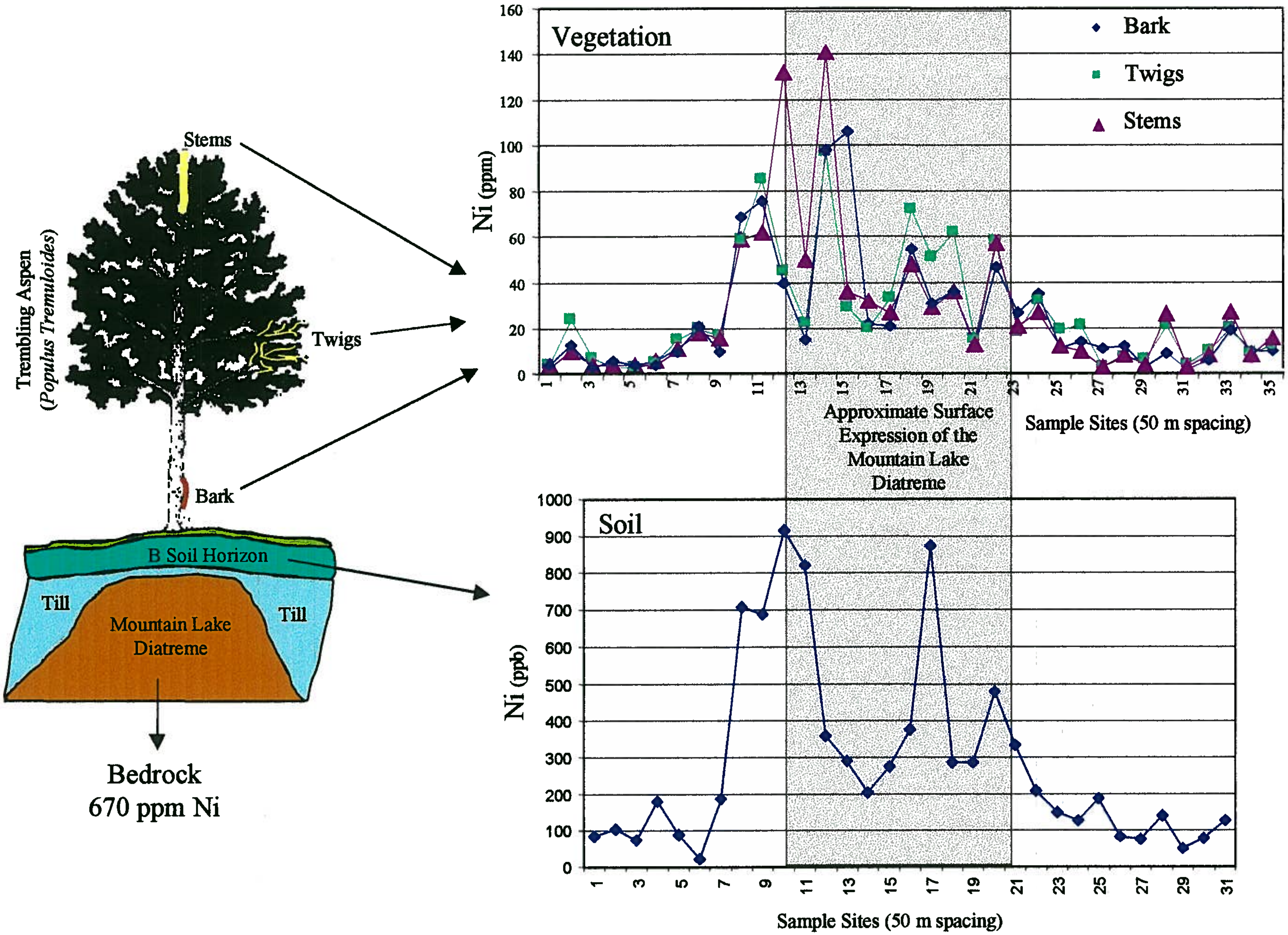


Figure 5. Vegetation, soil and bedrock nickel concentrations from the Mountain Lake Diatreme.



DISCUSSION

Surficial Expression over Kimberlites

Distinctive vegetation expressions have been identified all over the world for many kimberlites. The contrasting vegetation patterns likely are enhanced by: (1) the soil development over kimberlites, which are commonly enriched in trace elements such as Cr, Co, Mg, Nb, Ni, P and light rare earth elements; (2) kimberlite alteration, which usually results in better water retention capacity through association of montmorillonitic clays; and (3) morphologies associated with the pipes such dome-shaped, concentric-radial structures indicative of basement uplift and faulting, and relatively small, circular to ellipsoidal structures formed by the kimberlite (Alcard, 1959; Haebig and Jackson, 1996; Kaminsky *et al.*, 1995; Litinskiy, 1964).

In Alberta, where several kimberlites discovered to date form topographic highs with exposed or nearly exposed bedrock, soil and bedrock geochemistry must play a key role in the definition of the geobotanical surface expression above the diatreme. Anomalous plant communities are most likely to occur over deposits which contribute: (1) more soluble and essential plant elements such as K, P, Mg, Mo, Fe; and (2) elements that are toxic to plant growth including immobile elements such as Cr and Ni. Thus many successful biogeochemical surveys are known over copper, lead, zinc, nickel, cobalt and uranium deposits and over carbonatites and kimberlites, the latter being particularly enriched with both soluble and immobile elements.

Measurements of the larches over eight Yakutian, Russia kimberlite pipes by Buks (1965), depicted a noticeable increase in height (up to 2.25 times the regional average), diameter (up to 2.5 times the regional average) and density per hectare (1.9 times the average). The 400 year old larches growing on the carbonates were approximately 0.15 m in diameter and comprised of rotting cores, while the cores of the 0.30 m diameter, 550 year old larches growing on the kimberlites remained healthy. Buks credited the health and size of the larches possibly to the release of phosphorous from apatite derived from the kimberlite pipes. Similarly, the tree layer over the Hinota kimberlite, central India, is characterized by a more healthy growth of several species than over the surrounding quartz arenite country rock, and the pipe can be picked out from a distance simply by the presence of tall, healthy trees (Alexander and Shrivastava, 1984). The difference was attributed to the sharp contrast in chemical elements such as Ca, Mo, Cr, Co, Fe, Mg and Ni of the kimberlite and that of the arenite, and in particular to the extremely rich K and P chemistry of kimberlite.

Conversely, many ultramafic belts of the world are characterized by sparseness of vegetation and shortage of species in relation to their surroundings and may develop a stunting of growth, or dwarfism, typical of a serpentine-type flora (Brooks, 1972). This has been attributed to the deficiency of macro nutrients nitrogen, potash, phosphorous (unlike kimberlites which are extremely rich in phosphorous and potash), Ca and Mo, and the toxic effects of higher amounts of Cr, Co, Fe, Mg and Ni. However, the vegetation cover associated with soils derived from the Redondão Kimberlite, Brazil comprises grasses and shrubs, displaying a markedly different serpentine-like flora vegetation pattern from the surrounding savanna-park vegetation (cerrado), particularly during the dry season when the grass cover is dry and the cerrado foliage remains green (Almeida-Filho and Castelo

Branco, 1992).

It is the belief of the author that the distinguishable vegetation patterns expressed over kimberlites are caused by morphological changes in vegetation and include "very subtle" features of dwarfism or gigantism. Whether the soil layer above the kimberlite is enriched with soluble, toxic (immobile), or a combination of soluble and toxic elements will have a major influence on the characteristics of the surficial expression including soil and vegetation patterns. Therefore, a specific vegetation pattern such as large, healthy growing trees cannot be assumed to occur over all kimberlites. And in fact, the vegetation pattern can change over a specific field of kimberlites depending on the associated geochemical soil profile of any individual kimberlite, which may be affected by numerous conditions such as emplacement characteristics, alteration, groundwater, transitional and surficial water drainage, and glacial deposits. For example, a topographic high may account for a greater amount of surficial and transitional groundwater run-off, and a convenient route for the down slope loss of soluble elements K and P, which in turn, leaves the soil directly over the kimberlite enriched in more immobile, toxic elements such as Ni and Cr. This scenario may be exactly the case at the Mountain Lake Diatreme as depicted by aspen circumference measurements and by the biogeochemical profiles. The trembling aspen have been measured as being smaller directly over the diatreme (45 cm circumference), where Ni and Cr are readily available for vegetation uptake, versus the larger trees (130 cm circumference) at the base of the slope directly surrounding the diatreme, where K and P are enriched at the boundaries of the pipe. Therefore, a "ring-like" vegetation pattern was observed by healthy and larger tree growth at the edge of the Mountain Lake Diatreme.

In summary, what is important to remember is that the geobotanical study should not focus on any particular vegetation pattern when exploring for kimberlites, but account for all variations in vegetation changes and the distribution patterns of those changes, at which time biogeochemical studies can be conducted.

Glaciation

As with most exploration techniques, geobotany is constrained by some terrain features. One of the main drawbacks to the successful use of biogeochemical methods in Canada is the presence of certain glacial deposits (e.g. tills and lacustrine deposits). In some areas of northern Alberta, a thick cover of multiple glacial deposits from differing directions is the most limiting factor, and may not only effectively mask the geochemical response of buried deposits, but affect the trees root system thereby placing too much emphasis on vertical ground water movement over the deposit. Vegetation geochemical profiles may be further complicated in glacial terrains by certain species that may reach heights of 20 m or more, but penetrate no further than 0.5 or 1.0 m vertically into the glacial overburden after which the roots grow laterally.

However, Wolfe (1971) concluded that biogeochemistry can be an effective exploration tool where plant root systems penetrate thick deposits of transported Pleistocene cover. He noted from a study of biogeochemical prospecting in glaciated terrain of the Canadian Precambrian shield that Mo, U, Pb, Co and probably Fe and Mn, may show moderate to high anomaly contrasts in the common deep-rooted tree species, but Cu, Zn, Ni and Ag responses generally show low contrast.

The successful correlation between vegetation and soil geochemical surveys at the Mountain Lake Diatreme, suggests that metals were obviously mobilized and that root systems are tapping the B-horizon, which has a metal-enriched amorphous Mn oxide component measured by Eccles (1998). Therefore, biogeochemistry may prove to be a quick and cost effective way of testing potential exploration targets in glaciated terrains.

In any event, the relationships between plant cover, soils and bedrock geology may be complex and their understanding may require studies of regional morphology, which when acquired, will only benefit the potential of a biogeochemistry survey's success in assisting to locate potentially economic targets such as kimberlites.

CONCLUSIONS

Bark, twig and stem samples from trembling aspen trees over the Mountain Lake Diatreme proved to be viable sampling medium in their ability to up take elements indicative of ultramafic and kimberlitic sources, and provided a distinctive biogeochemical signature that may be used elsewhere in Alberta. Bark, twig and stem aspen samples yielded a significant geochemical signature (up to 28 times background) directly over, or in the immediate vicinity of, the Mountain Lake Diatreme for trace elements including Co, Cr, Mg and Ni, along with incompatible elements such as La, Rb and Sm. Other notable elements that yield elevated concentrations directly over the pipe include Al, As, Au, Fe, Na, V and W. Nickel may be singled out as the most diagnostic element of the survey, with concentrations of up to 28 times background (141 ppm Ni) from a stem sample occurring directly over the pipe. Elements that yielded an elevated concentration over the pipe, but in selected sampling media, include: Hf, Sb and Zr from bark, Ce from twig, and Cs and Nd from stem samples. Elements that are depleted directly over the pipe include Ba, Ca, Cu, and Zn. Potassium yields a slight depletion over the centre of the pipe, which is enhanced by a slight elevation in the K concentration at the edges of the pipe. The stem and twig samples yielded elevated and distinct P concentrations over the eastern slope of the pipe and in the lowlands to the west of the pipe.

Analysis from a second sampling transect, located over a similar - but non-kimberlitic - topographic high 6.5 km east of Mountain Lake, did not yield anomalous concentrations for elements indicative of kimberlites. For example, the maximum Ni concentration (35 ppm Ni) yielded from vegetation samples collected over the second sampling transect, are comparable to the background Ni values in the Mountain Lake area, and no where near elevated Ni concentrations (up to 141 ppm Ni) yielded from samples collected directly over the Mountain Lake Diatreme. The geochemical variance between the second sampling transect and the Mountain Lake Diatreme transect indicate that the postive geochemical pattern obtained over the diatreme is not related to the physiographic environment and that biogeochemical sampling can detect an ultramafic signature from its corresponding soil and bedrock.

Stem samples, followed by bark and then twig samples, provide the best overall relative element abundance association with the adjacent soils and bedrock. A strong geochemical correlation between the vegetation survey and a soil geochemistry survey completed by the Alberta Geological Survey in 1997 is evident for key kimberlite indicator elements including Ce, Co, Cr, Cu, La, Ni, Rb, Sm and Sr. A negative correlation occurs between elements Ba and Zn, where the vegetation profiles exhibit a depletion over the diatreme as apposed to the elevated profile exhibited in the soil geochemistry. This illustrates that while the aspen is not absorbing all of the elements present in the soil, it is duplicating the anomalous soil concentration levels of elements considered important for diamond exploration.

A "ring-like" vegetation pattern was observed by healthy and larger tree growth at the edge of the Mountain Lake Diatreme. The topographic high formed by the diatreme may account for a greater amount of surficial and transitional ground water run-off, and a convenient route for the down slope loss of soluble elements K and P promoting tree growth at the base of the diateme. And conversely, the soil directly over the kimberlite will be enriched in more immobile, toxic elements such as Ni and Cr which may stunt the vegetation growth. This vegetation pattern may be enhanced in Alberta, where several pipes discovered to date form as topographic highs due to the preferential weathering of the shale and sandstone country rock. The soil layer above the kimberlite may be enriched with soluble, toxic, or a combination of soluble and toxic elements that will have a major influence on the characteristics of the surficial expression including soil and vegetation patterns. Therefore, a specific vegetation pattern such as large, healthy growing trees cannot be assumed to occur over all kimberlites and the explorationist should account for all variations in vegetation changes and the distribution patterns of those changes, at which time biogeochemical studies can be conducted.

This study has shown that biogeochemistry can be an effective low cost, rapid sampling tool (either by itself or in conjunction with other ground exploration surveys), for the investigation of kimberlitic targets in Alberta, which have been preliminarily defined as topographic highs with associated geobotanical expressions or magnetic highs.

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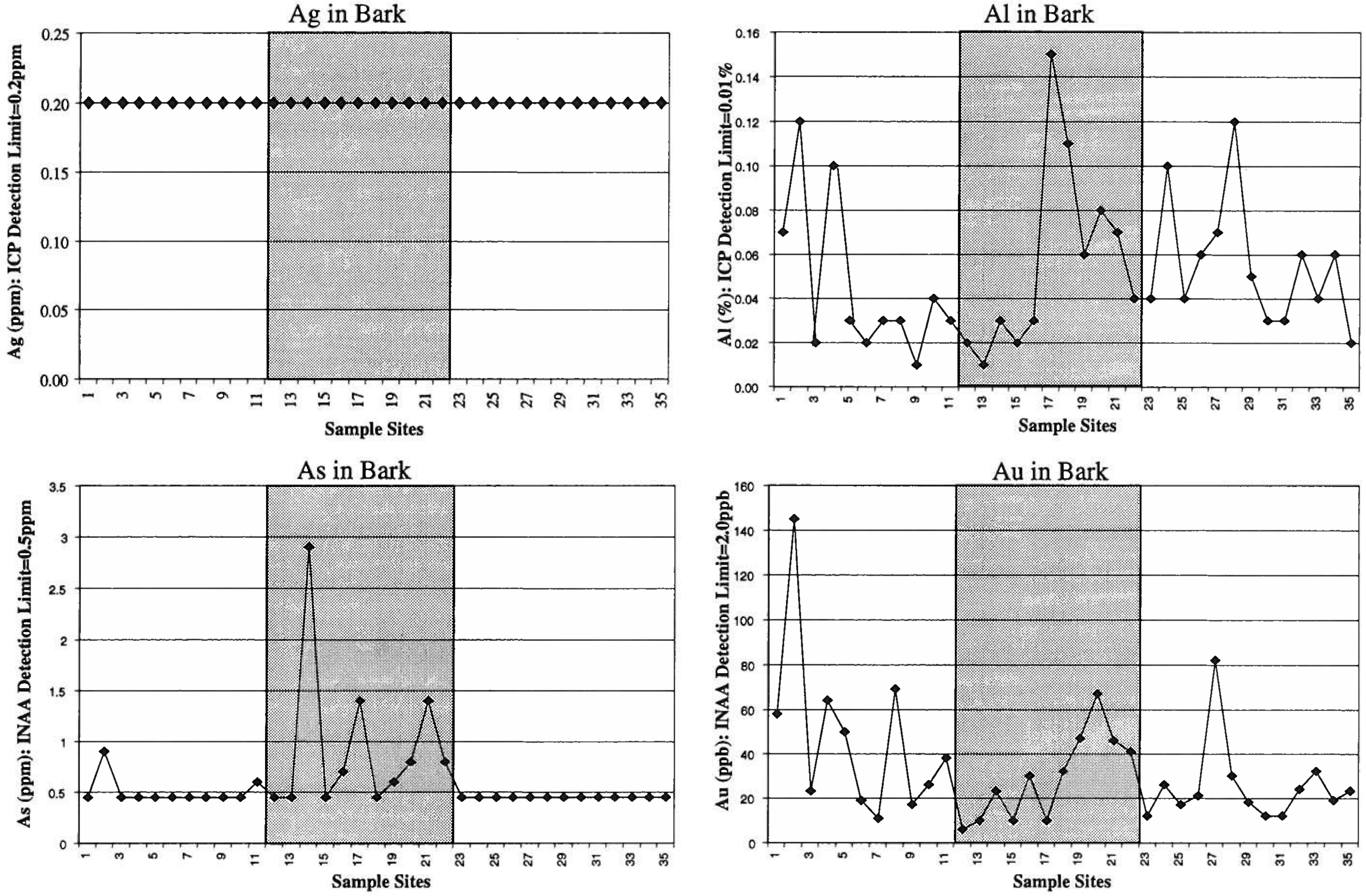
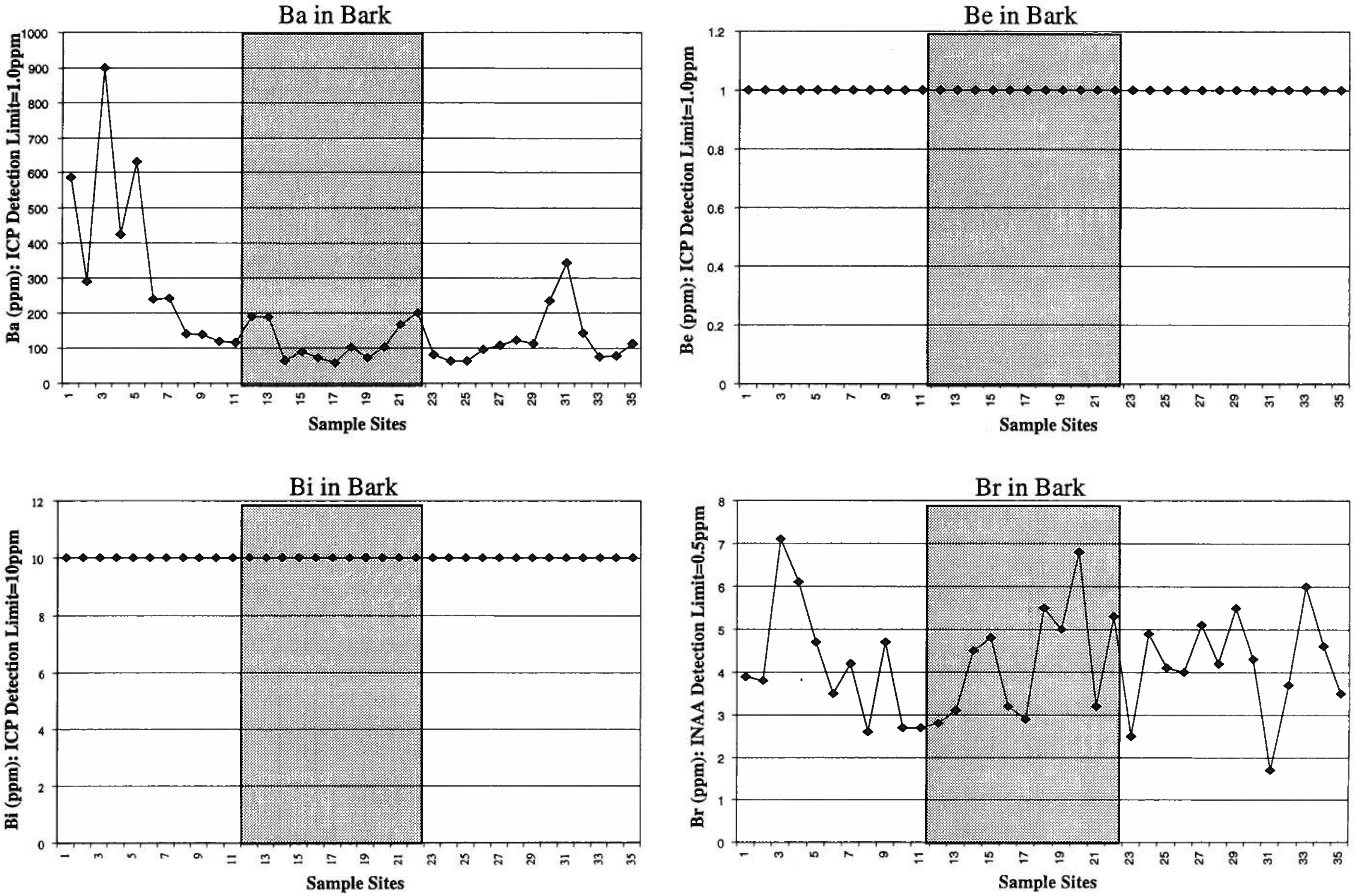
APPENDIX 1

BARK, TWIG AND STEM BIOGEOCHEMICAL PROFILES

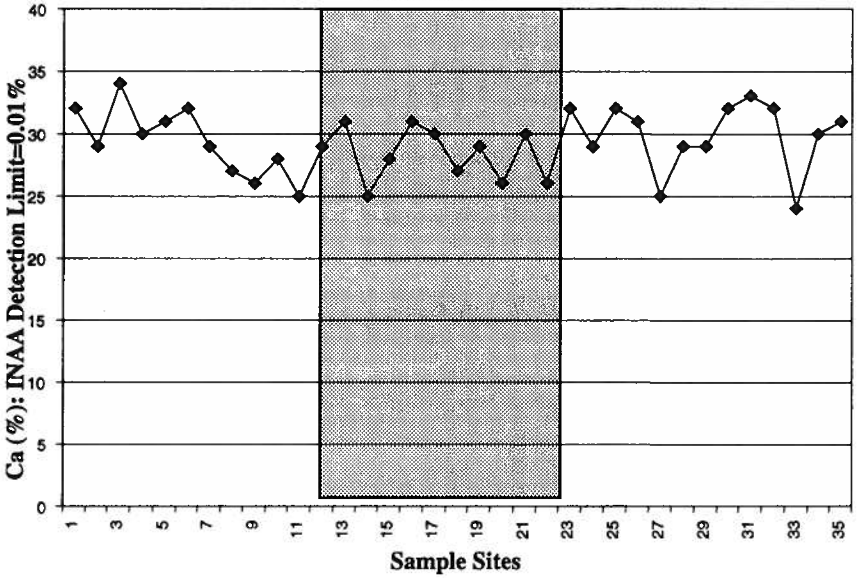
Mountain Lake Biogeochemistry Profiles Ag, Al, As and Au (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



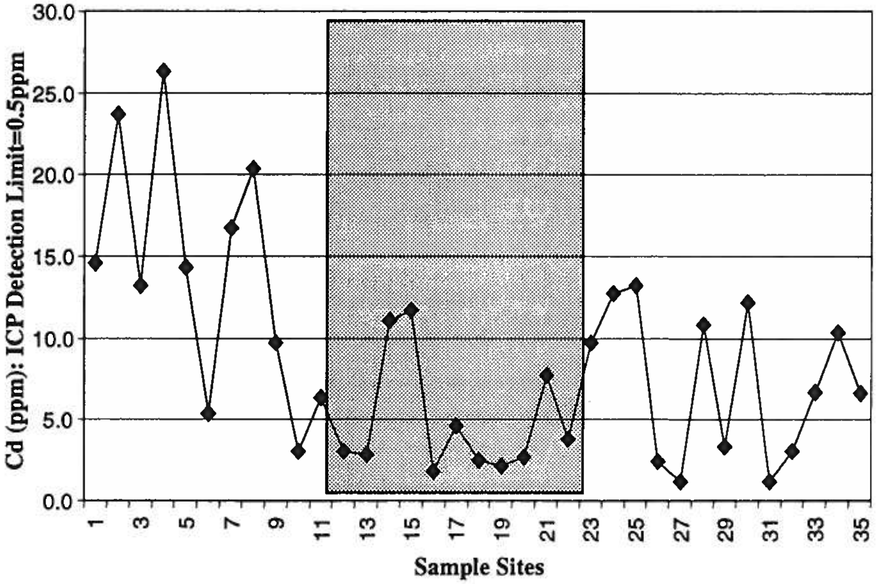
Mountain Lake Biogeochemistry Profiles Ba, Be, Bi and Br (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



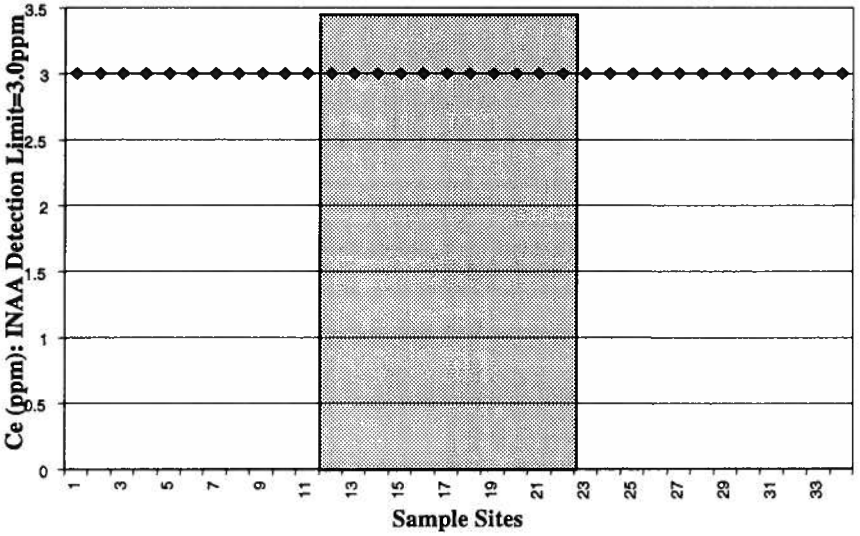
Mountain Lake Biogeochemistry Profiles Ca, Cd, Ce and Co (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.



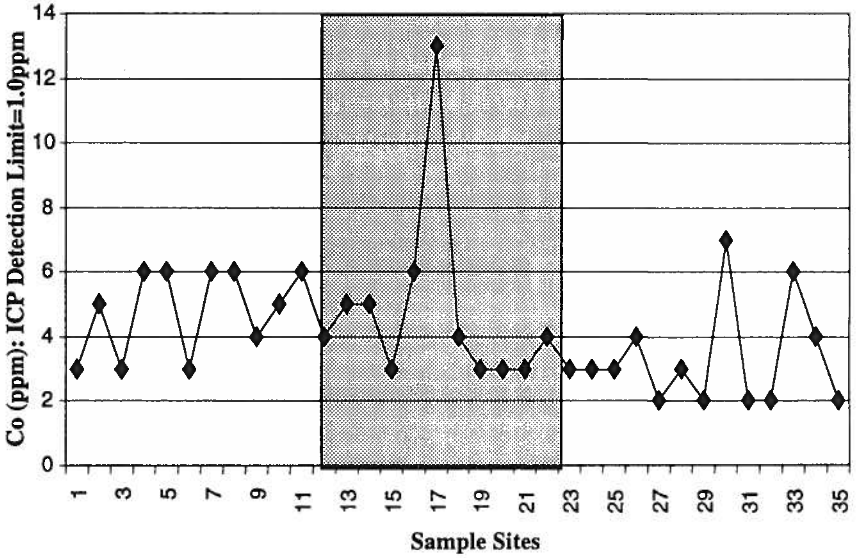
Ca in Bark



Cd in Bark



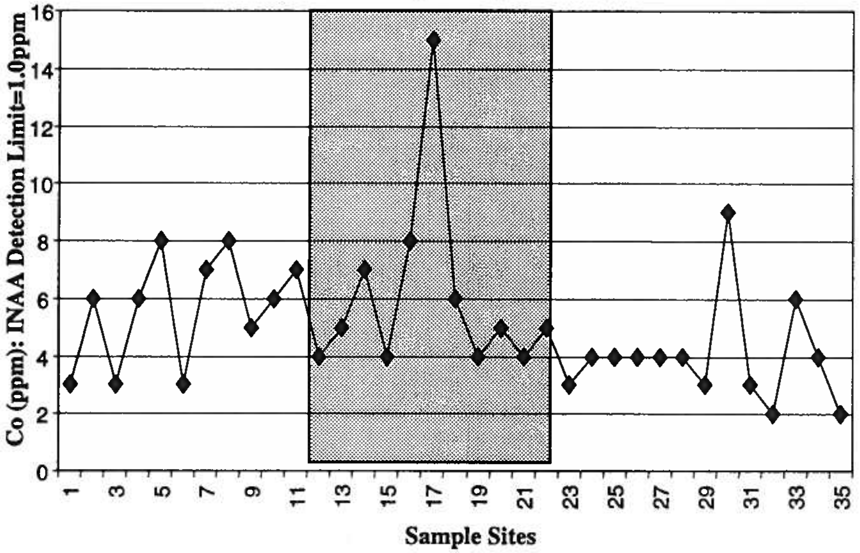
Ce in Bark



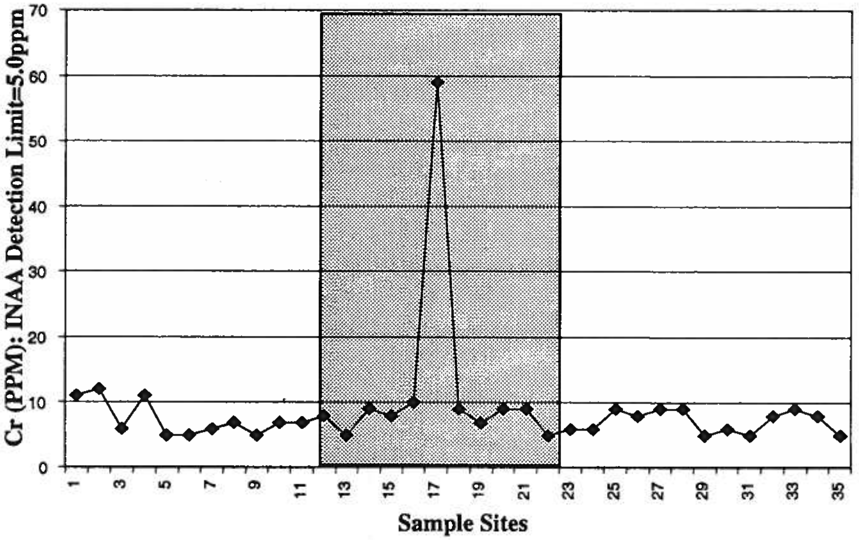
Co in Bark (#1: By ICP)

Mountain Lake Biogeochemistry Profiles Co, Cr and Cs (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

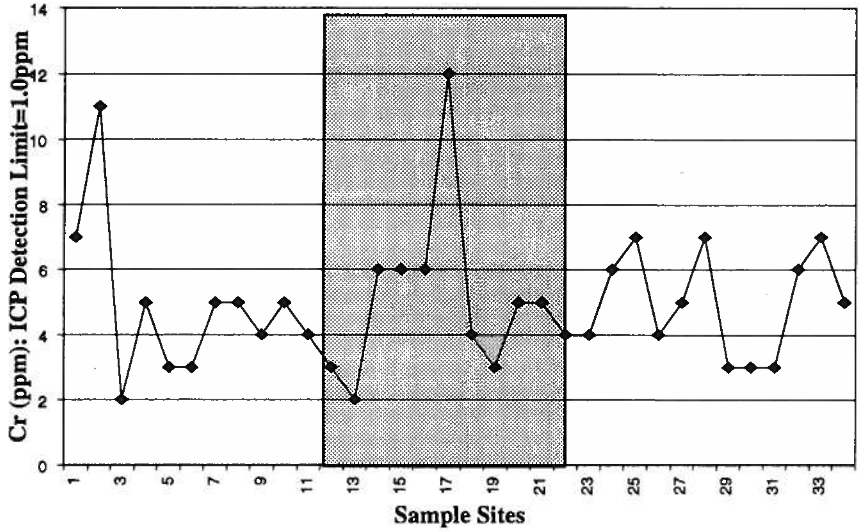
Co in Bark (#2: By INAA)



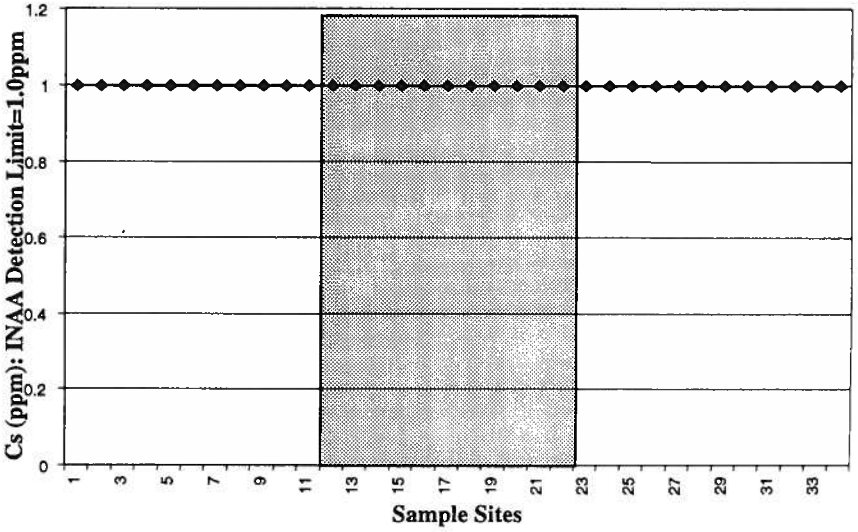
Cr in Bark (#1: By INAA)



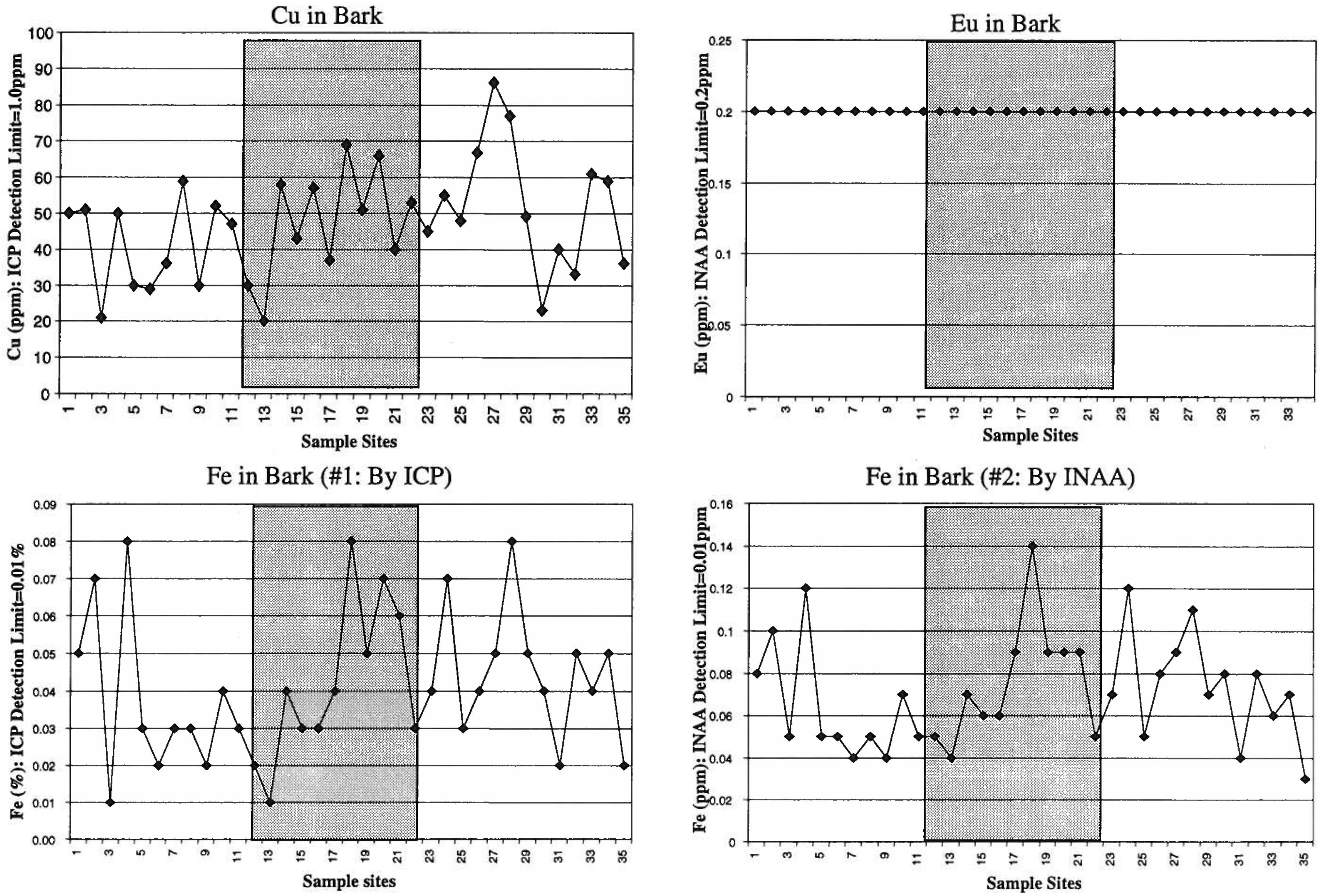
Cr in Bark (#2: By ICP)



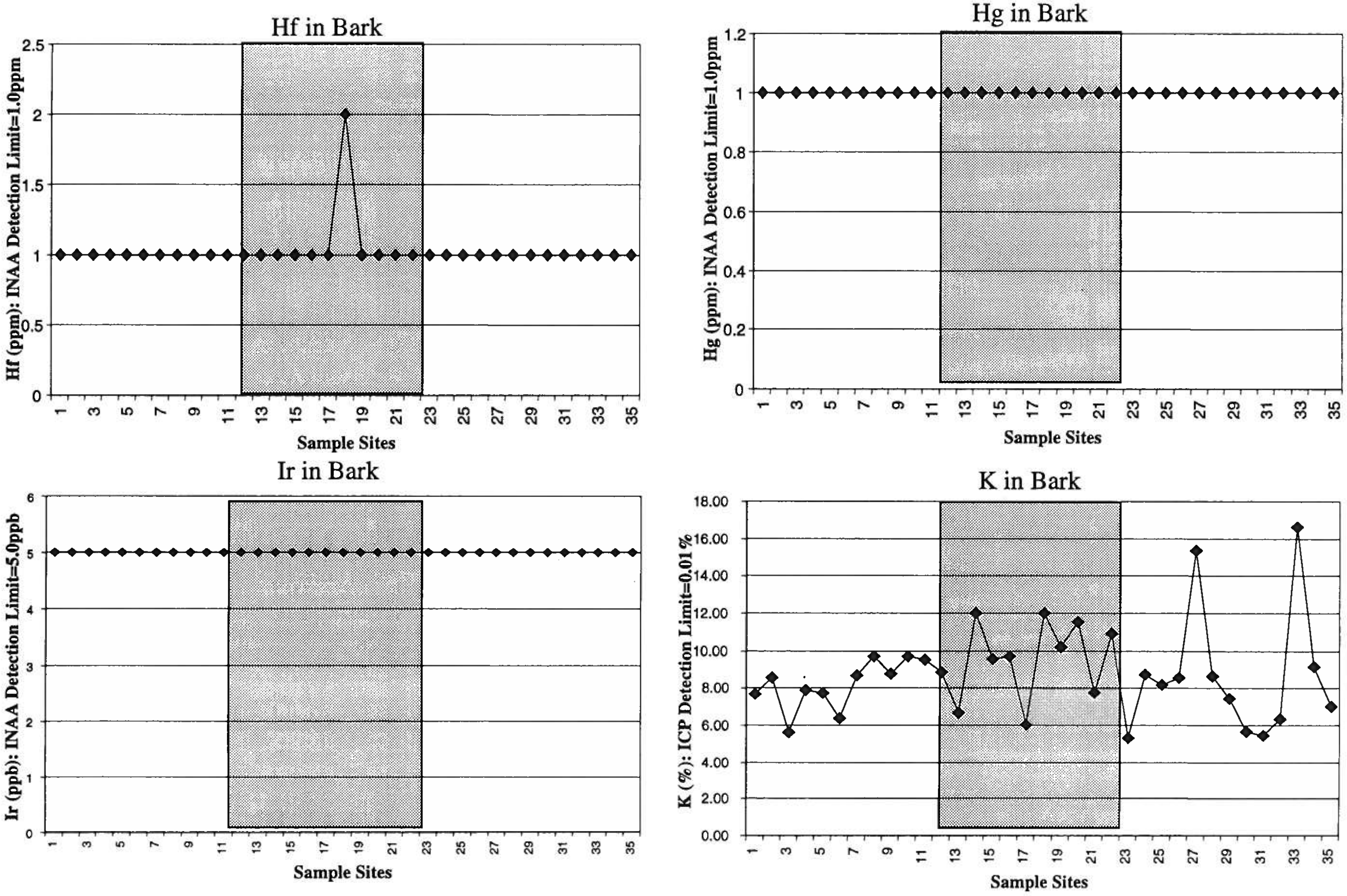
Cs in Bark



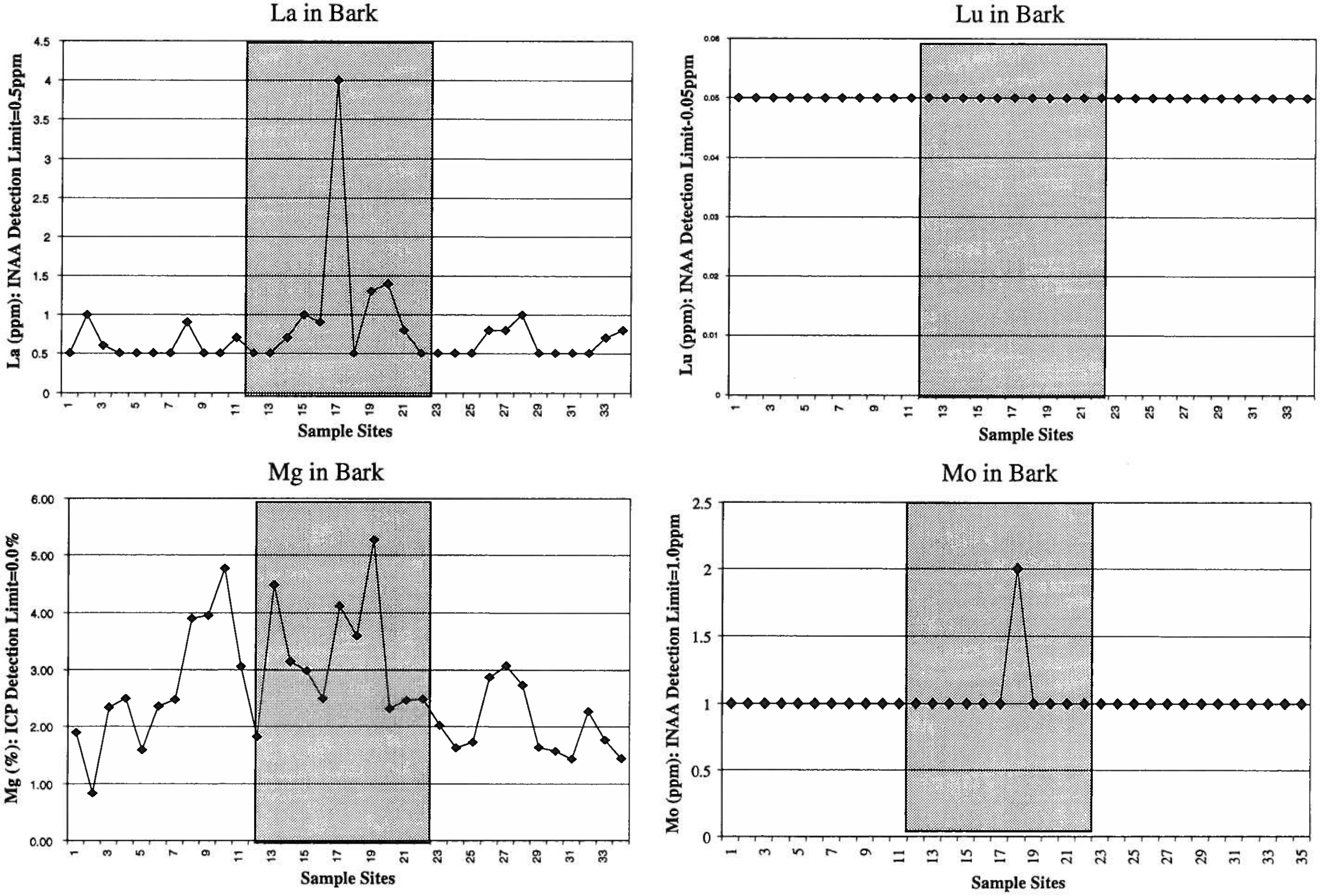
Mountain Lake Biogeochemistry Profiles Cu, Eu and Fe (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



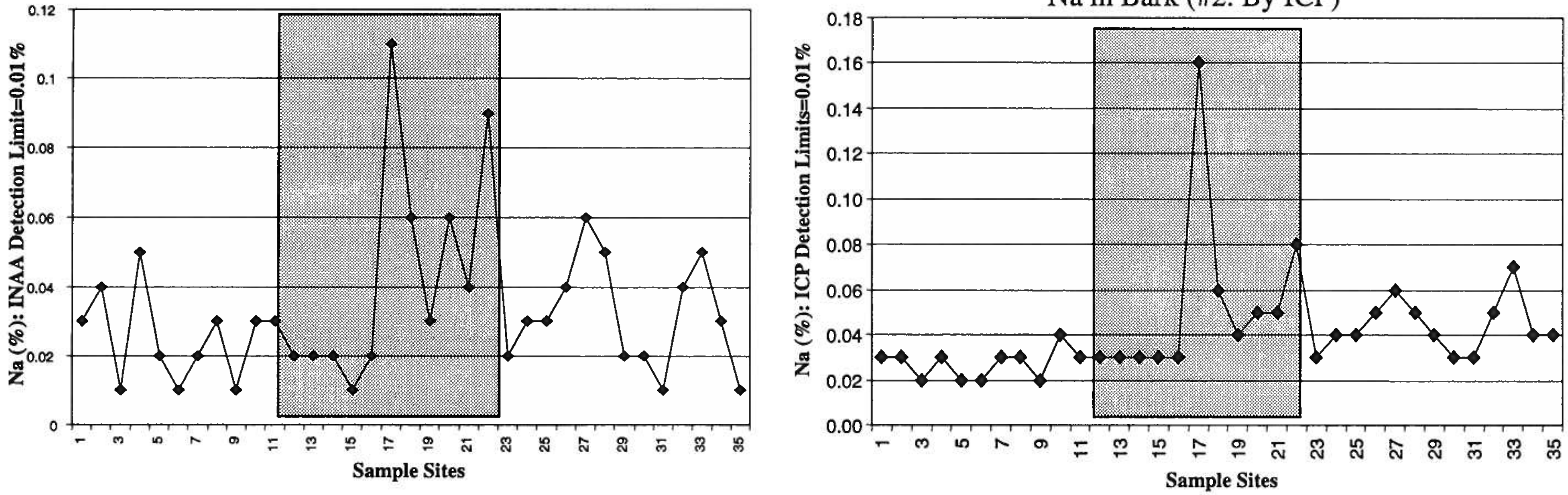
Mountain Lake Biogeochemistry Profiles Hf, Hg, Ir and K (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



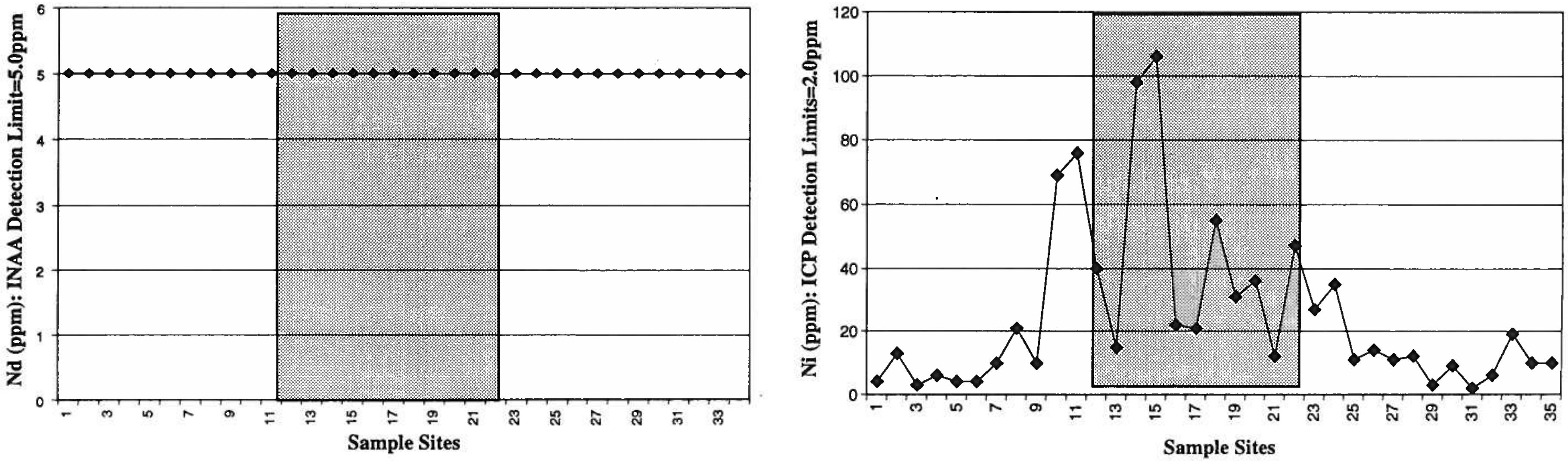
Mountain Lake Biogeochemistry Profiles La, Lu, Mg and Mo (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



Mountain Lake Biogeochemistry Profiles Na, Nd and Ni (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.


Na in Bark (#1: By INAA)

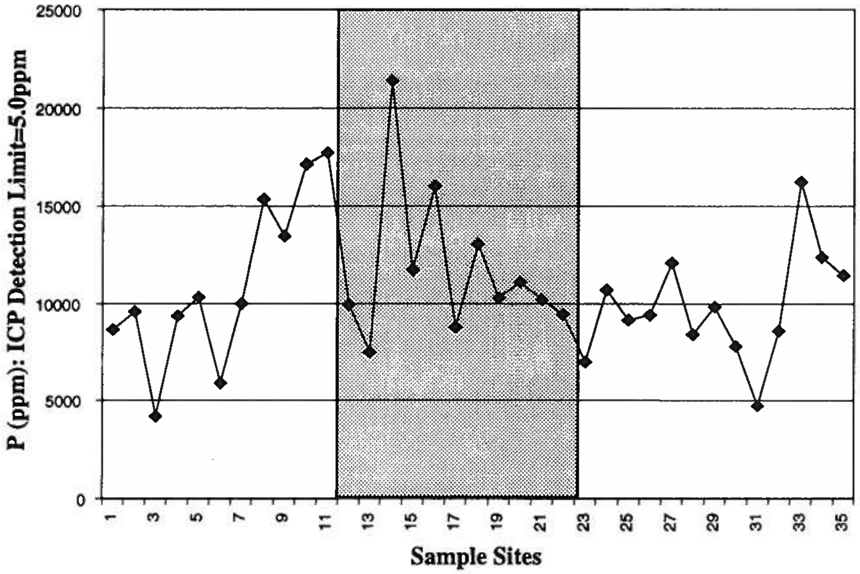
Na in Bark (#2: By ICP)


Nd in bark

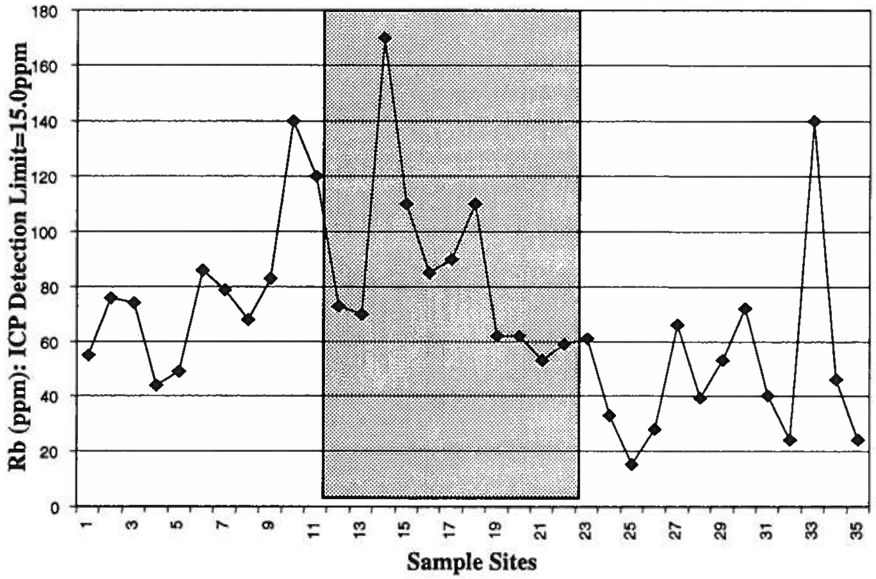
Ni in Bark

Mountain Lake Biogeochemistry Profiles P, Rb, Sb and Sc (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

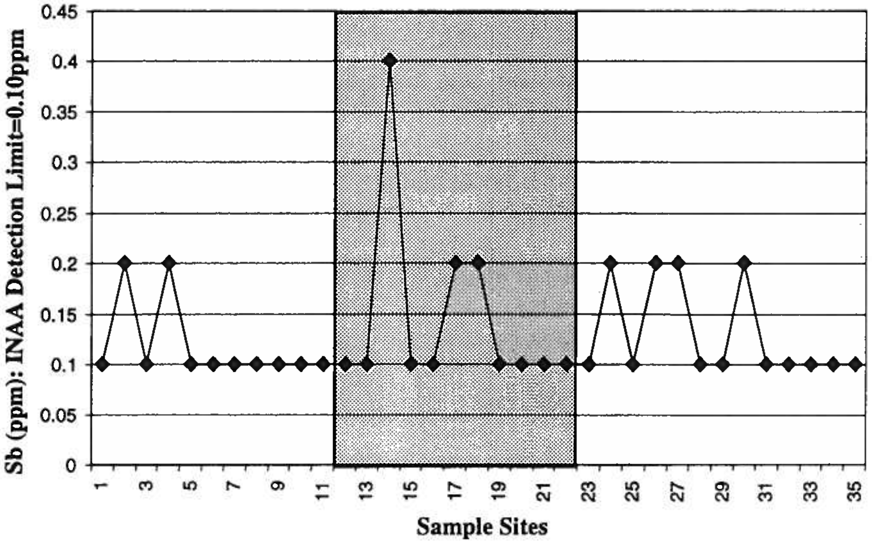
P in Bark



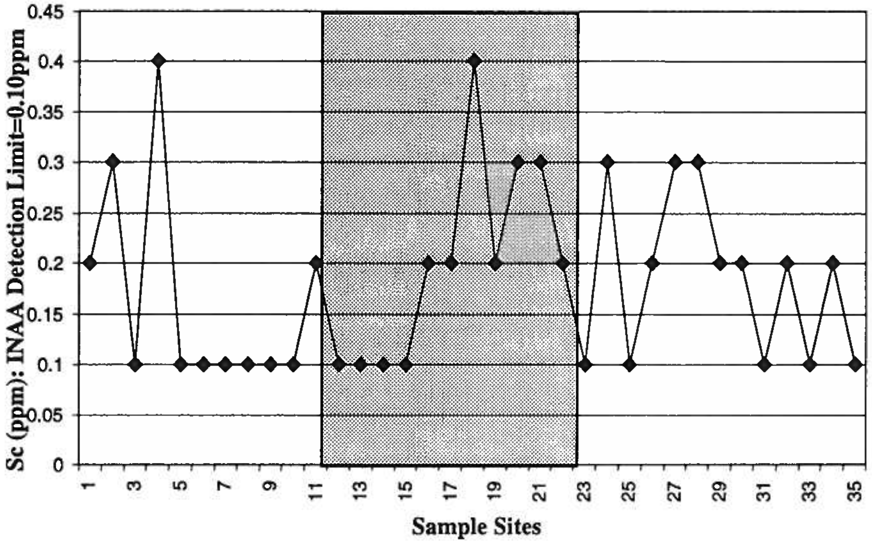
Rb in Bark



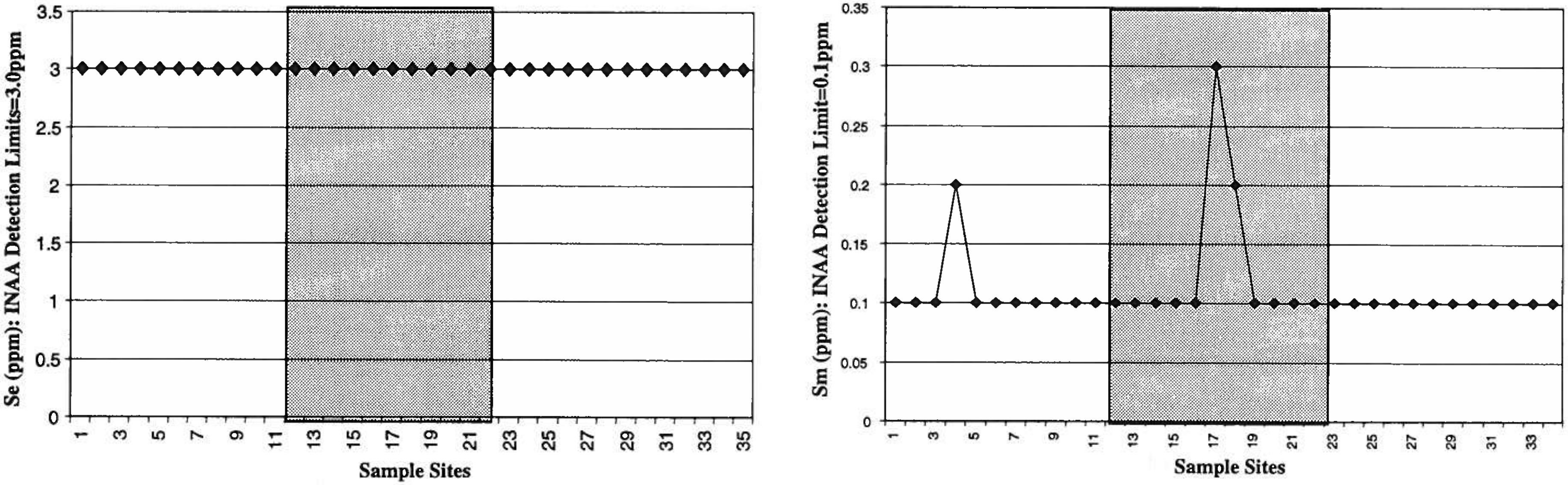
Sb in Bark



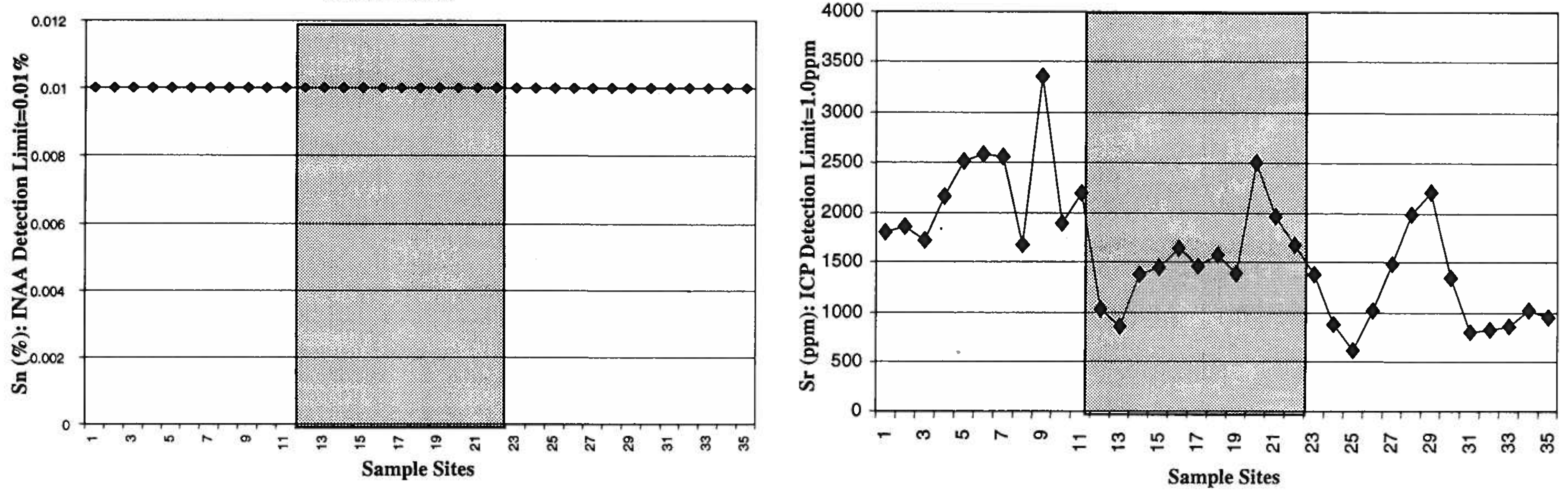
Sc in Bark



Mountain Lake Biogeochemistry Profiles Se, Sm, Sn and Sr (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.


Se in Bark

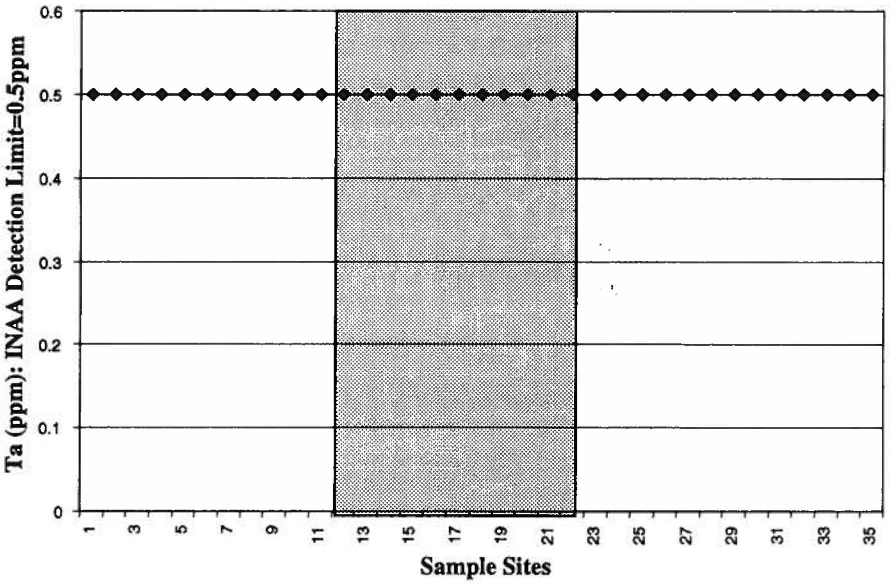
Sm in Bark


Sn in Bark

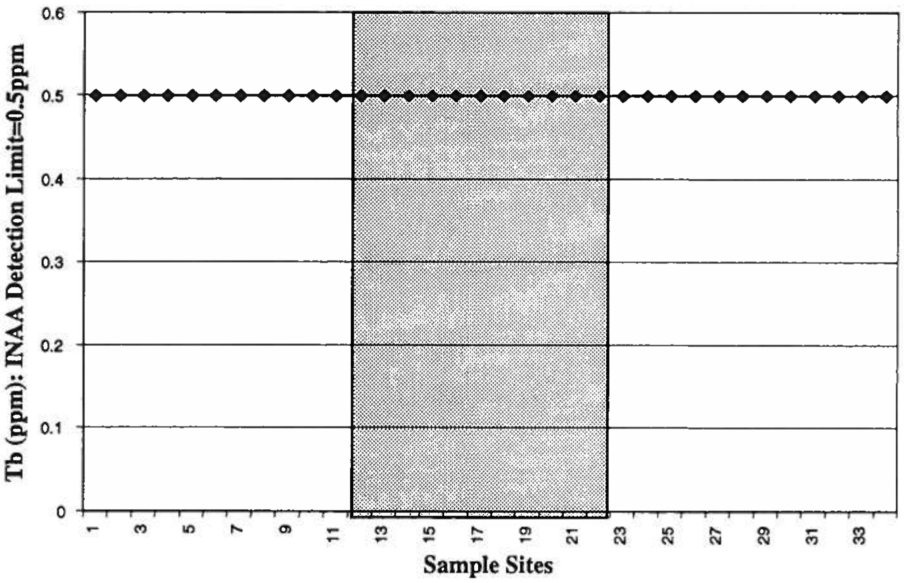
Sr in Bark

Mountain Lake Biogeochemistry Profiles Ta, Tb, Ti and Th (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

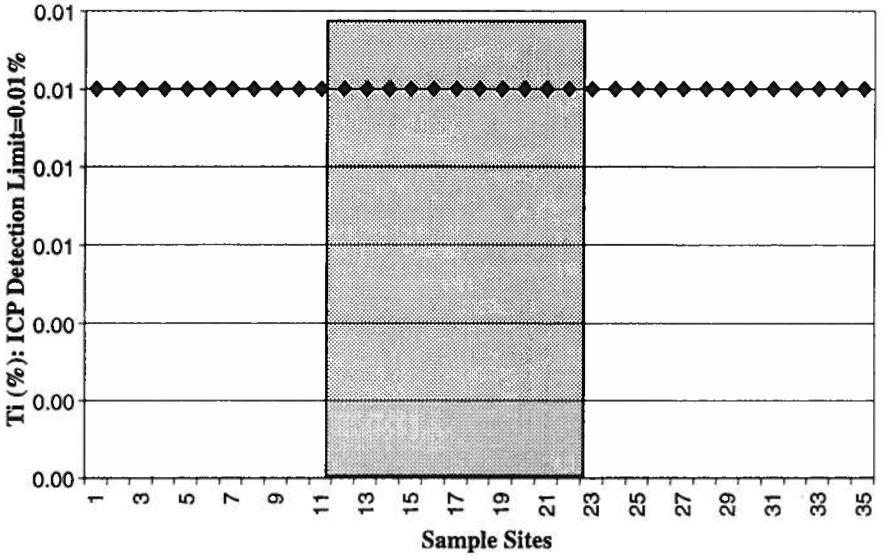
Ta in Bark



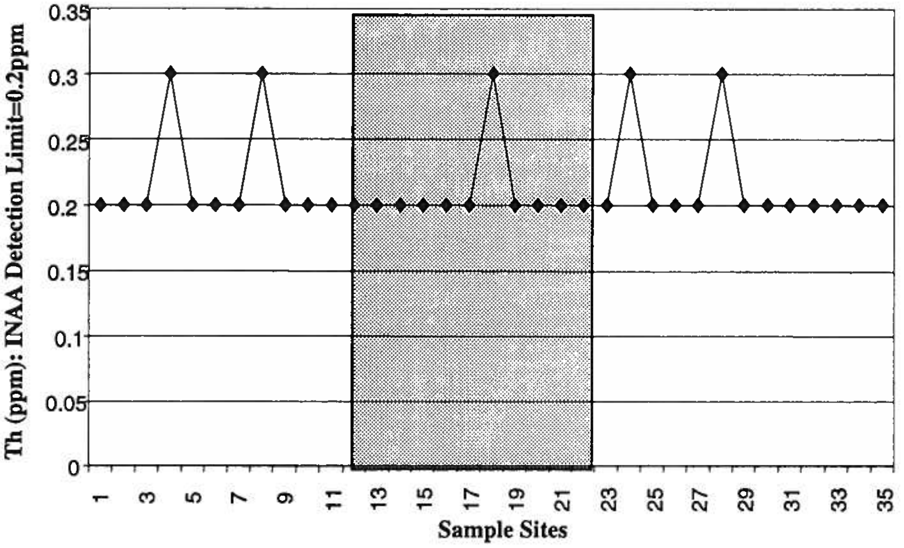
Tb in Bark



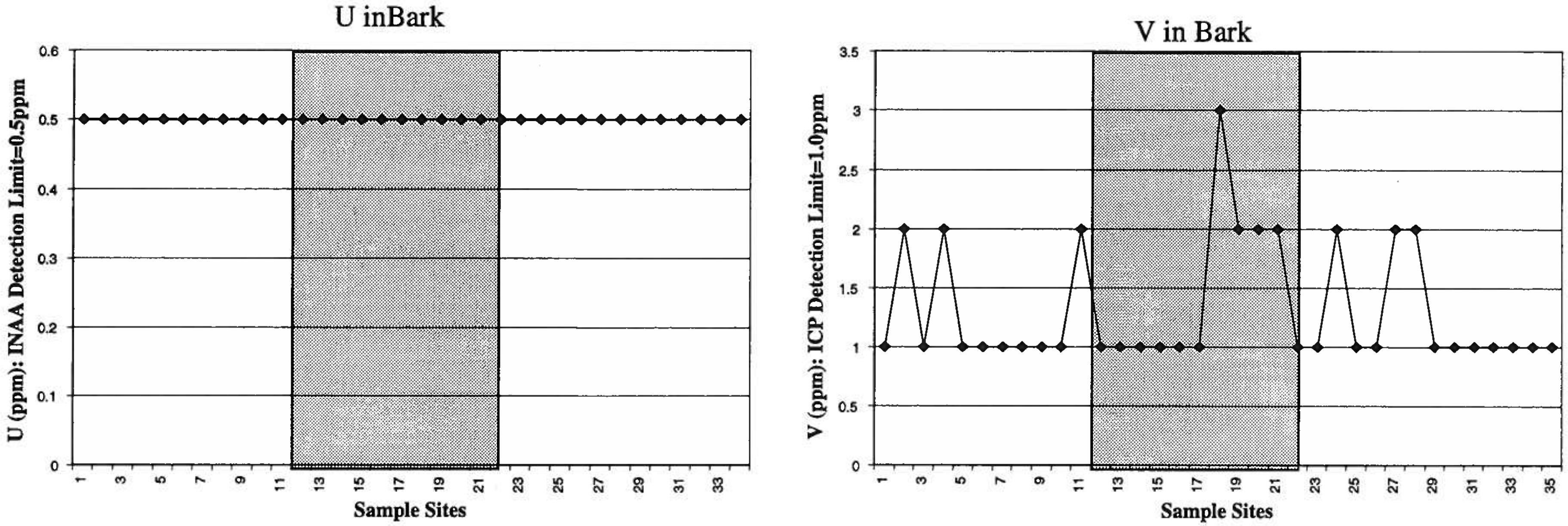
Ti in Bark



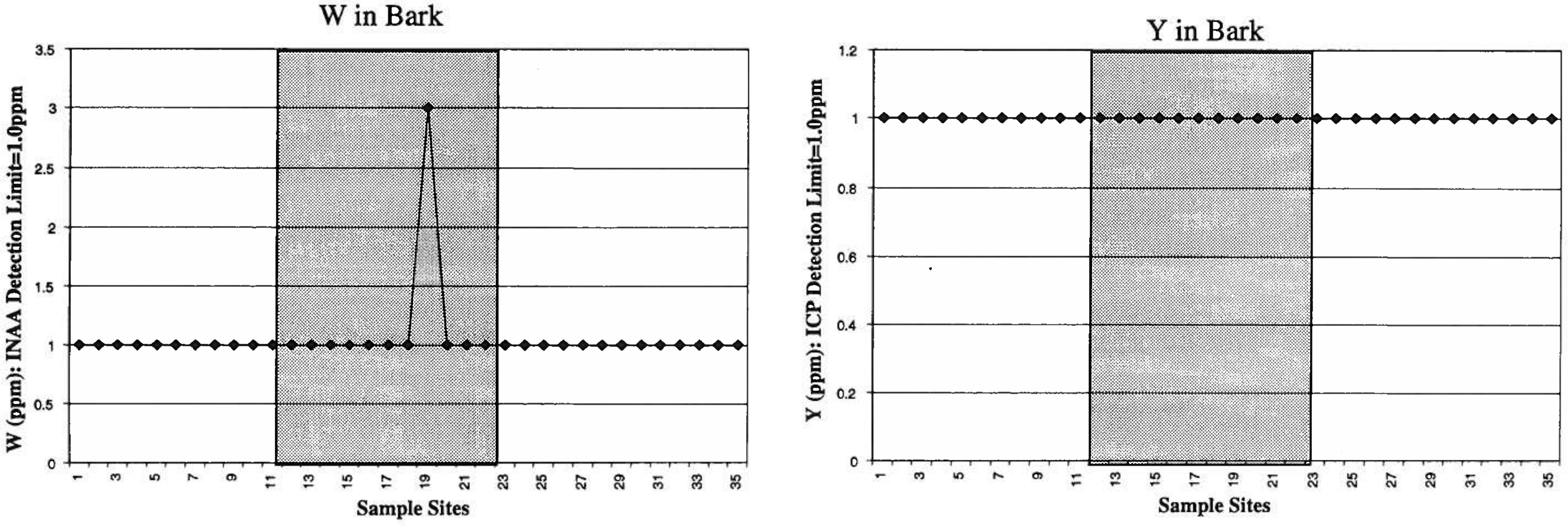
Th in Bark



Mountain Lake Biogeochemistry Profiles U, V, W and Y (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

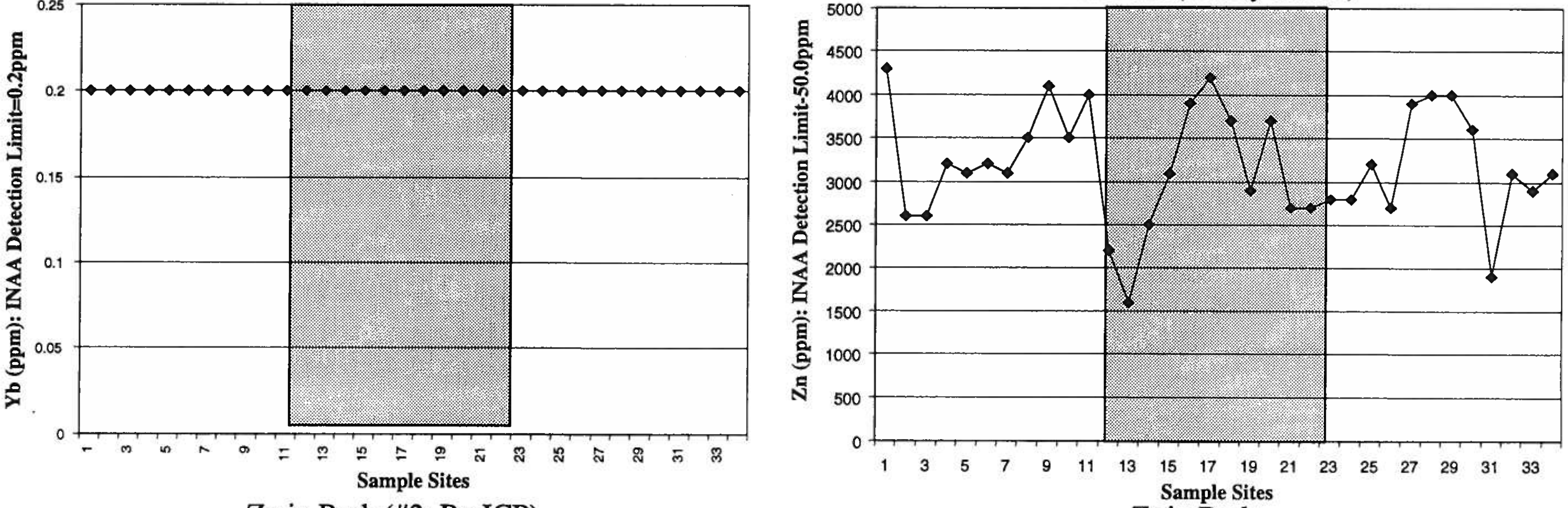

U inBark

V in Bark

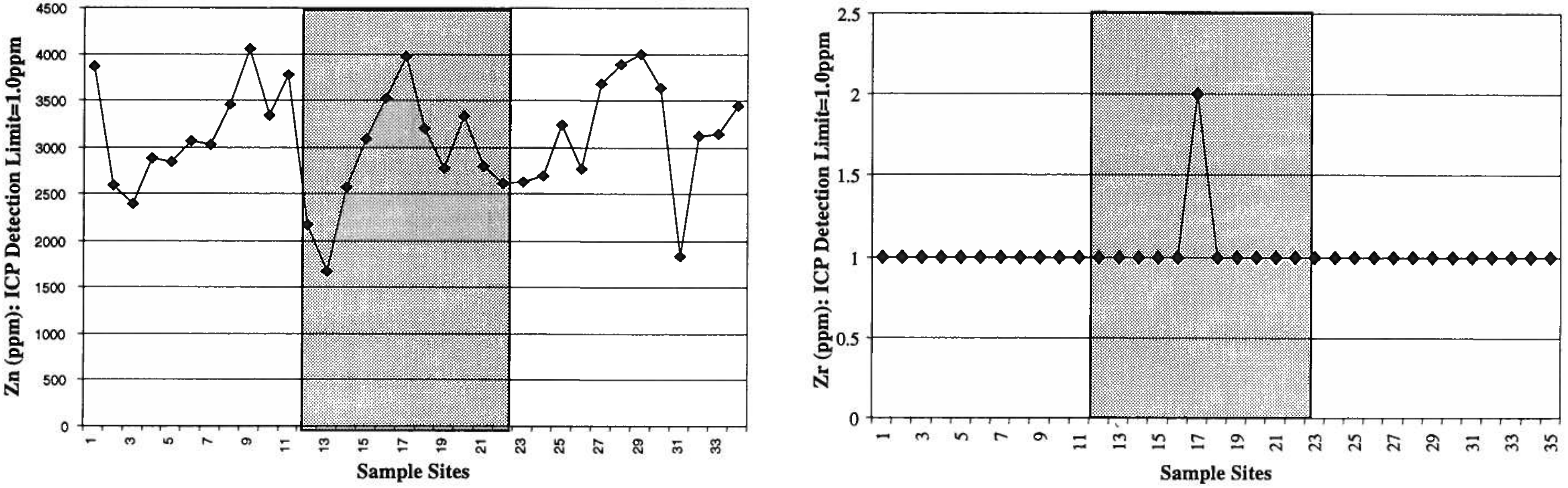

W in Bark

Y in Bark

Mountain Lake Biogeochemistry Profiles Yb, Zn and Zr (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

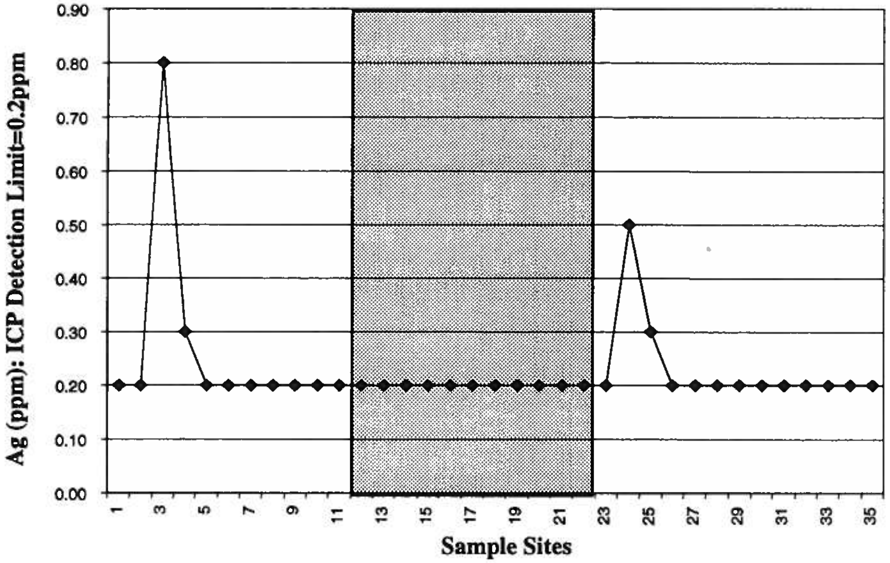

Yb in Bark

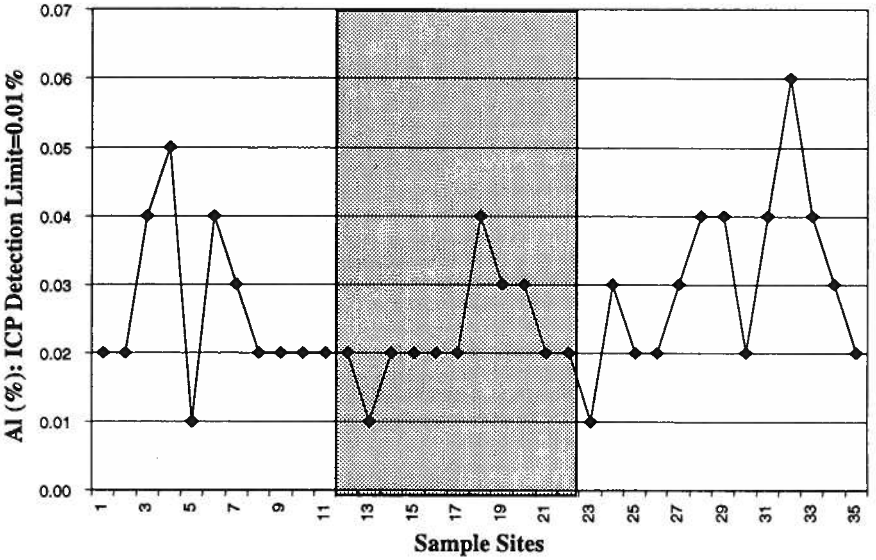
Zn in Bark (#1: By INAA)

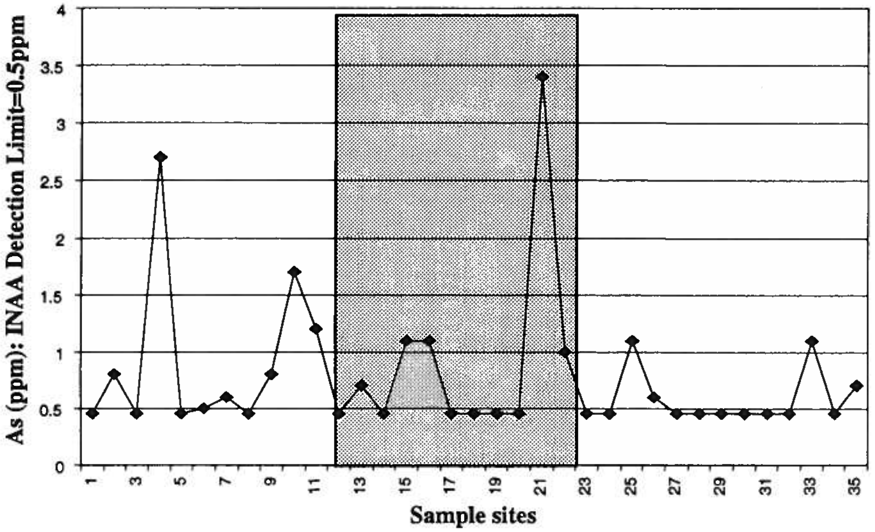

Zn in Bark (#2: By ICP)

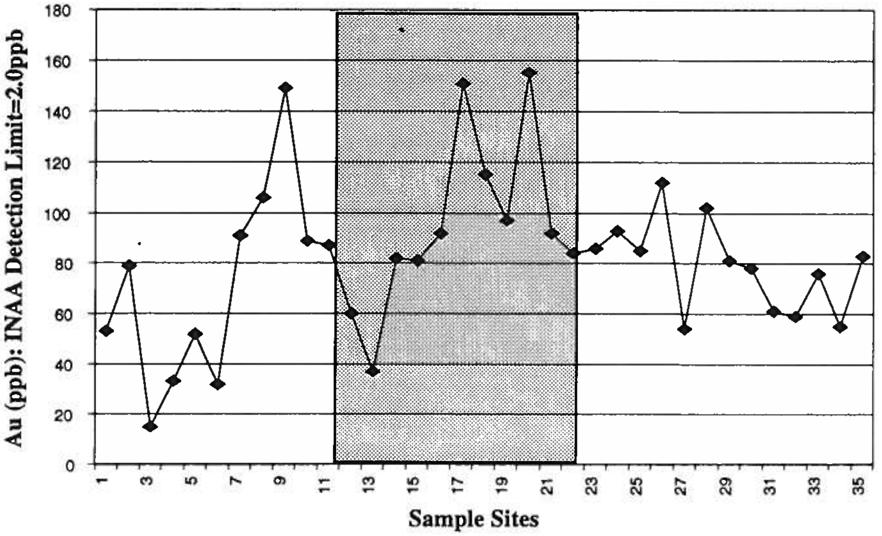
Zr in Bark

Mountain Lake Biogeochemistry Profiles Ag, Al, As and Au (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.


Ag in Twigs

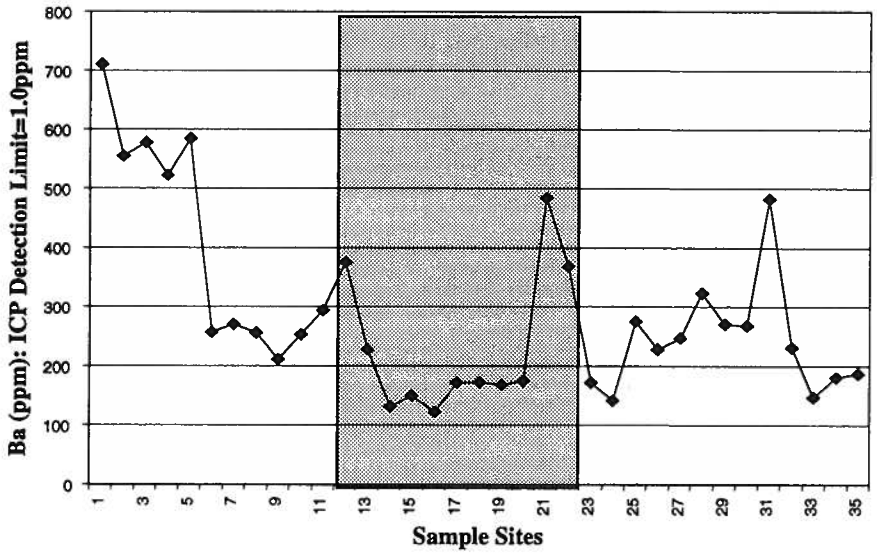

Al in Twigs


As in Twigs

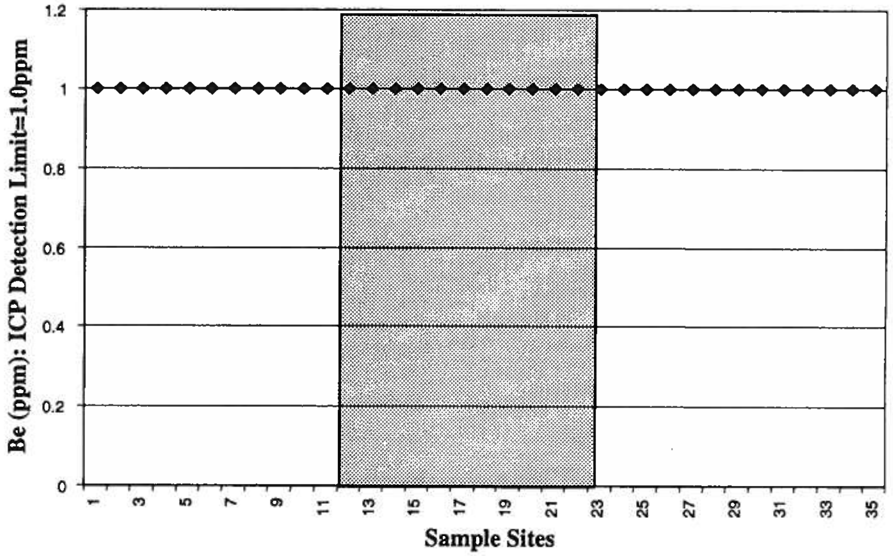

Au in Twigs

Mountain Lake Biogeochemistry Profiles Ba, Be, Bi and Br (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

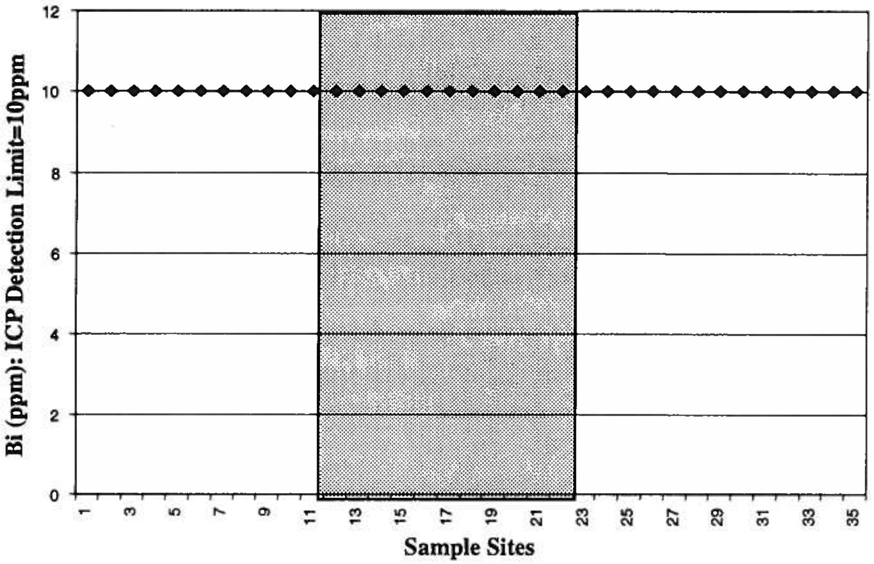
Ba in Twigs



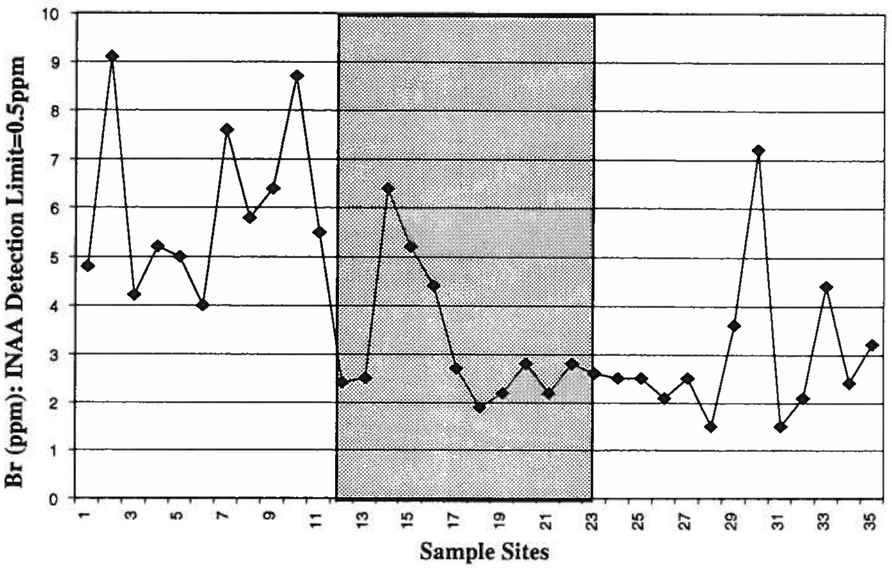
Be in Twigs



Bi in Twigs

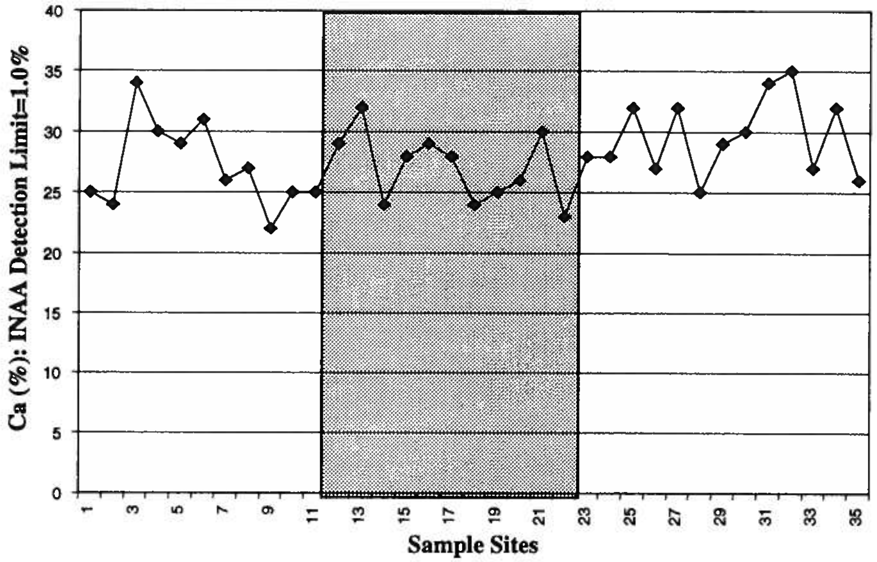


Br in Twigs

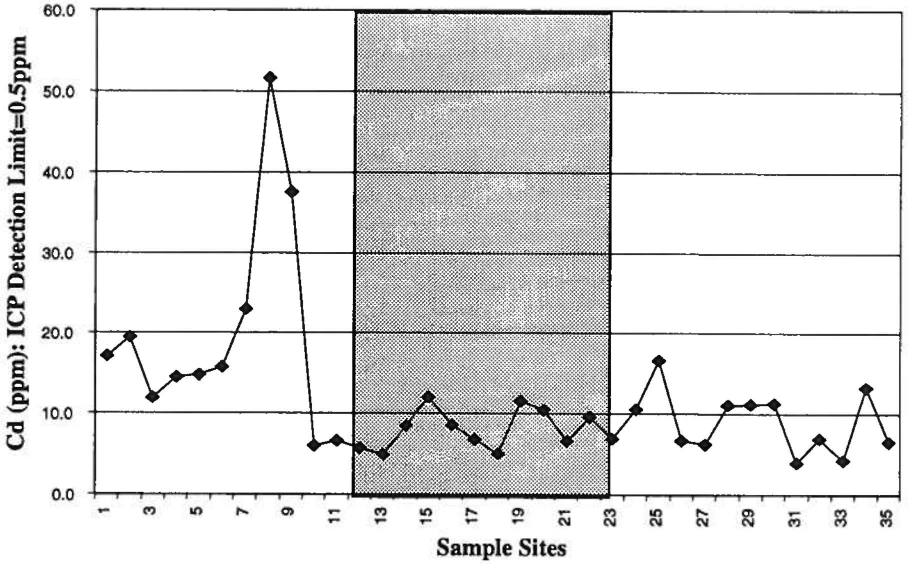


Mountain Lake Biogeochemistry Profiles Ca, Cd, Ce and Co (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

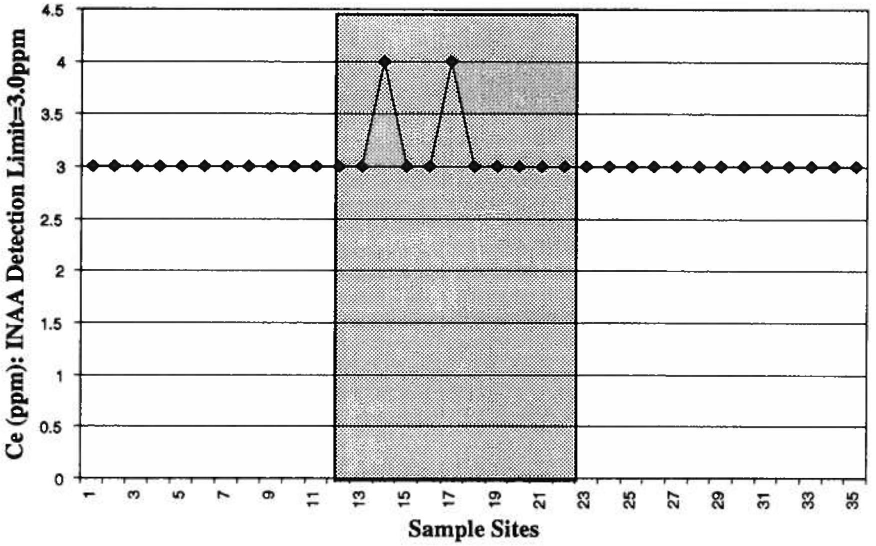
Ca in Twigs



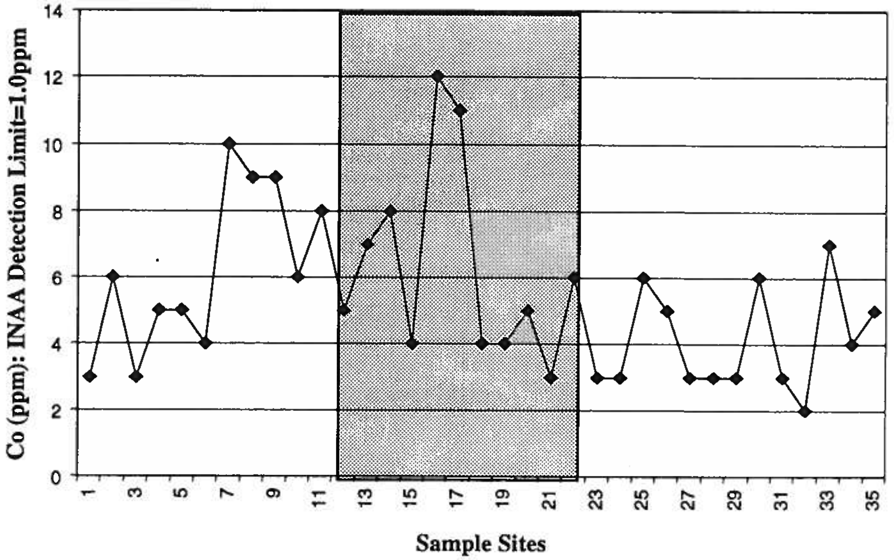
Cd in Twigs



Ce in Twigs



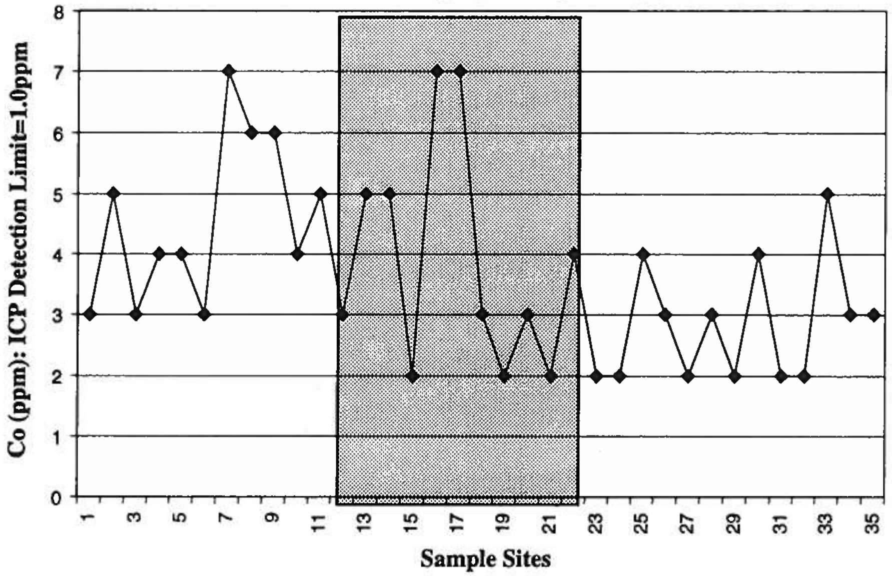
Co in Twigs (#1: By INAA)



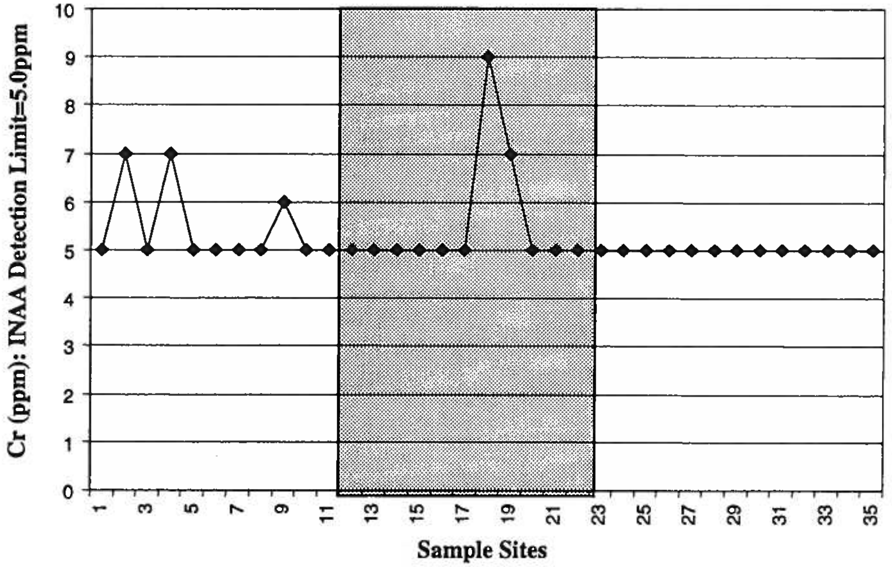
Mountain Lake Biogeochemistry Profiles Co, Cr and Cs (samples RE-ML97-001 to REML97-035).

Shading represents the approximate surface expression of the pipe.

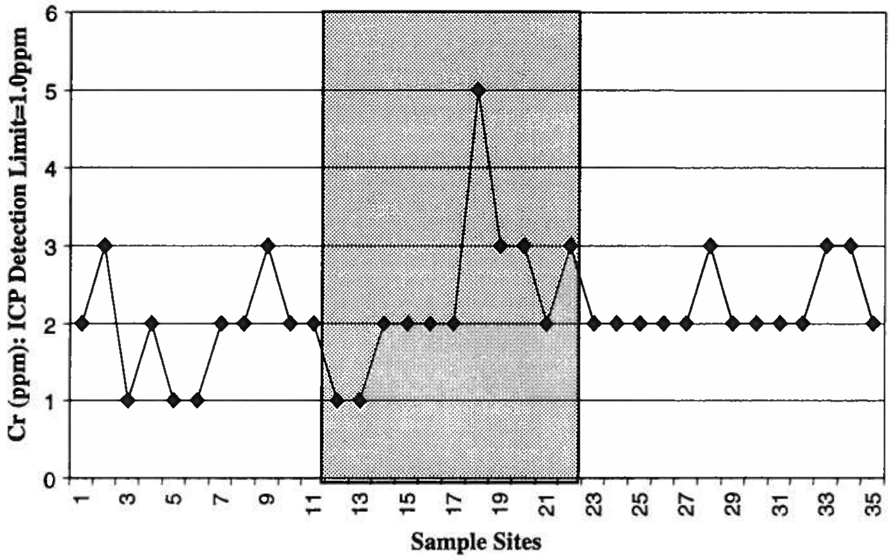
Co in Twigs (#2: By ICP)



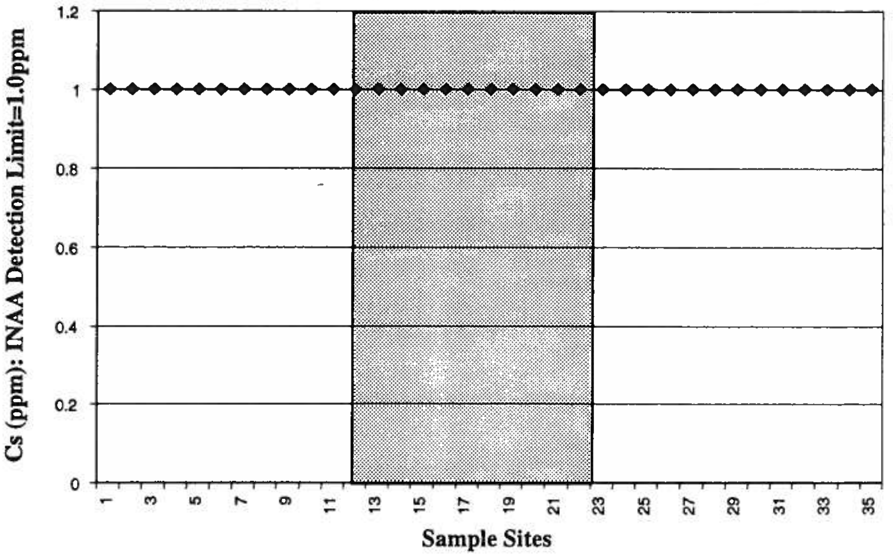
Cr in Twigs (#1: By INAA)



Cr in Twigs (#2: By ICP)



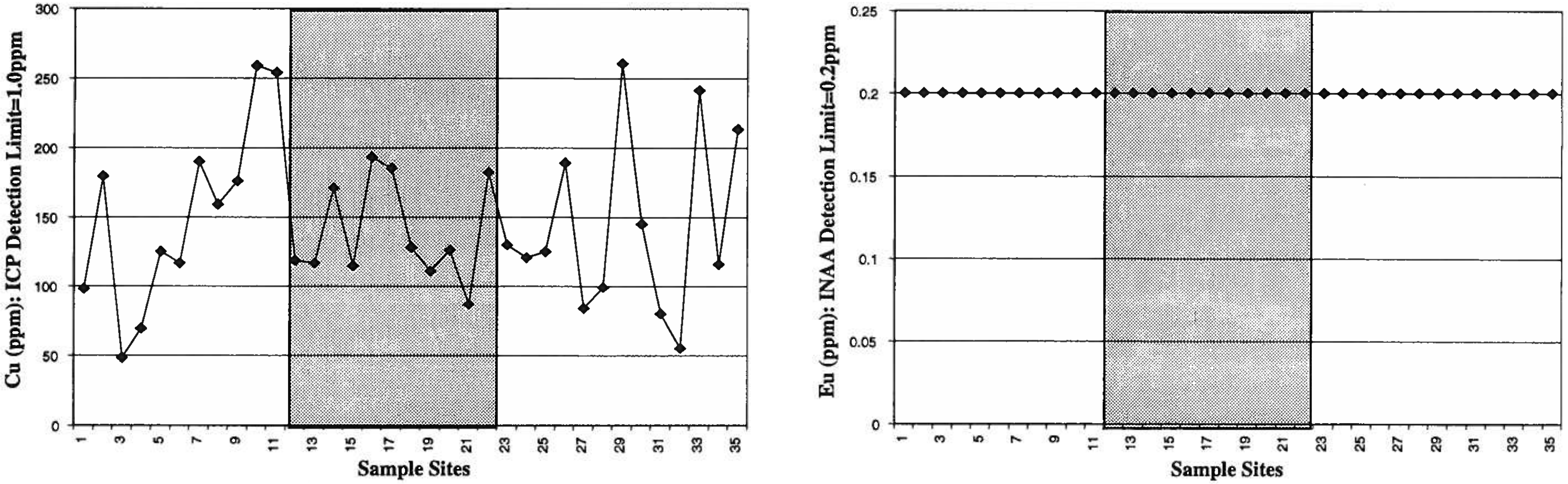
Cs in Twigs



Mountain Lake Biogeochemistry Profiles Cu, Eu and Fe (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

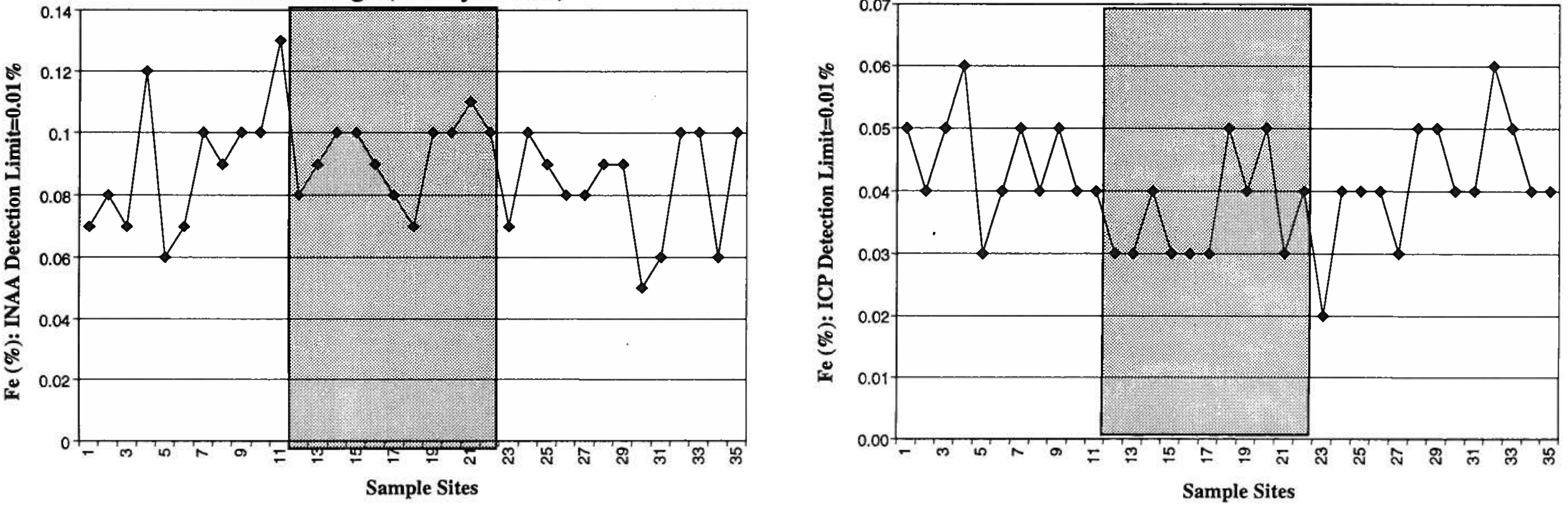
Cu in Twigs

Eu in Twigs



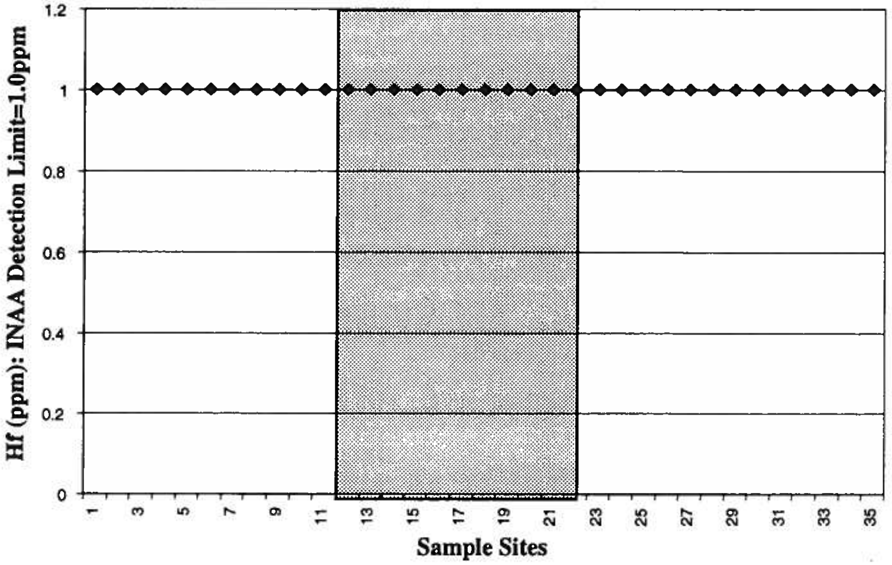
Fe in Twigs (#1: By INAA)

Fe in Twigs (#2: By ICP)

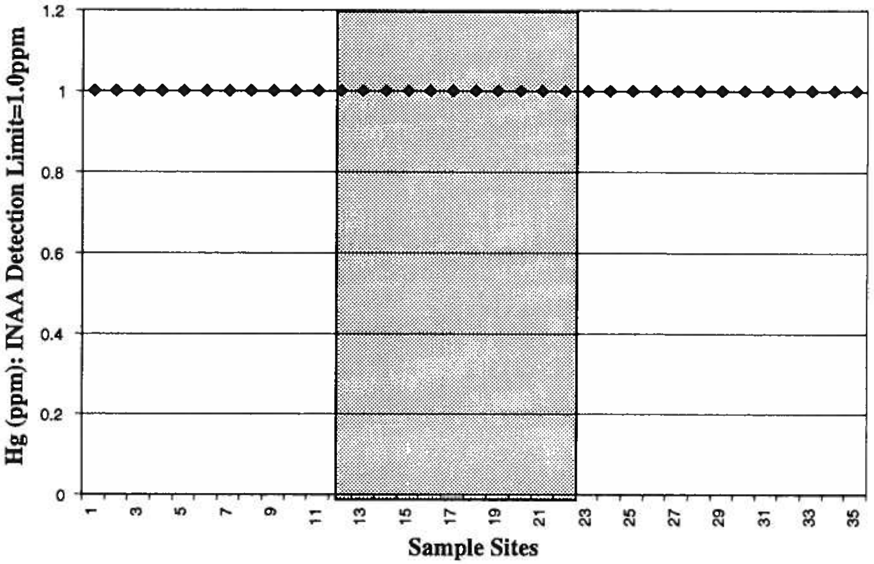


Mountain Lake Biogeochemistry Profiles Hf, Hg, Ir and K (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

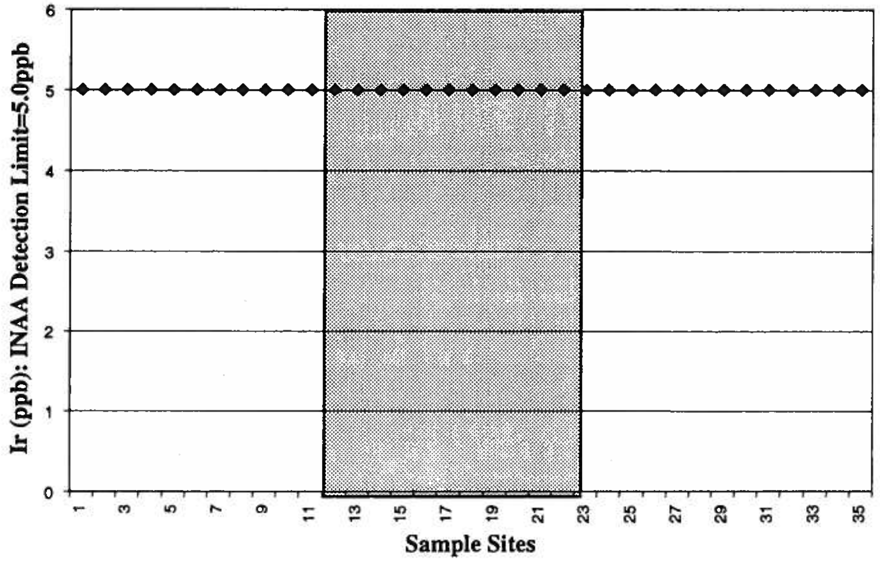
Hf in Twigs



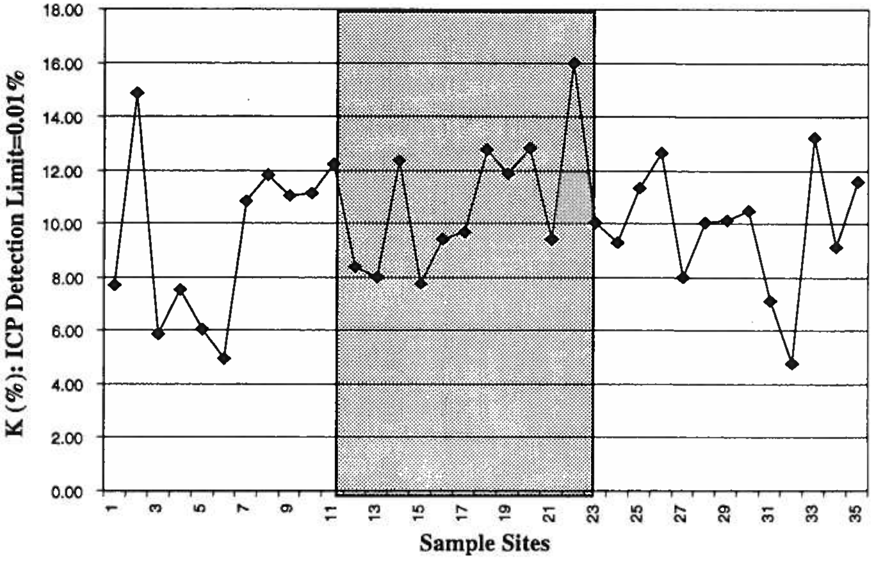
Hg inTwigs



Ir in Twigs

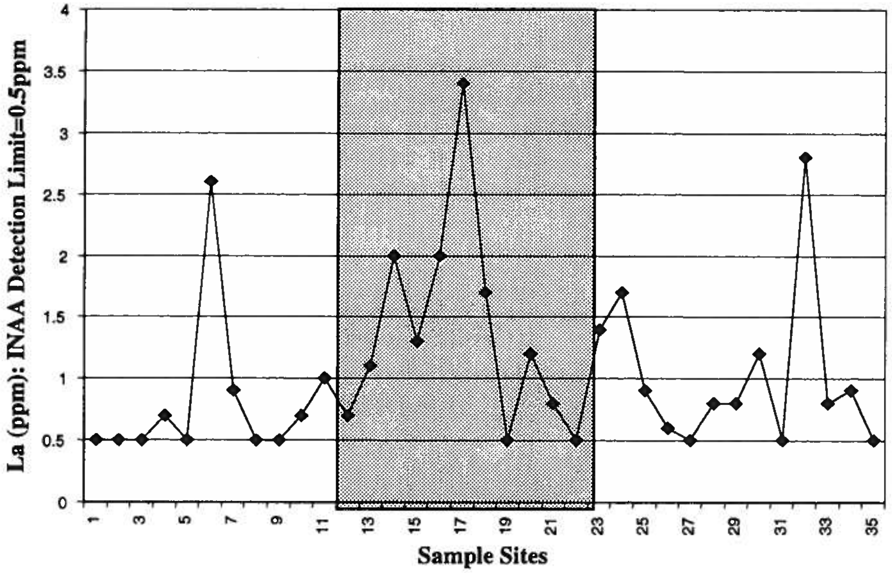


K in Twigs

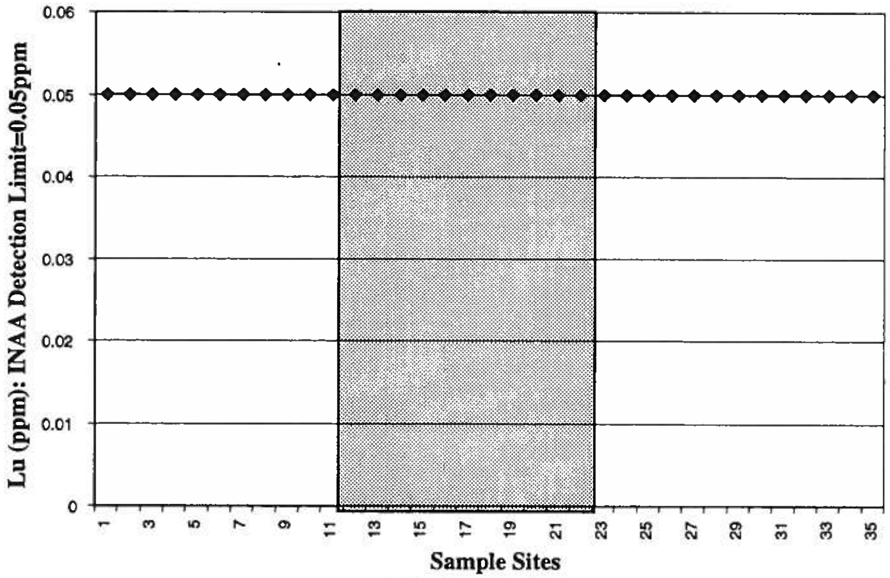


Mountain Lake Biogeochemistry Profiles La, Lu, Mg and Mo (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

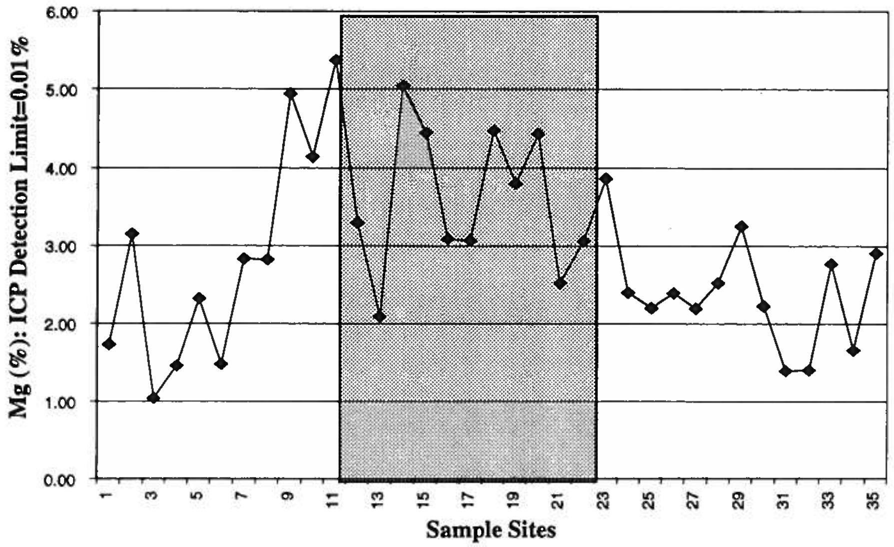
La in Twigs



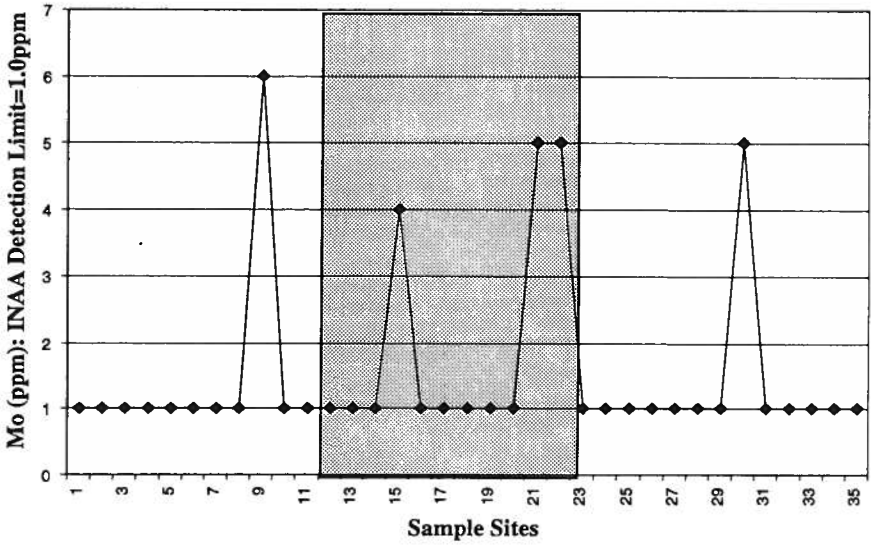
Lu in Twigs



Mg in Twigs

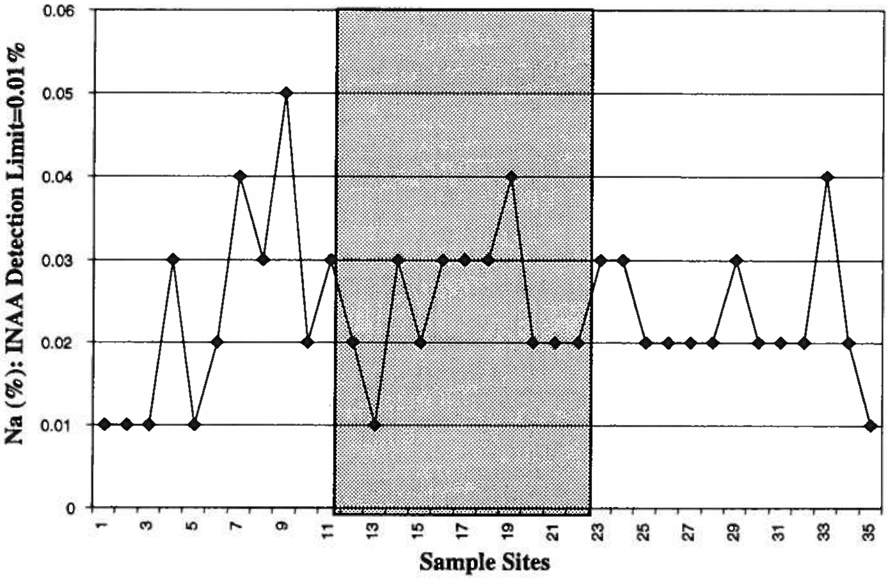


Mo in Twigs

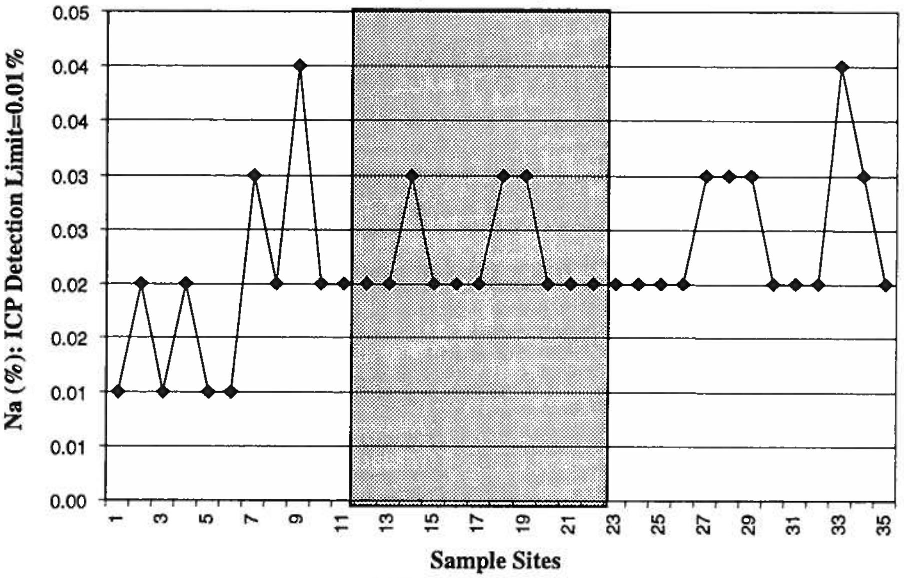


Mountain Lake Biogeochemistry Profiles Na, Nd and Ni (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

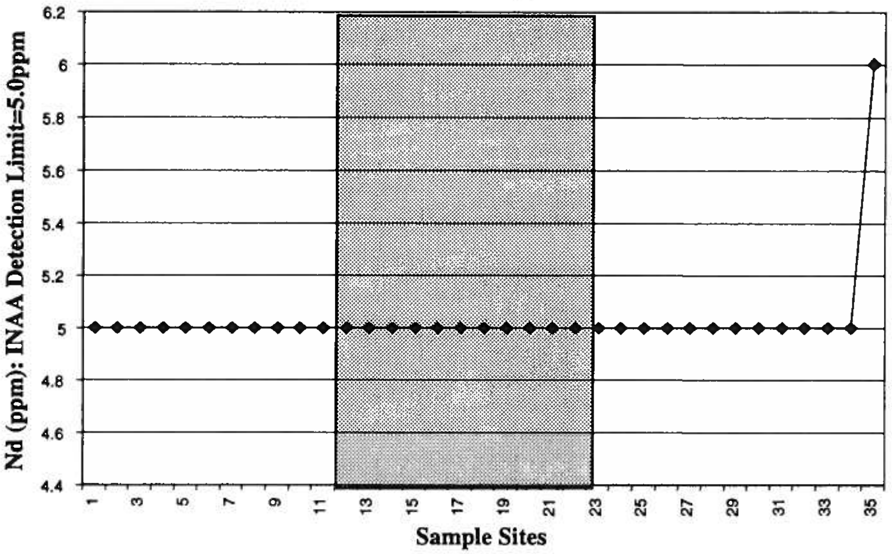
Na in Twigs (#1: By INAA)



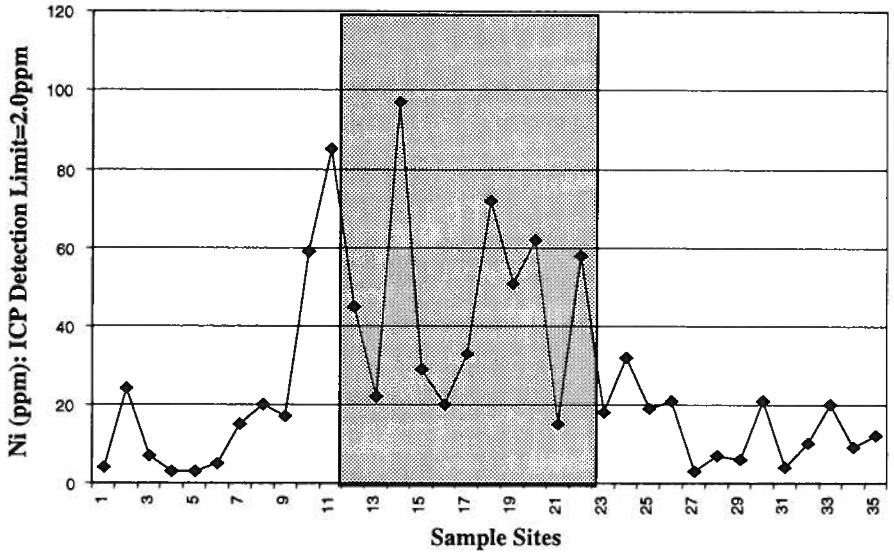
Na in Twigs (#2: By ICP)



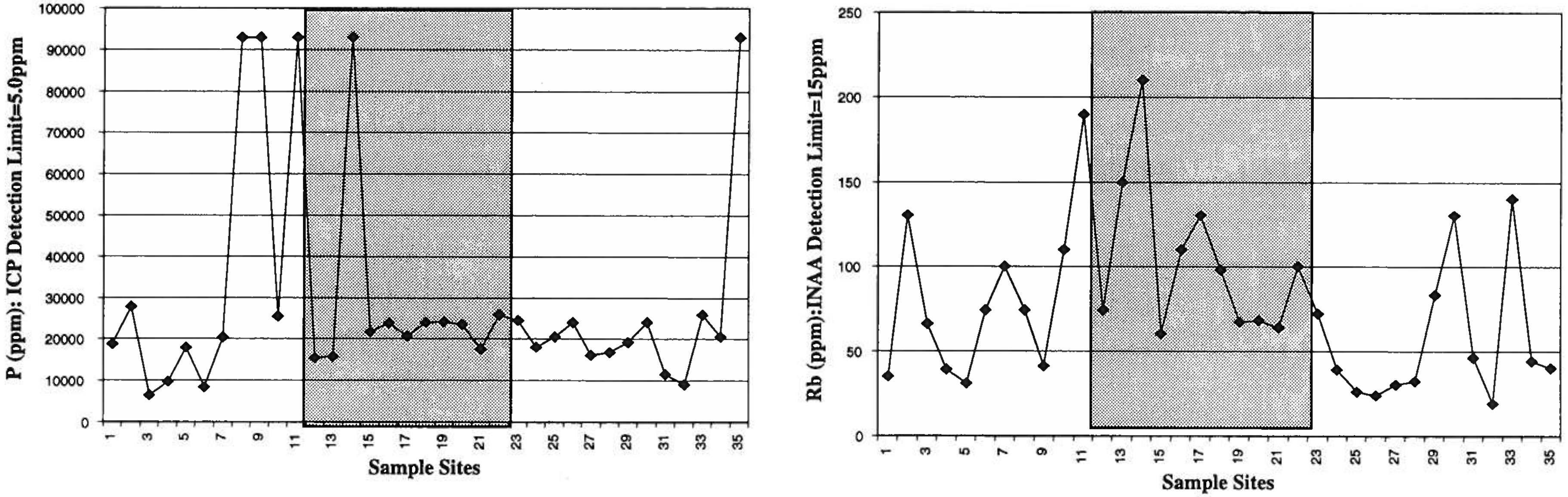
Nd in Twigs



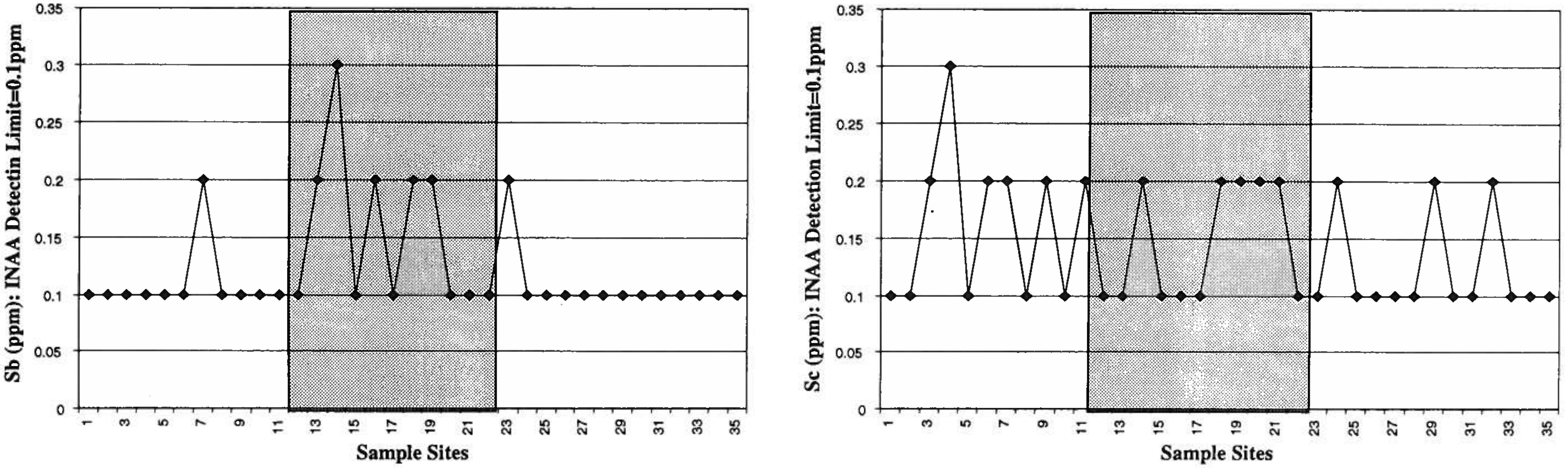
Ni in Twigs



Mountain Lake Biogeochemistry Profiles P, Rb, Sb and Sc (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.


P in Twigs

Rb in Twigs

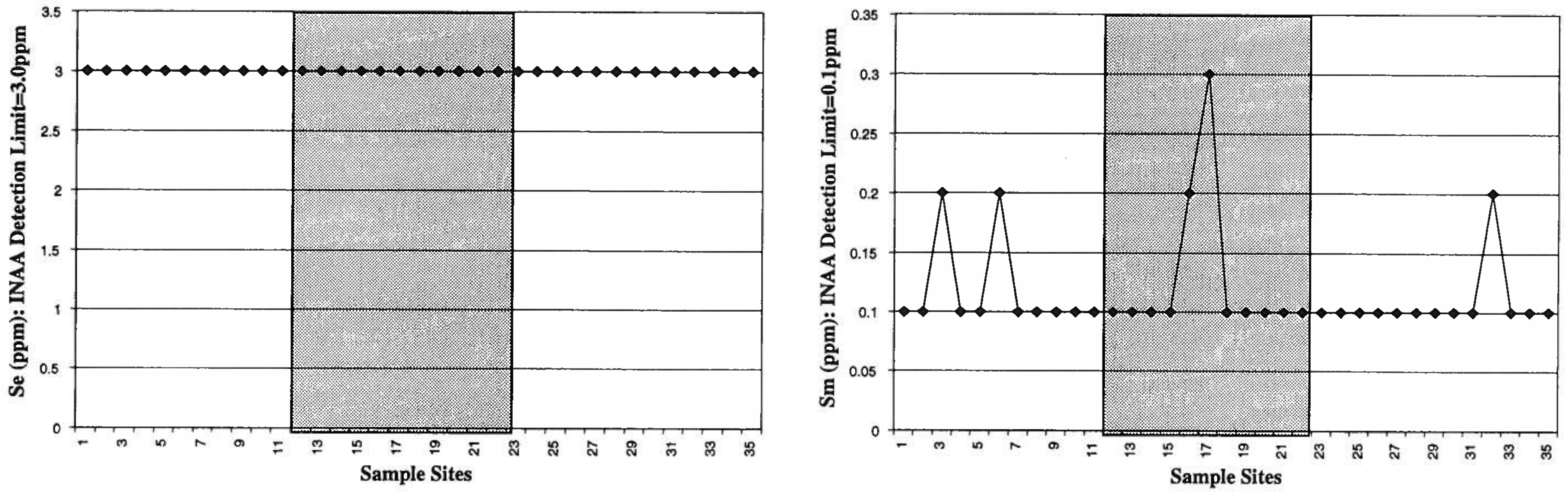

Sb in Twigs

Sc in Twigs

Mountain Lake Biogeochemistry Profiles Se, Sm, Sn and Sr (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

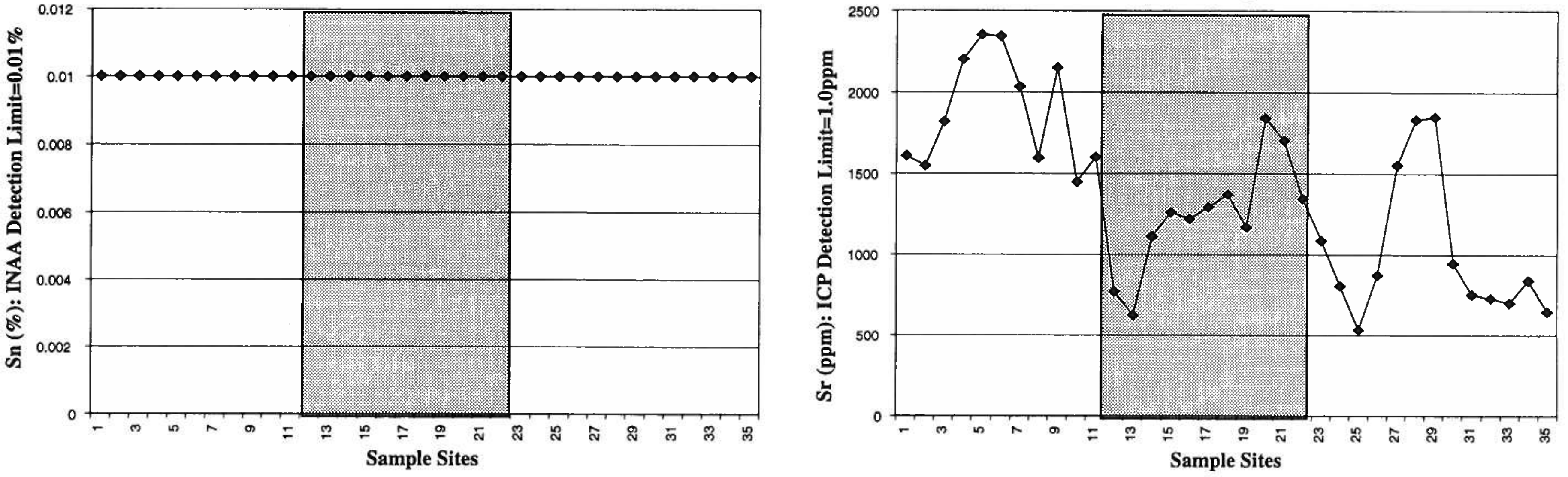
Se in Twigs

Sm in Twigs

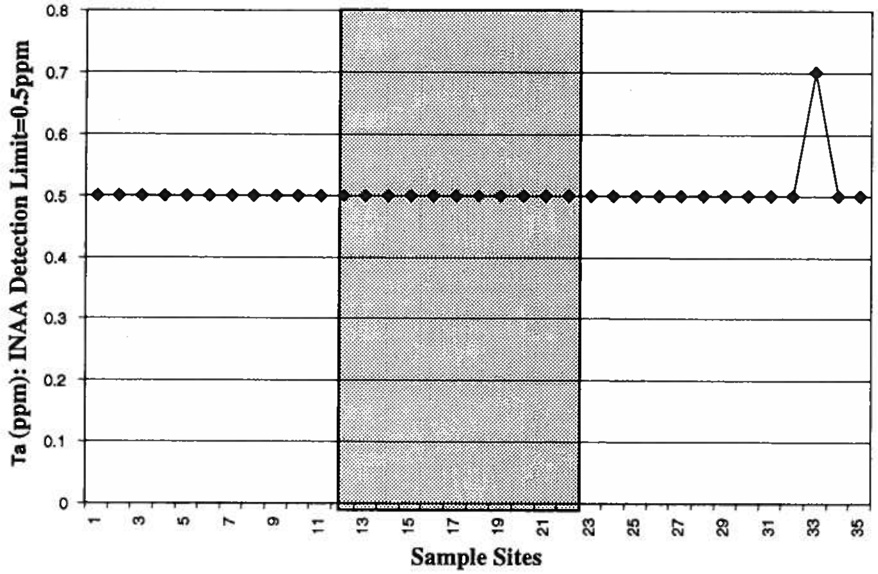


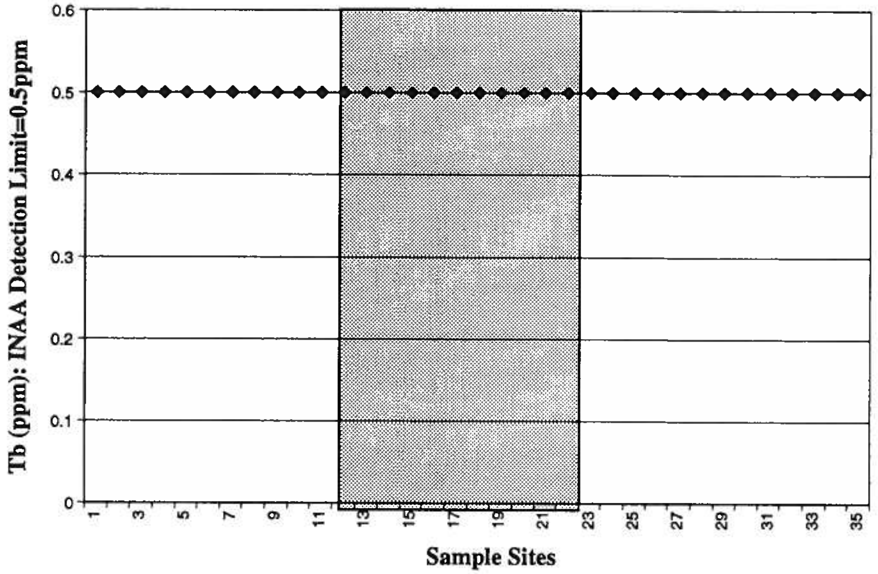
Sn in Twigs

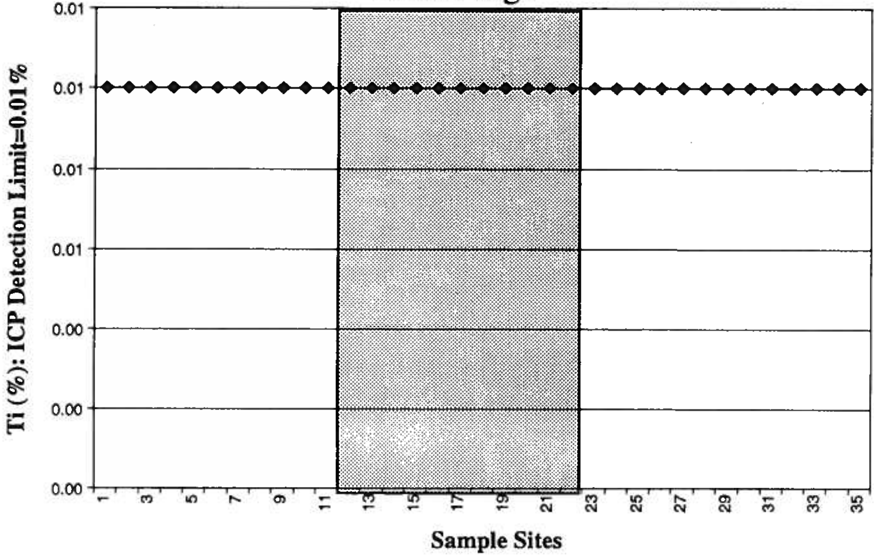
Sr in Twigs

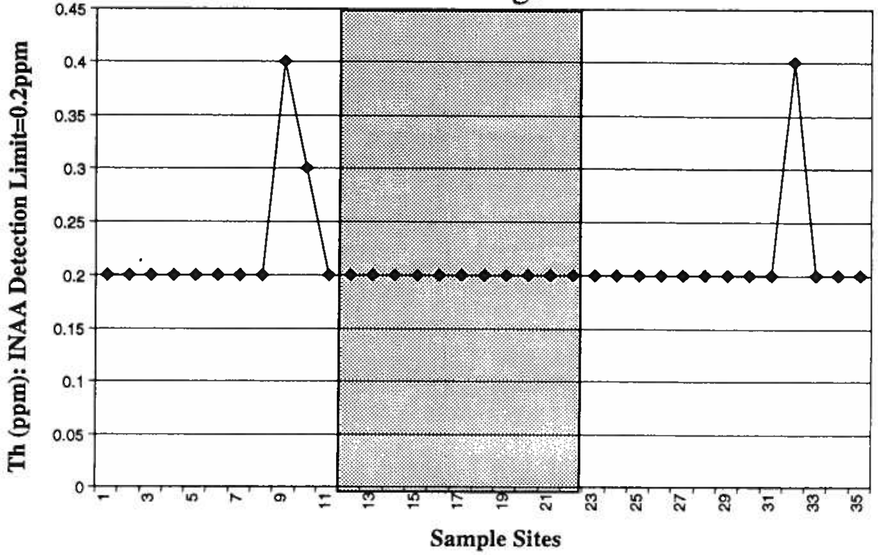


Mountain Lake Biogeochemistry Profiles Ta, Tb, Ti and Th (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.


Ta in Twigs

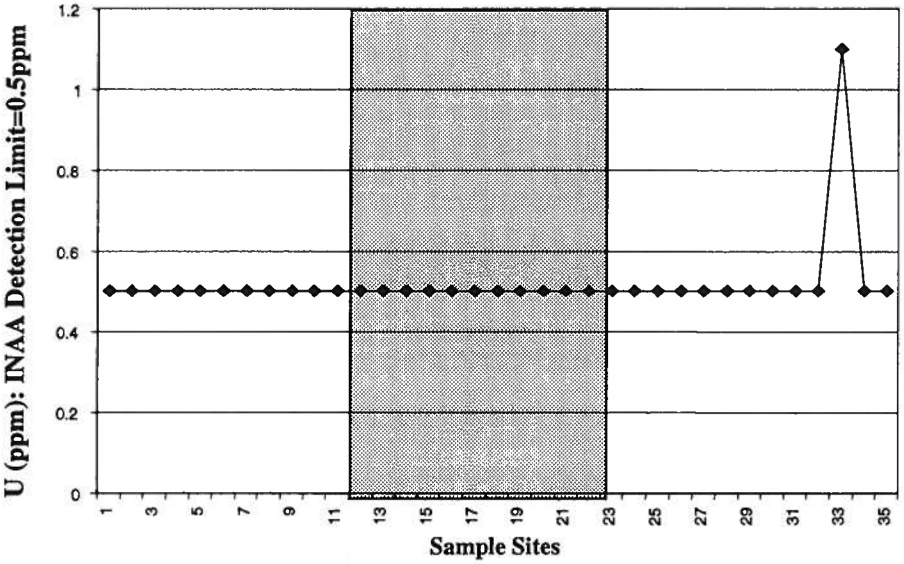

Tb in Twigs


Ti in Twigs

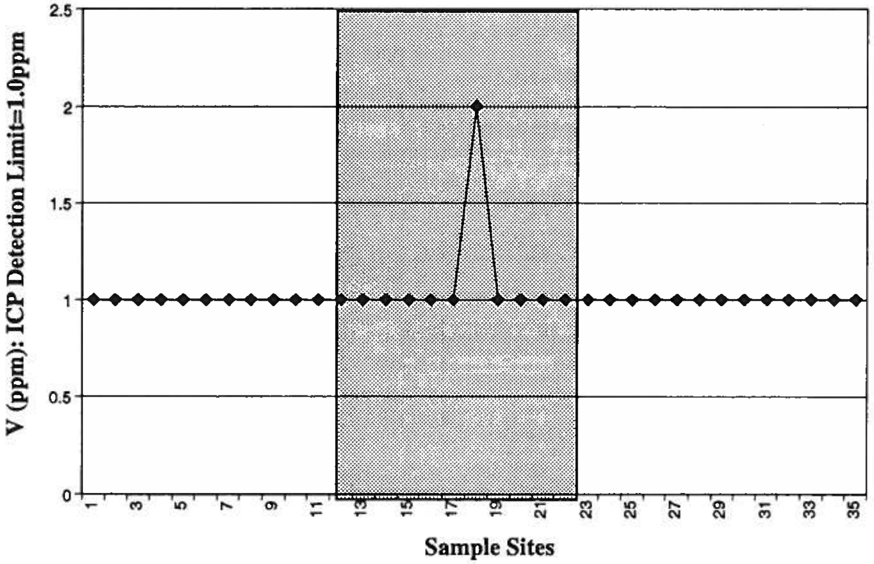

Th in Twigs

Mountain Lake Biogeochemistry Profiles U, V, W and Y (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

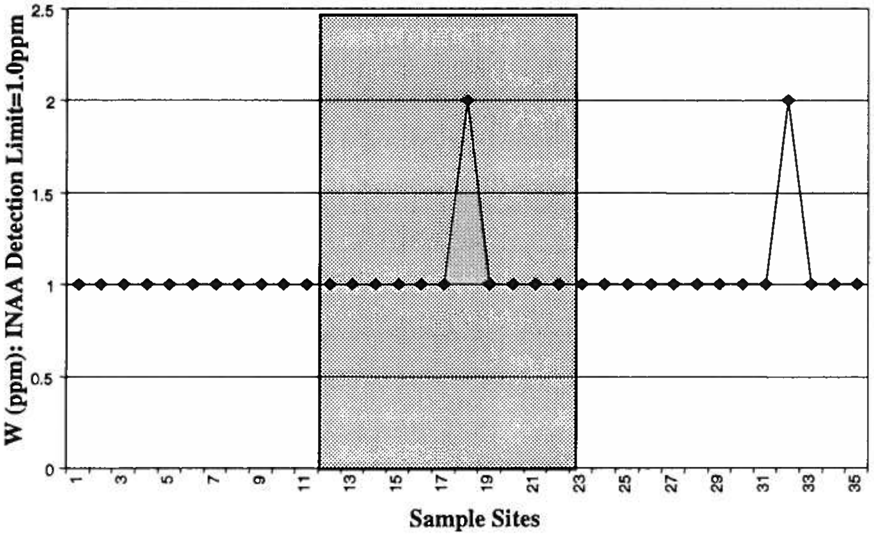
U in Twigs



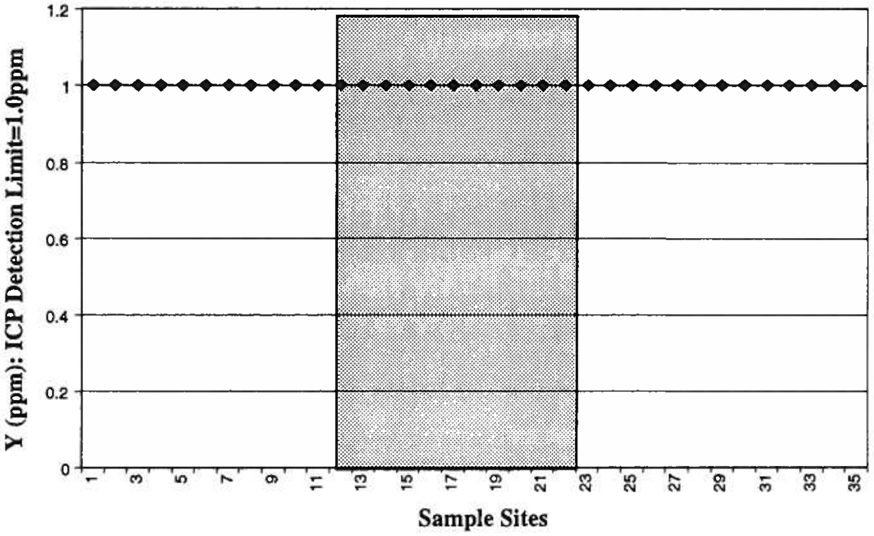
V in Twigs



W in Twigs

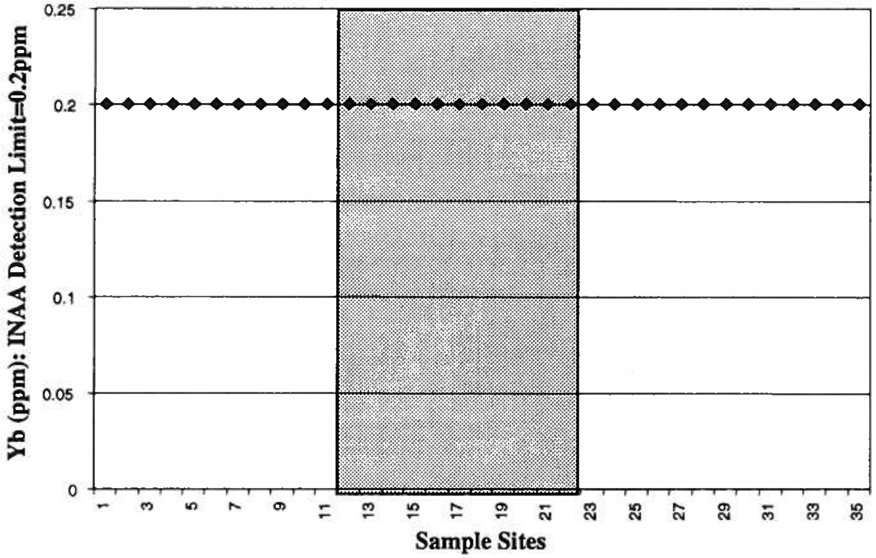


Y in Twigs

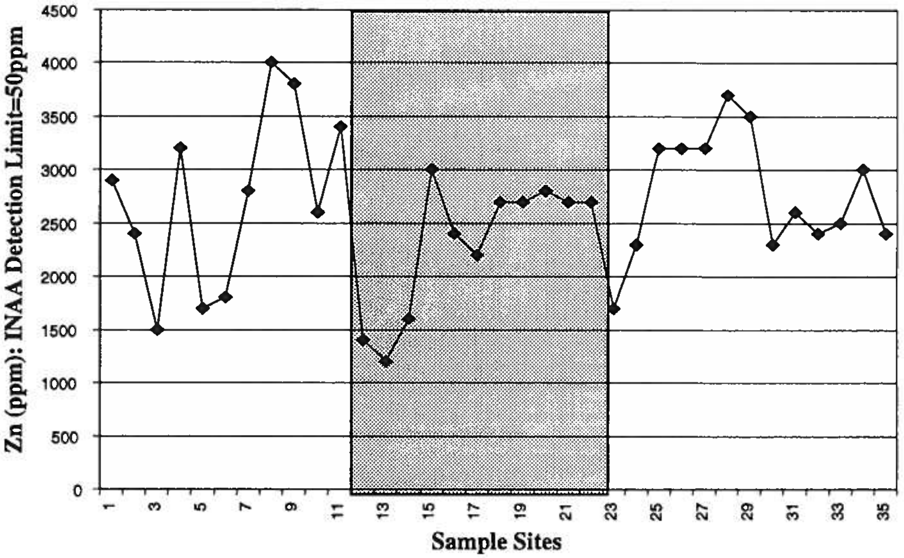


Mountain Lake Biogeochemistry Profiles Yb, Zn and Zr (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

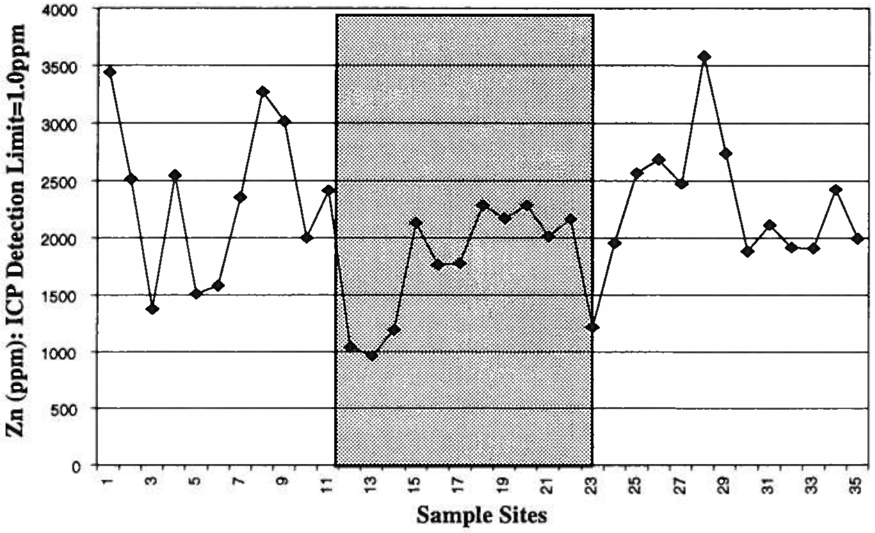
Yb in Twigs



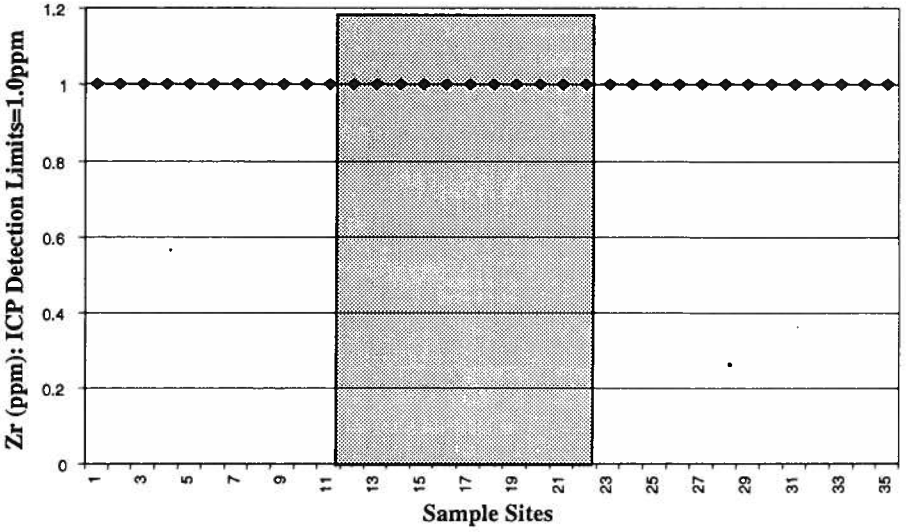
Zn in Twigs (#1: By INAA)



Zn in Twigs (#2: By ICP)

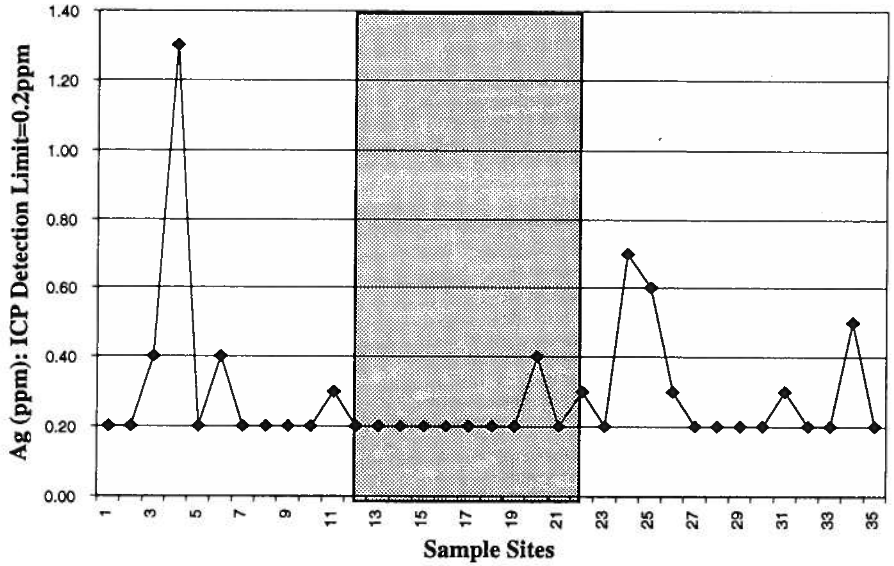


Zr in Twigs

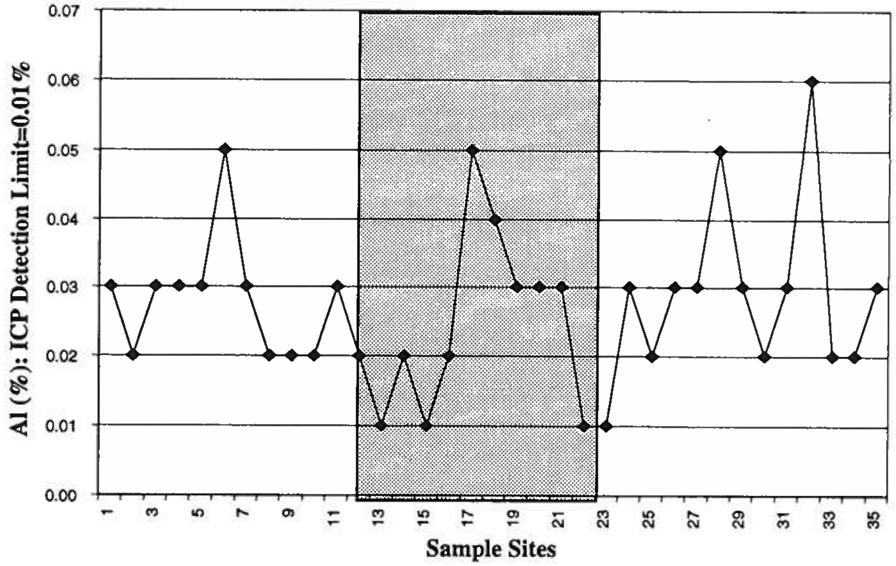


Mountain Lake Biogeochemistry Profiles Ag, Al, As and Au (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

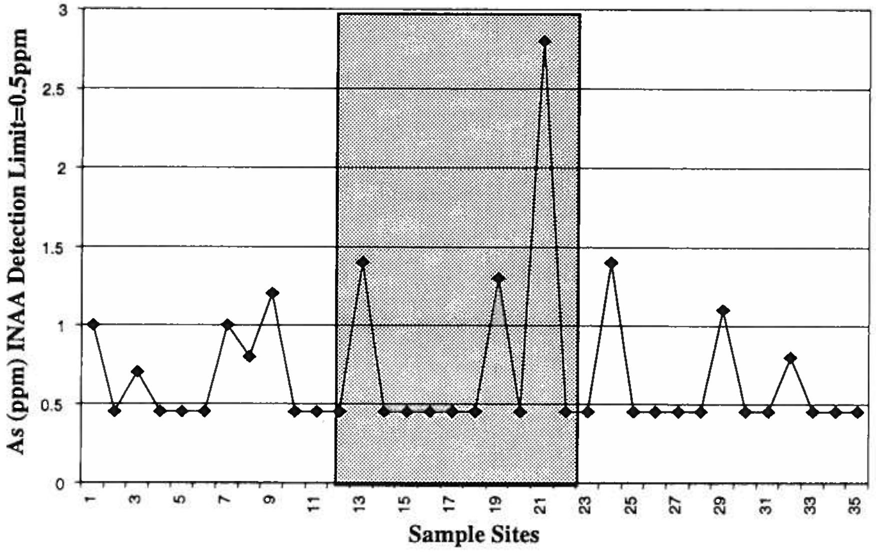
Ag in Stems



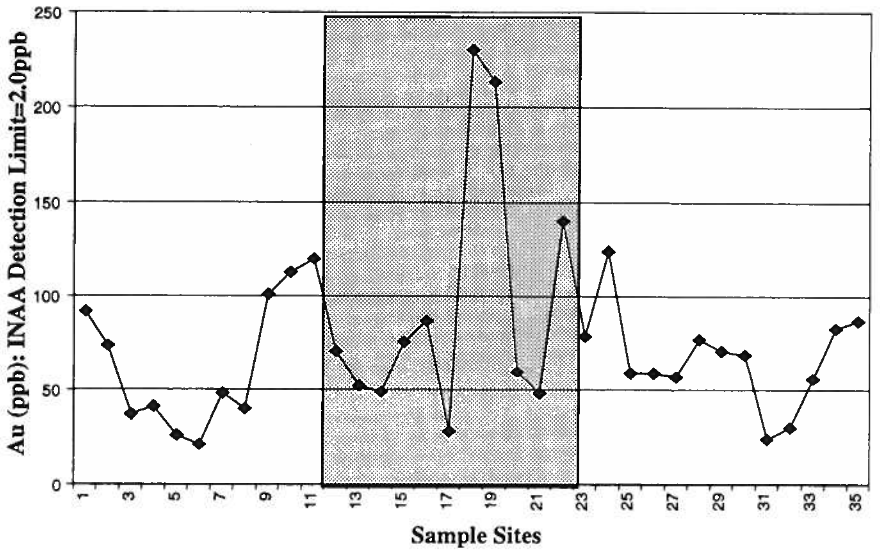
Al in Stems



As in Stems

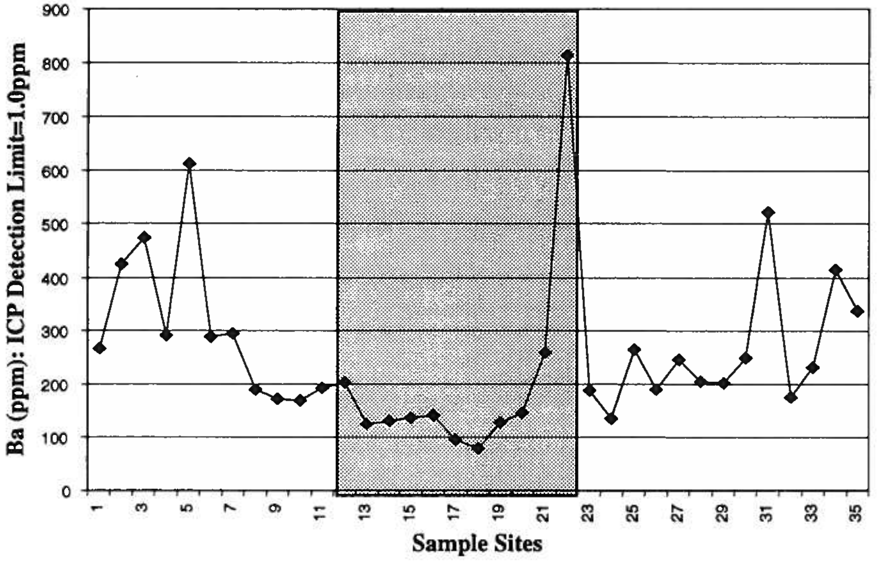


Au in Stems

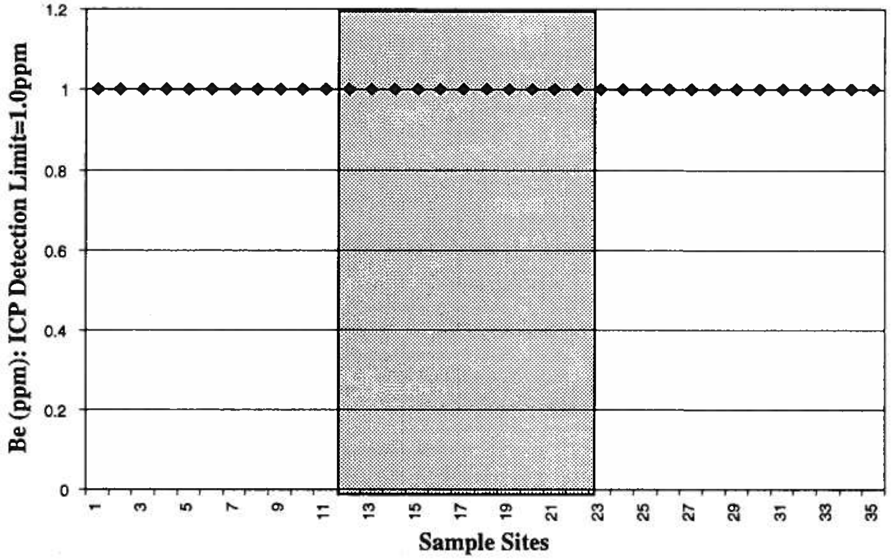


Mountain Lake Biogeochemistry Profiles Ba, Be, Bi and Br (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

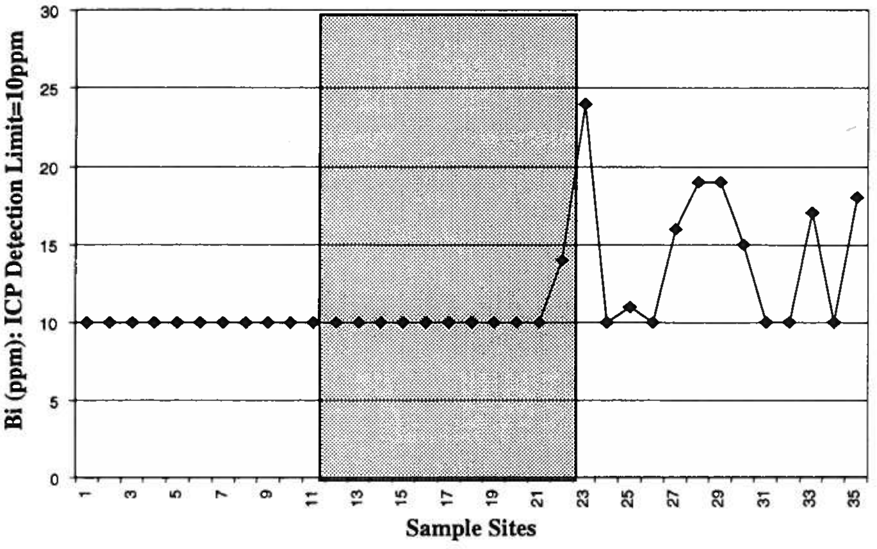
Ba in Stems



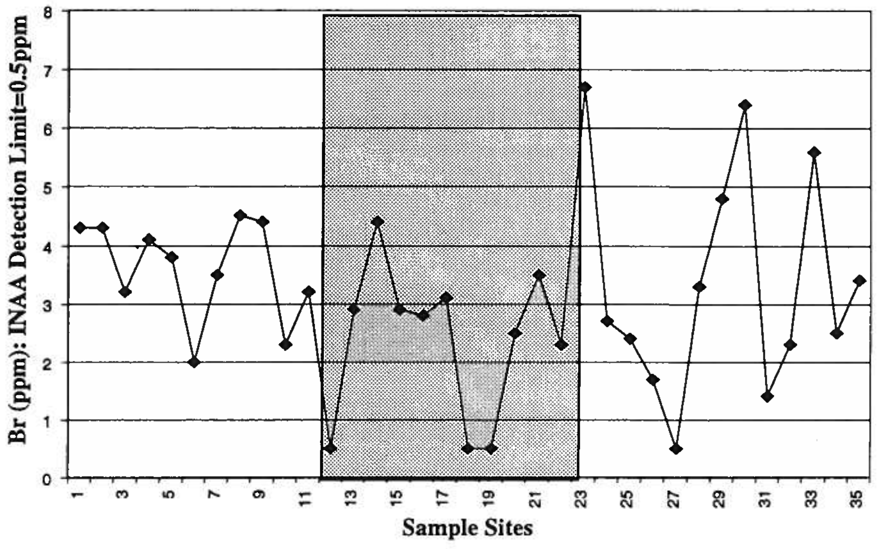
Be in Stems



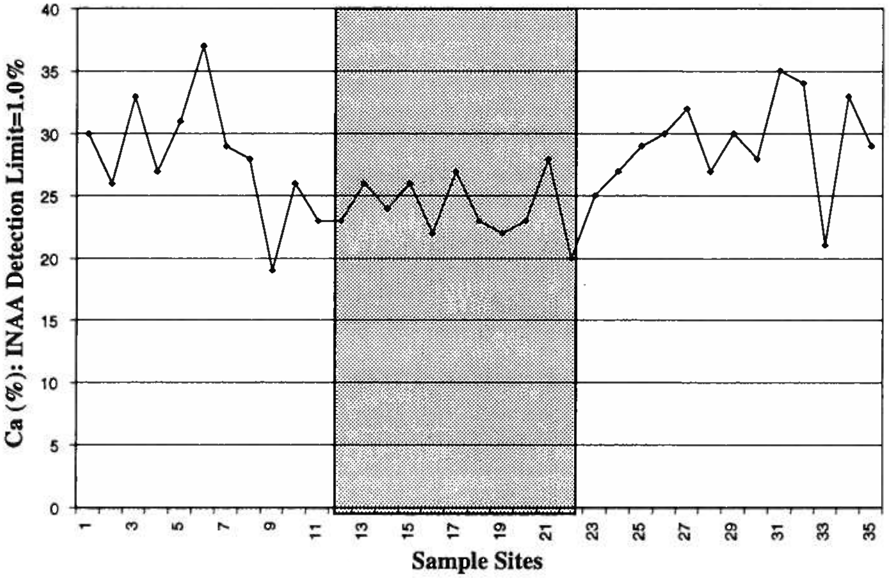
Bi in Stems

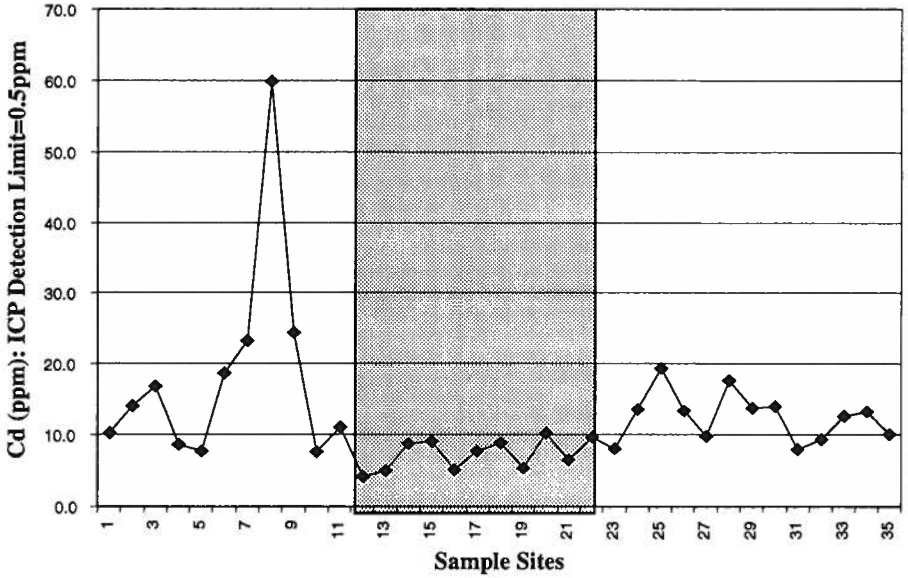


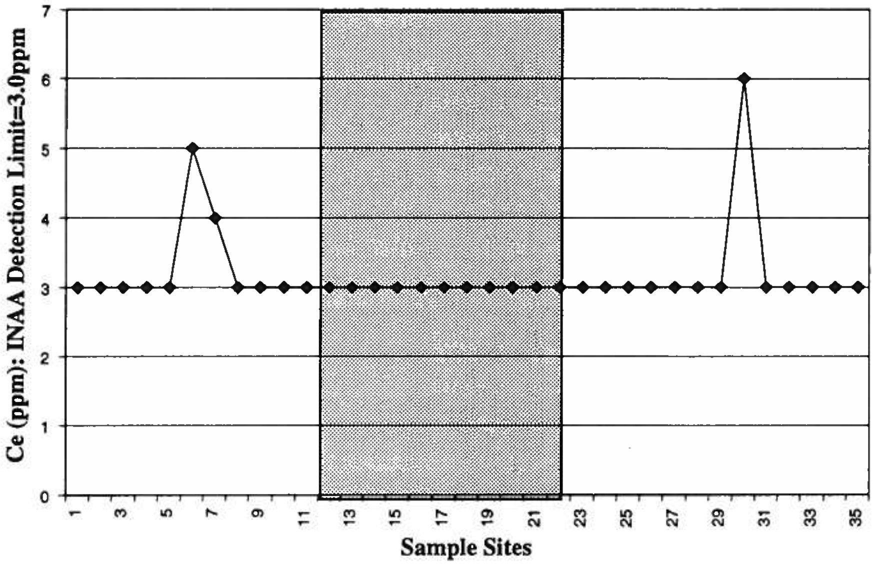
Br in Stems

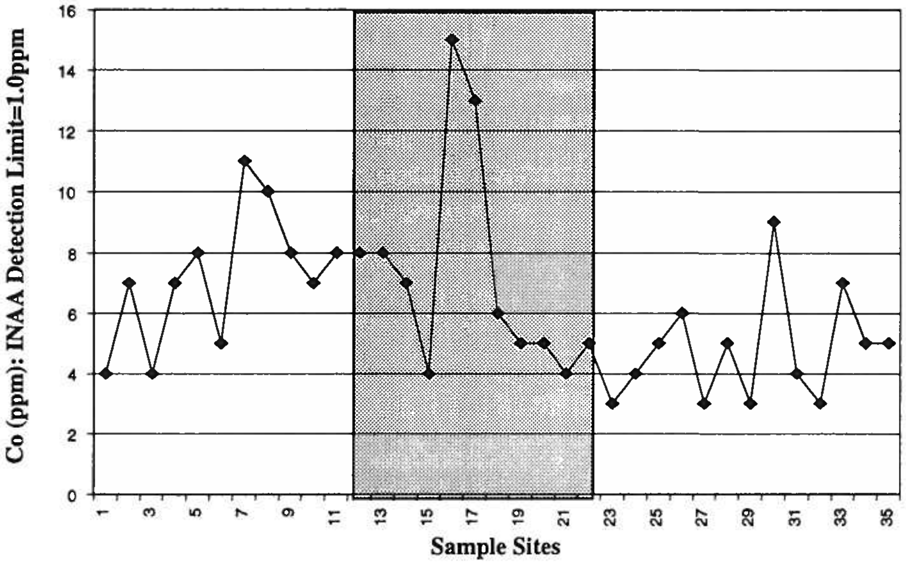


Mountain Lake Biogeochemistry Profiles Ca, Cd, Ce and Co (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.


Ca in Stems

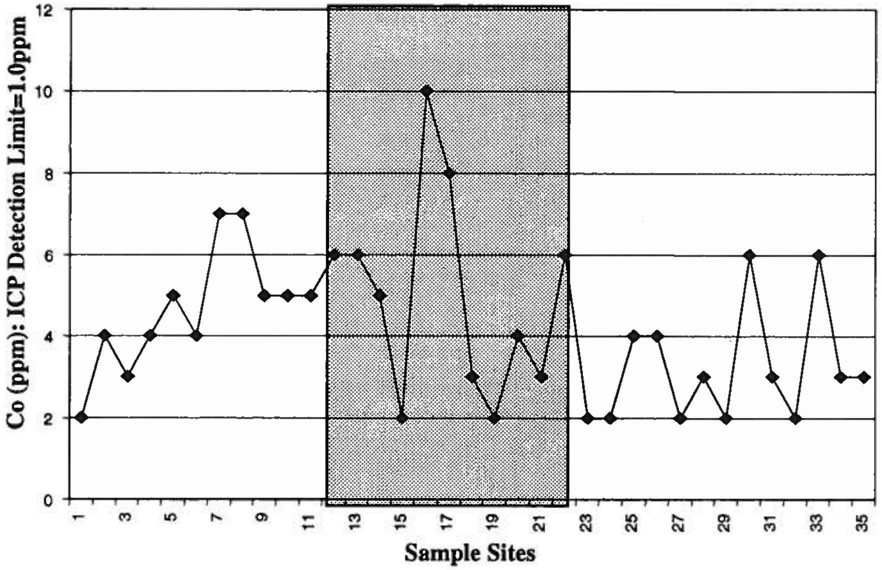

Cd in Stems


Ce in Stems

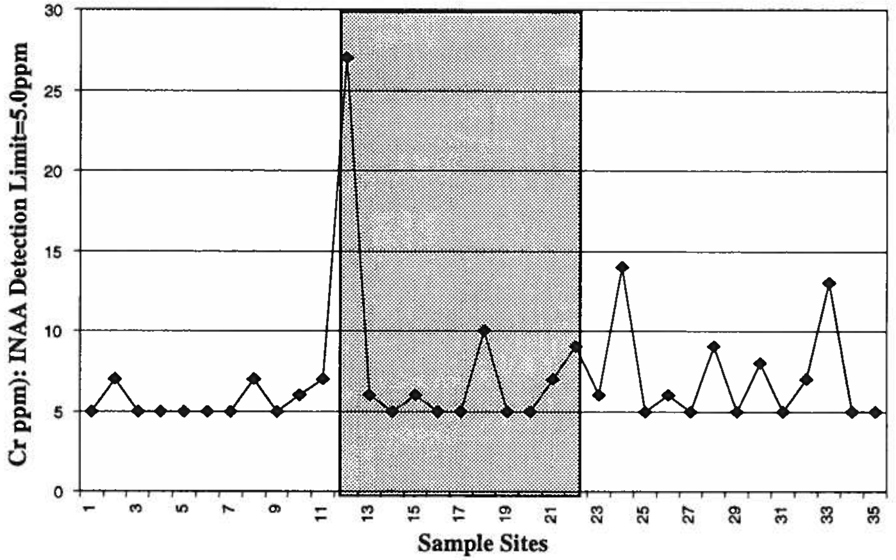

Co in Stems (#1: By INAA)

Mountain Lake Biogeochemistry Profiles Co, Cr and Cs (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

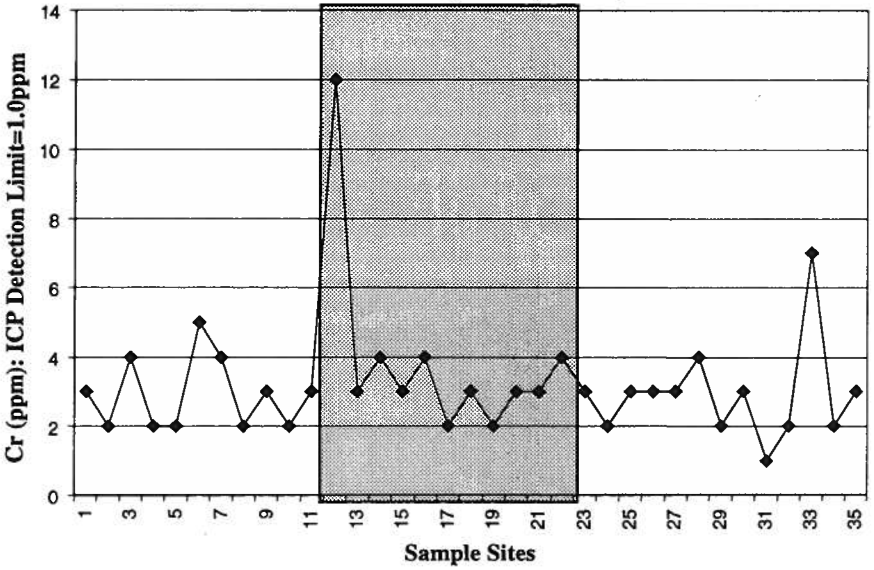
Co in Stems (#2: By ICP)



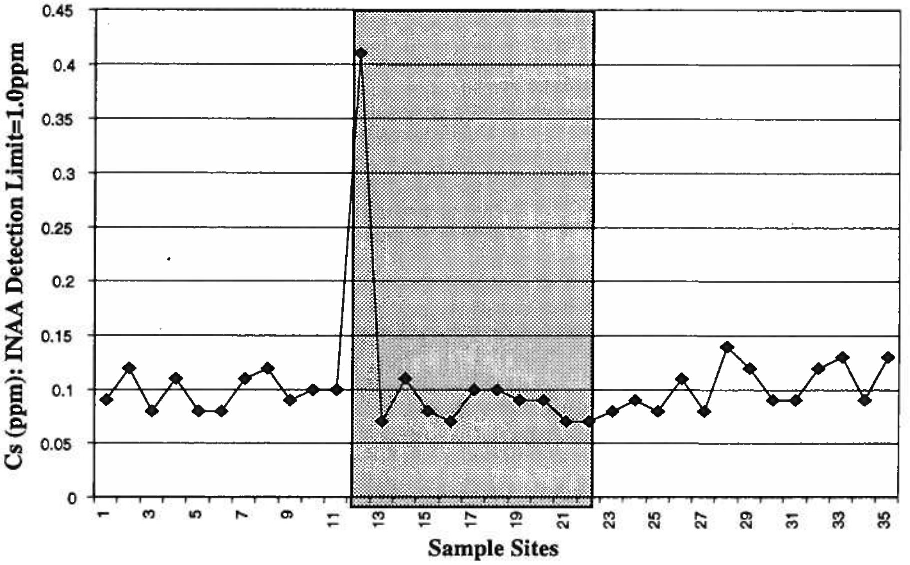
Cr in Stems (#1: By INAA)



Cr in Stems (#2: By ICP)



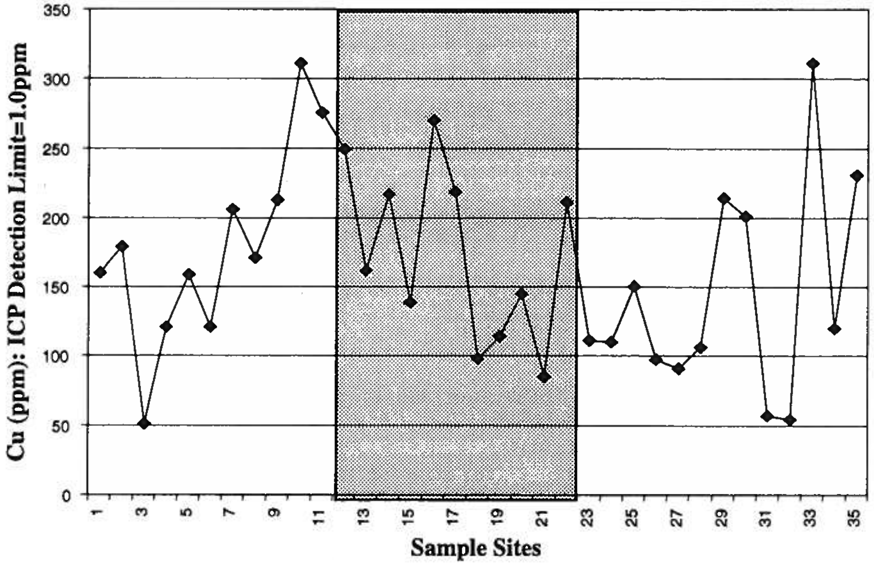
Cs in Stems



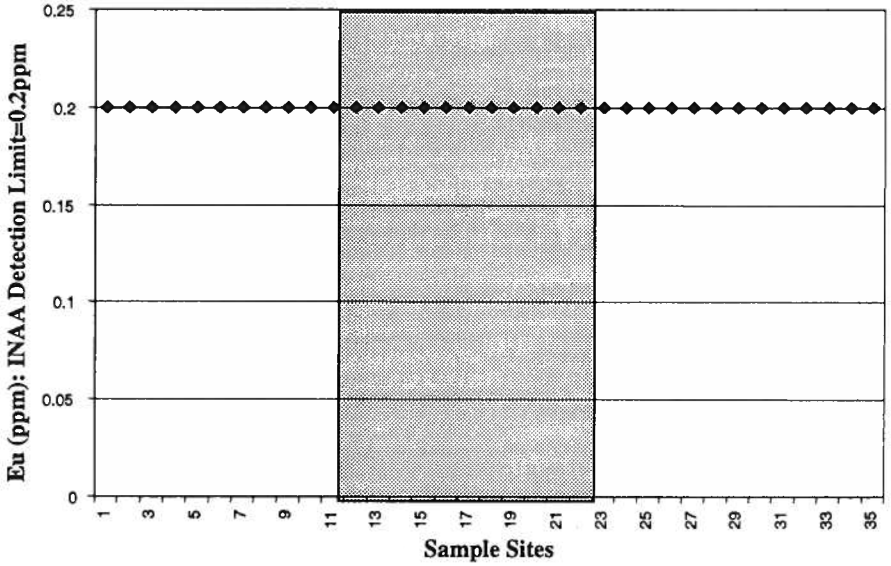
Mountain Lake Biogeochemistry Profiles Cu, Eu and Fe (samples RE-ML97-001 to REML97-035).

Shading represents the approximate surface expression of the pipe.

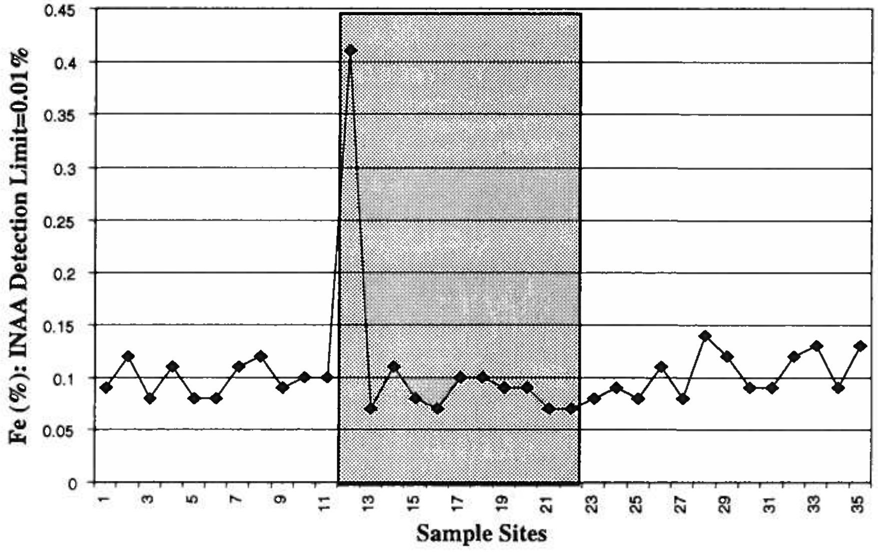
Cu in Stems



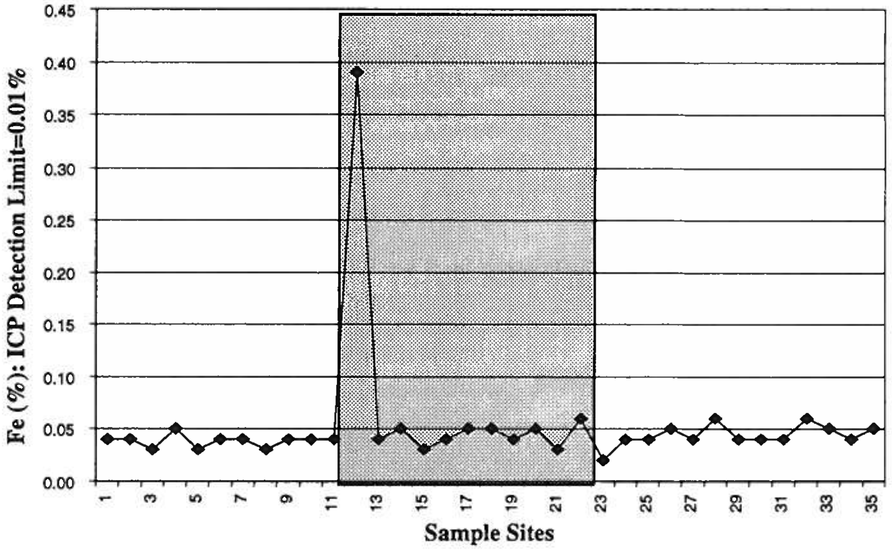
Eu in Stems



Fe in Stems (#1: By INAA)

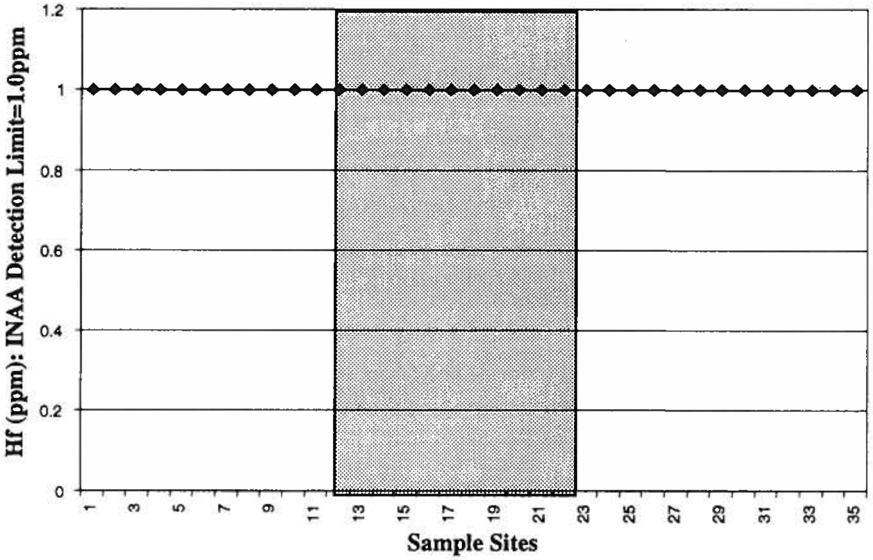


Fe in Stems (#2: By ICP)

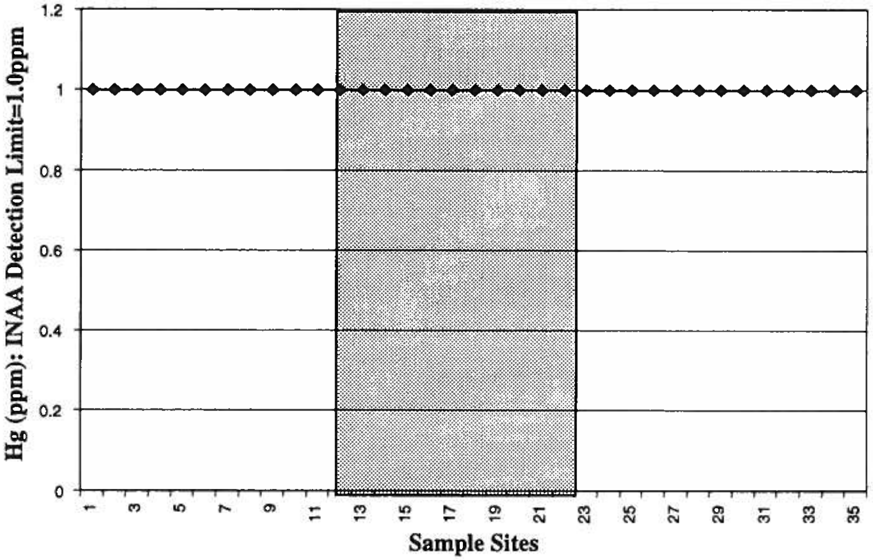


Mountain Lake Biogeochemistry Profiles Hf, Hg, Ir and K (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

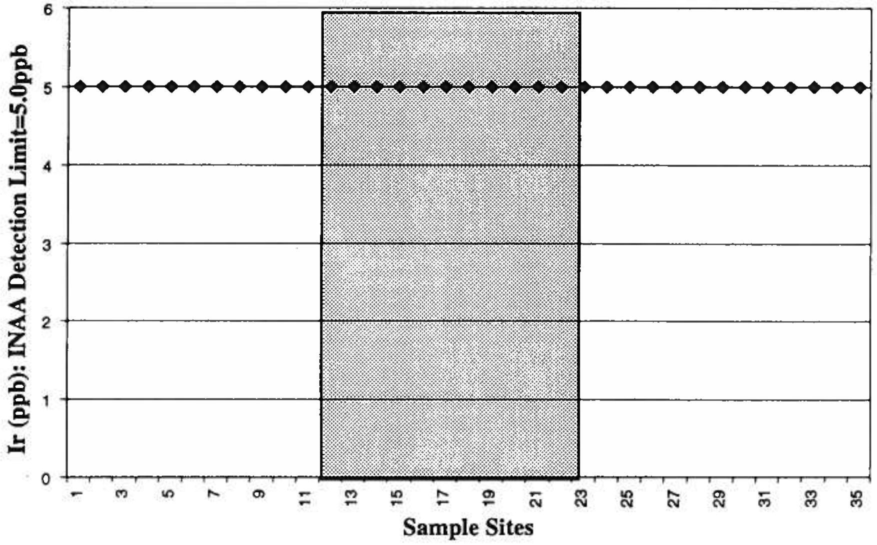
Hf in Stems



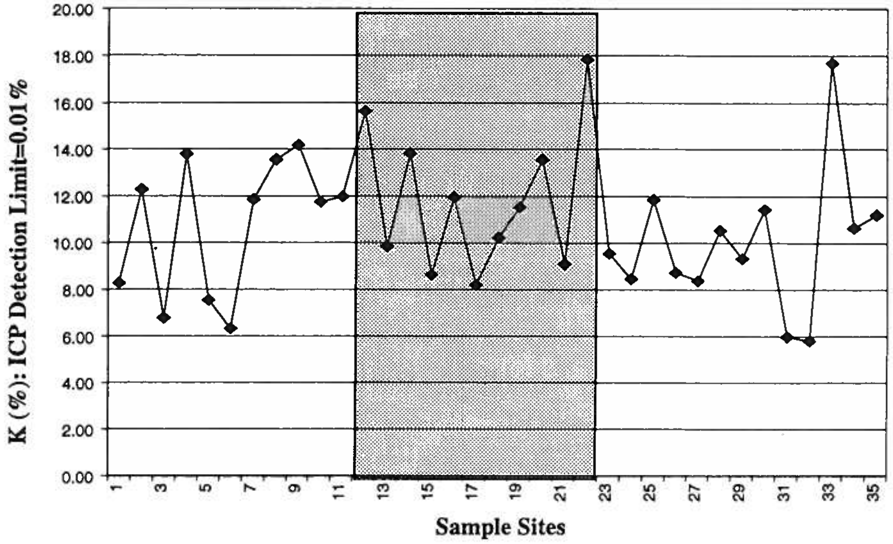
Hg in Stems



Ir in Stems

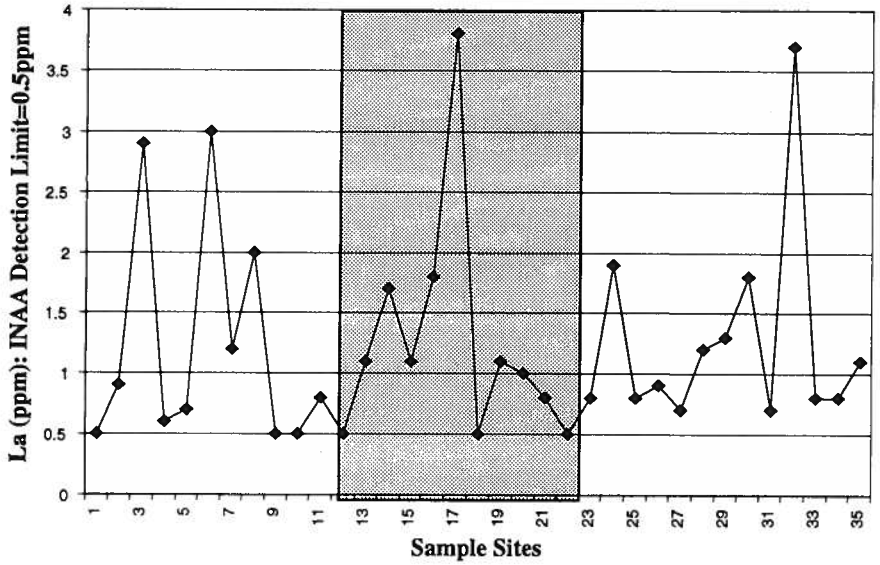


K in Stems

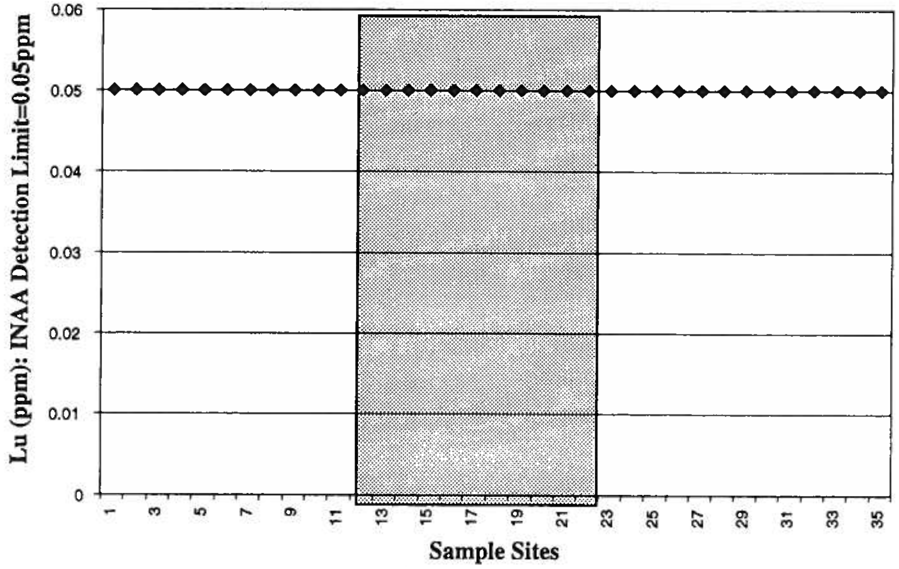


Mountain Lake Biogeochemistry Profiles La, Lu, Mg and Mo (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

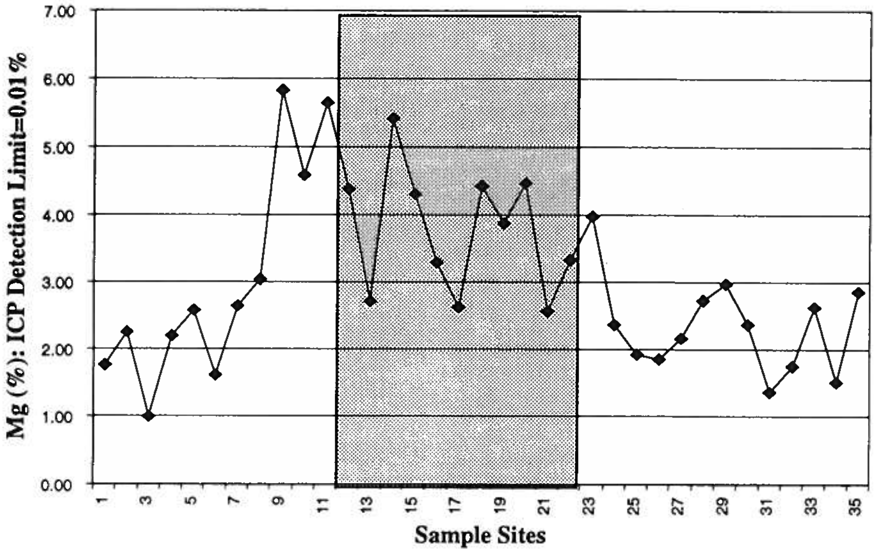
La in Stems



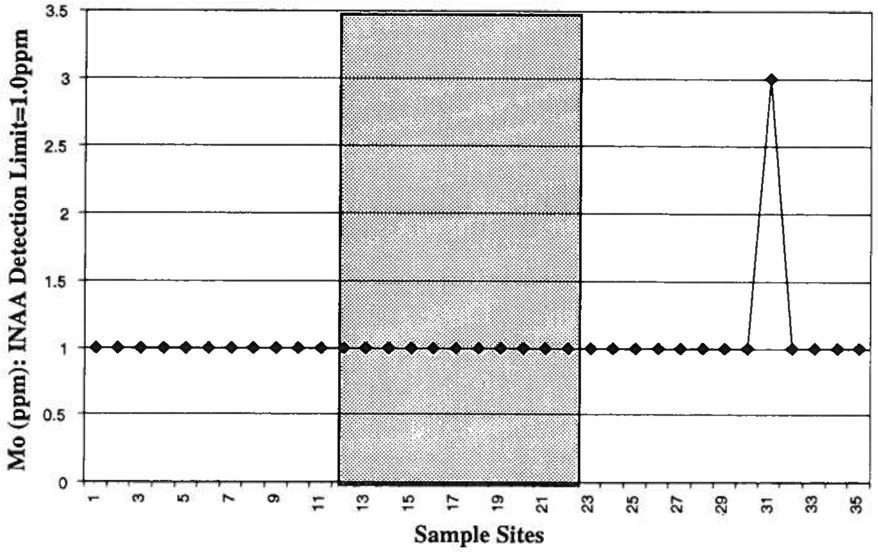
Lu in Stems



Mg in Stems



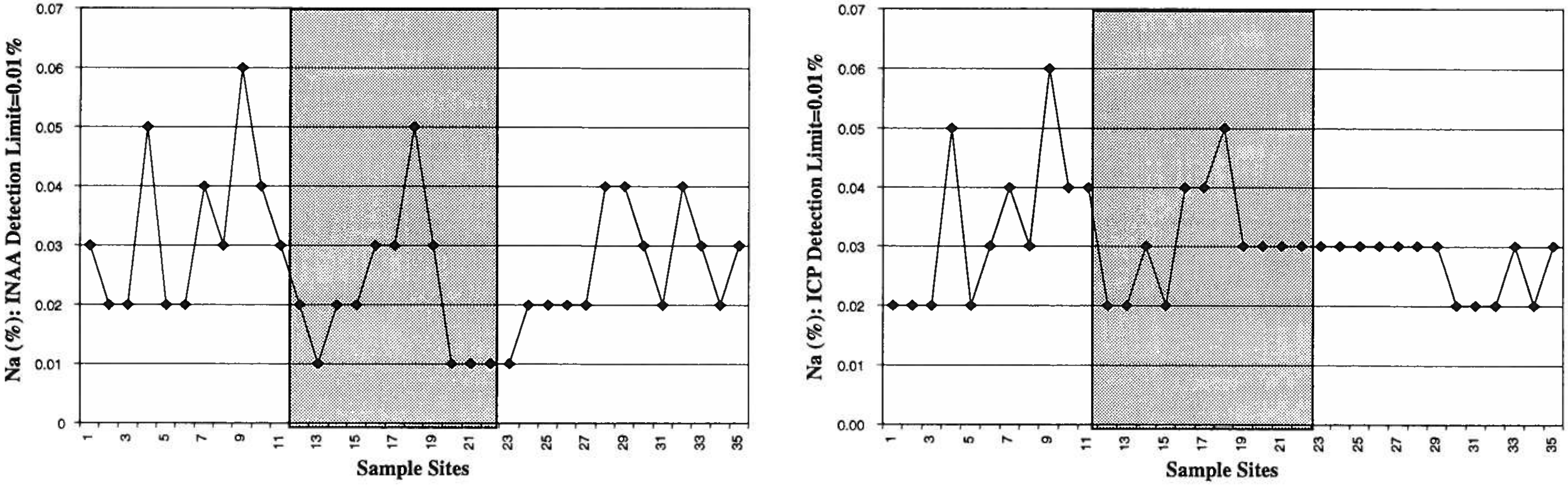
Mo in Stems



Mountain Lake Biogeochemistry Profiles Na, Nd and Ni (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

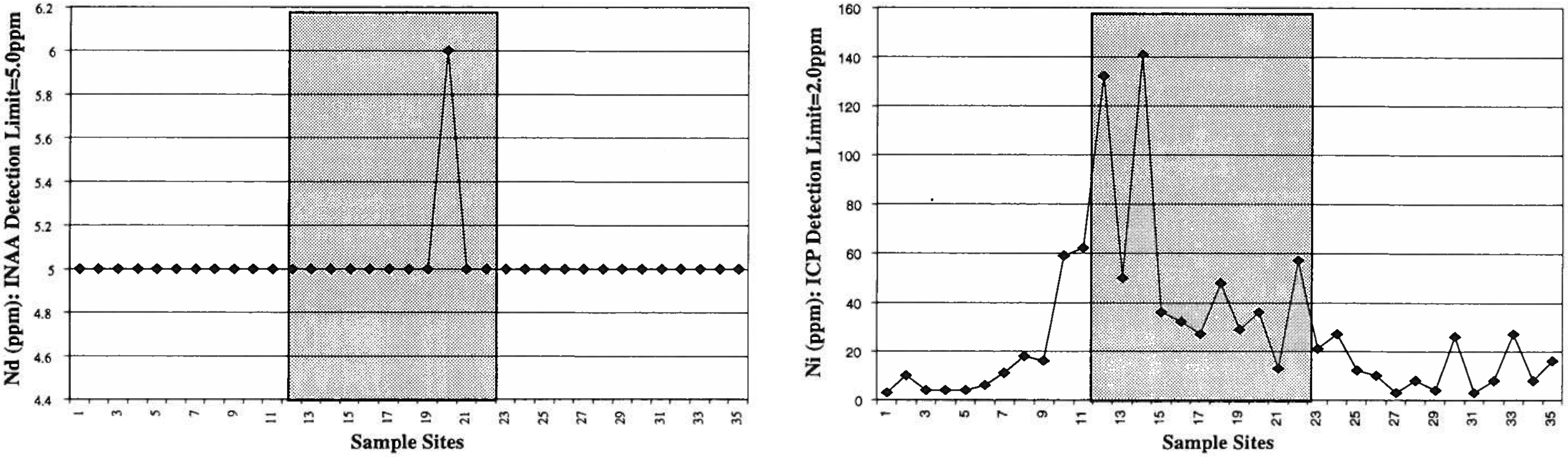
Na in stems (#1: By INAA)

Na in Stems (#2: By ICP)

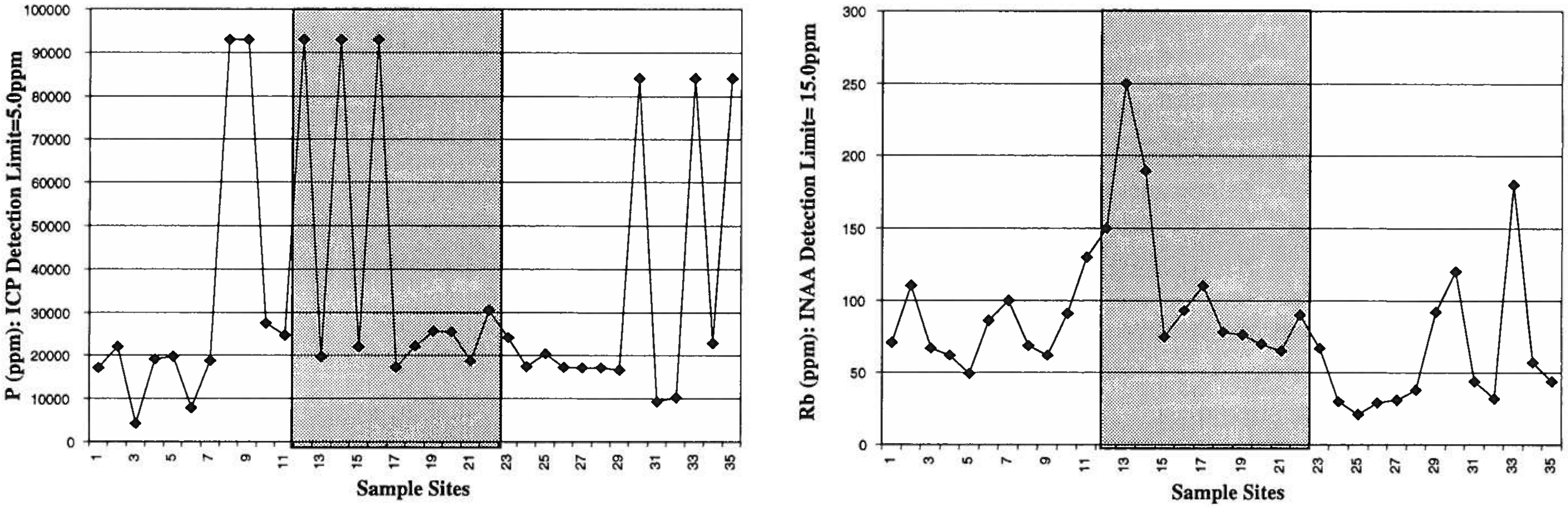


Nd in Stems

Ni in Stems

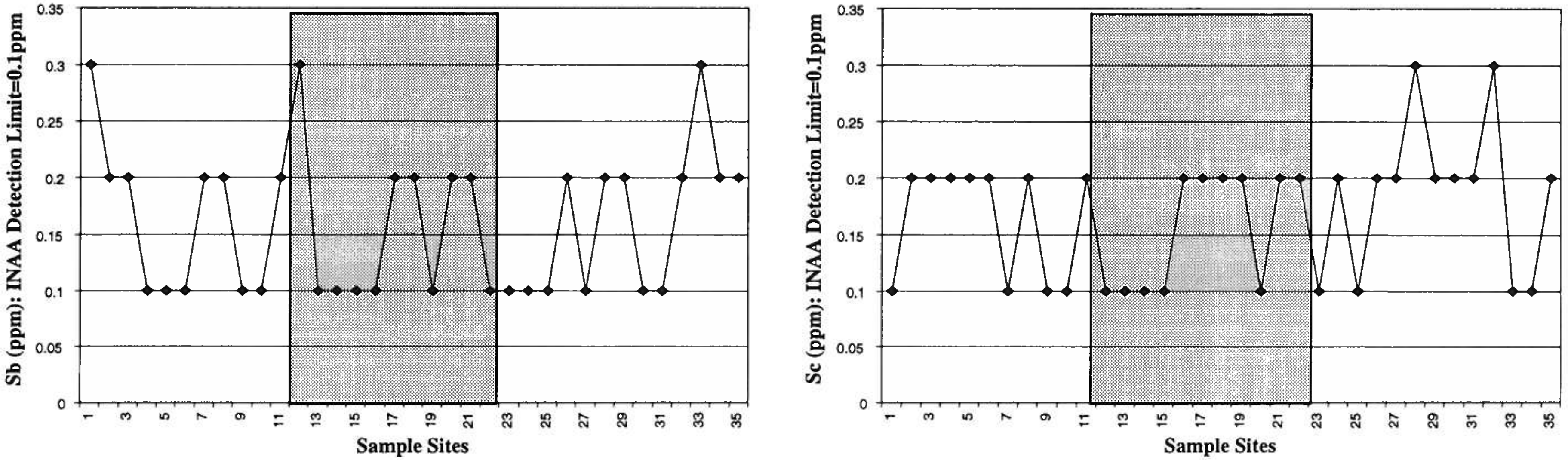


Mountain Lake Biogeochemistry Profiles P, Rb, Sb and Sc (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.



P in Stems

Rb in Stems

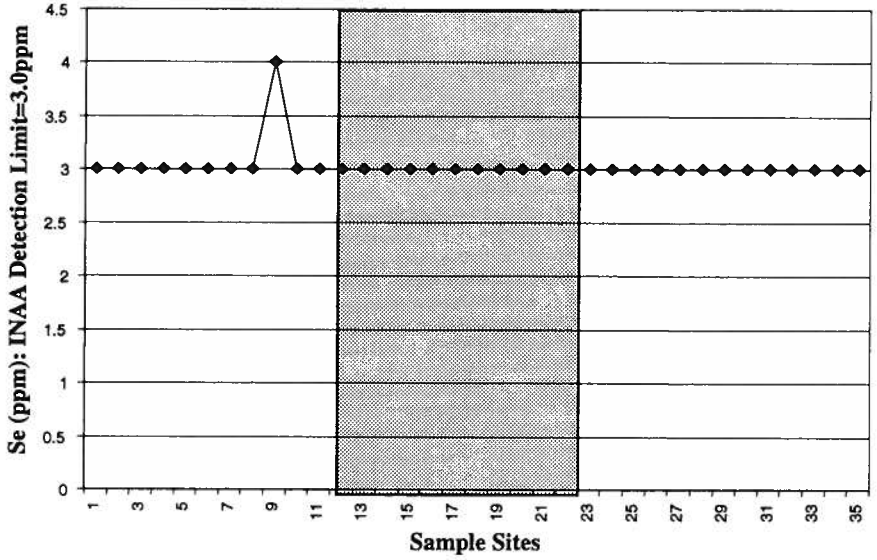


Sb in Stems

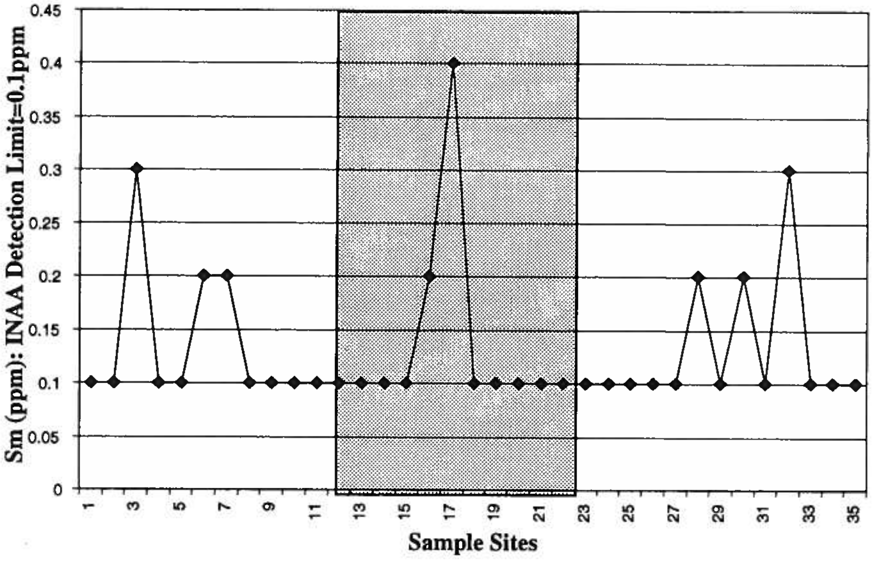
Sc in Stems

Mountain Lake Biogeochemistry Profiles Se, Sm, Sn and Sr (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

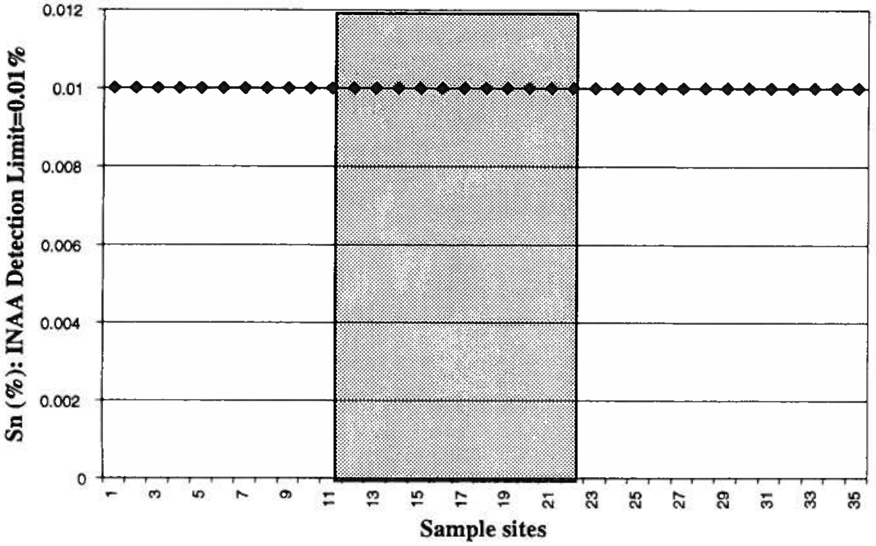
Se in Stems



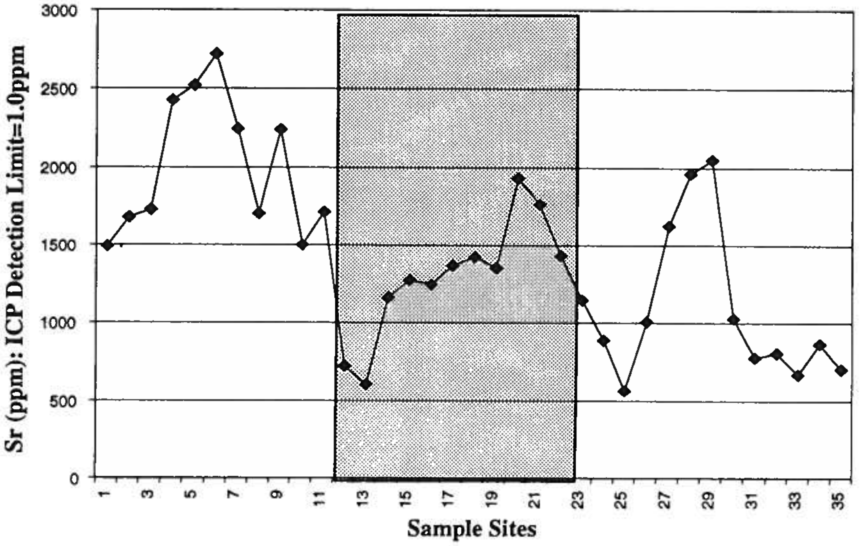
Sm in Stems



Sn in Stems

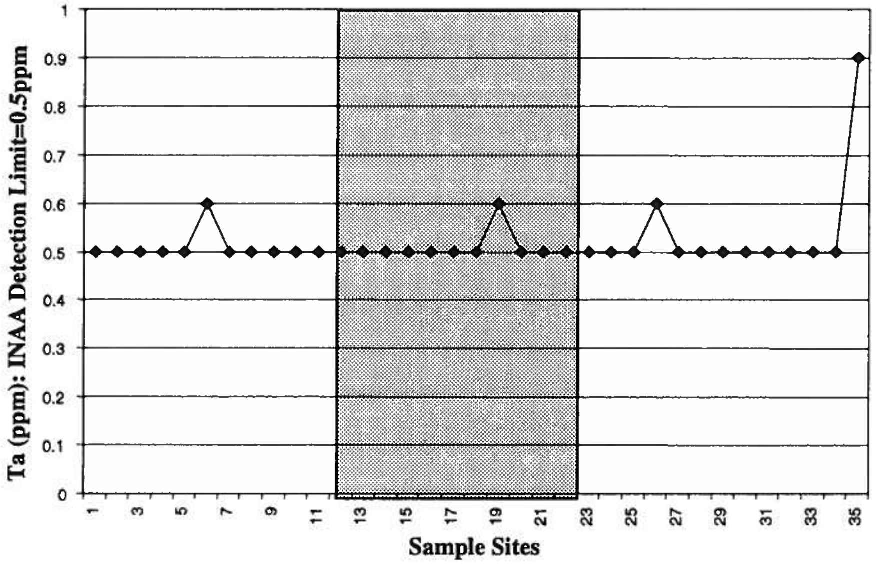


Sr in Stems

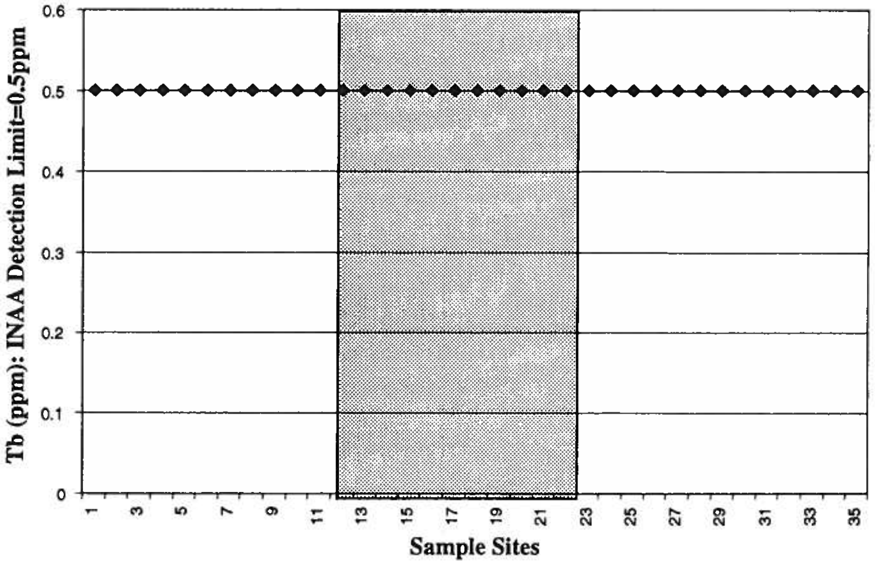


Mountain Lake Biogeochemistry Profiles Ta, Tb, Ti and Th (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

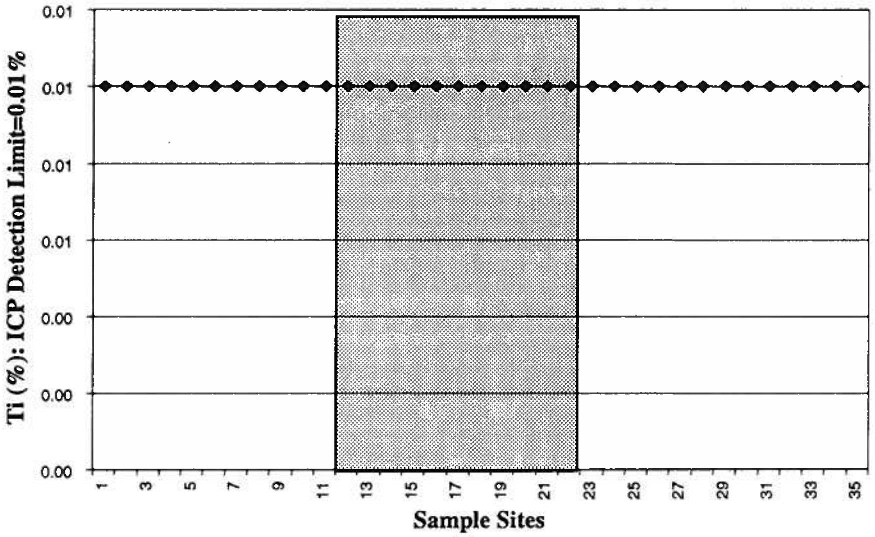
Ta in Stems



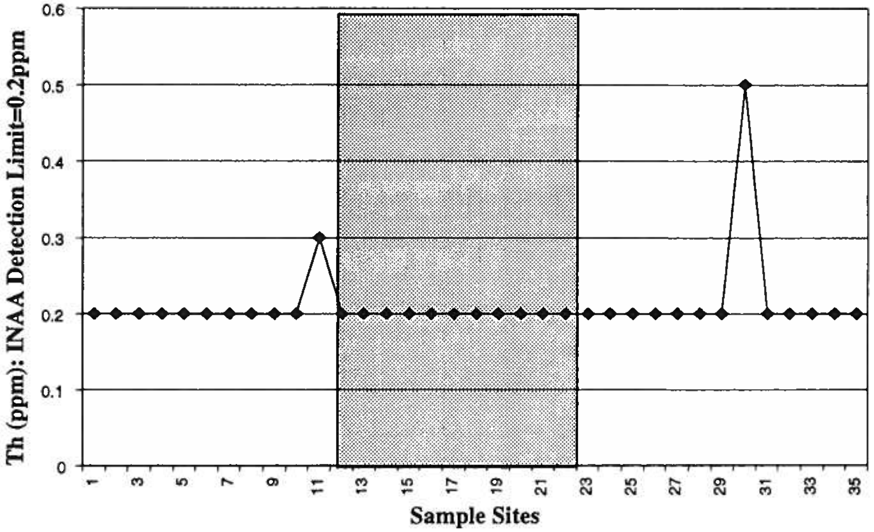
Tb in Stems



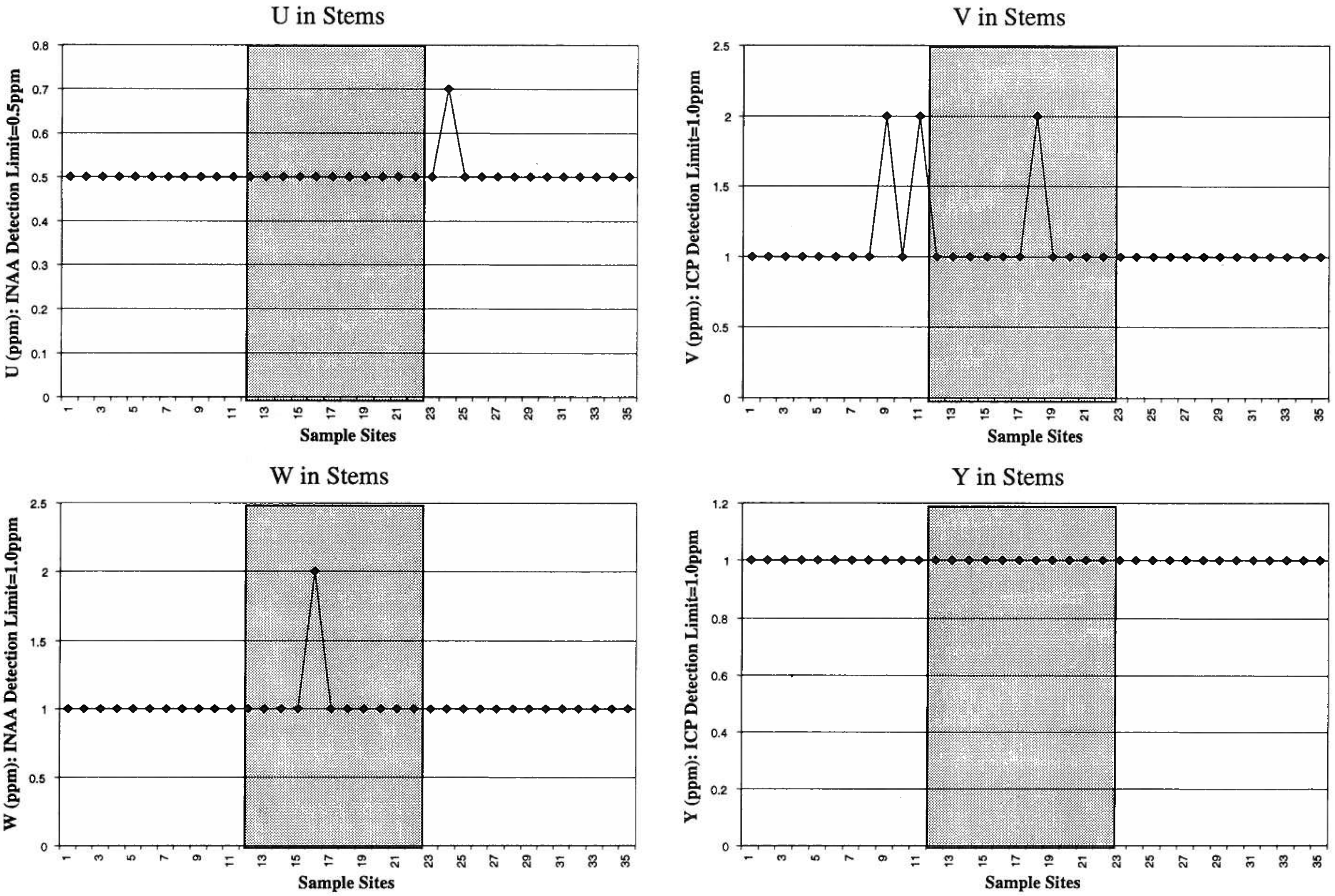
Ti in Stems



Th in Stems

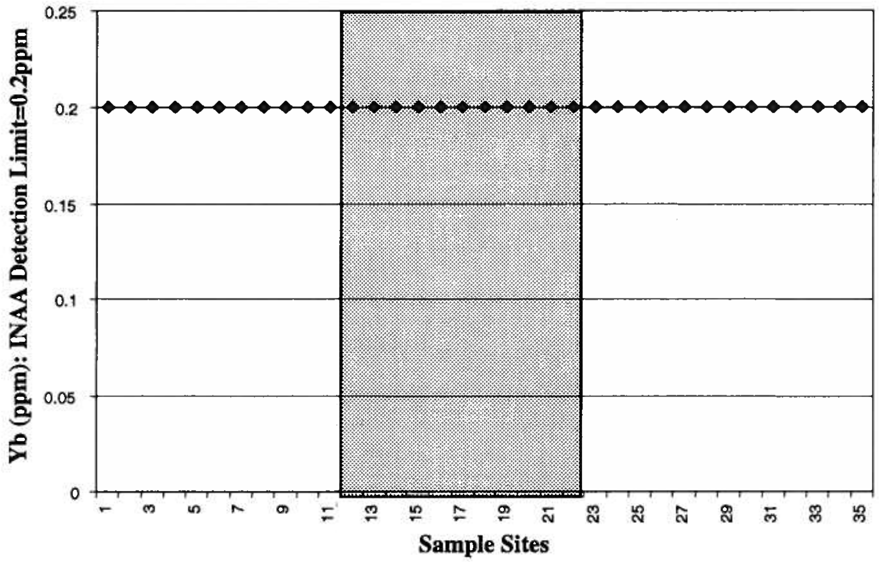


Mountain Lake Biogeochemistry Profiles U, V, W and Y (samples RE-ML97-001 to REML97-035).
Shading represents the approximate surface expression of the pipe.

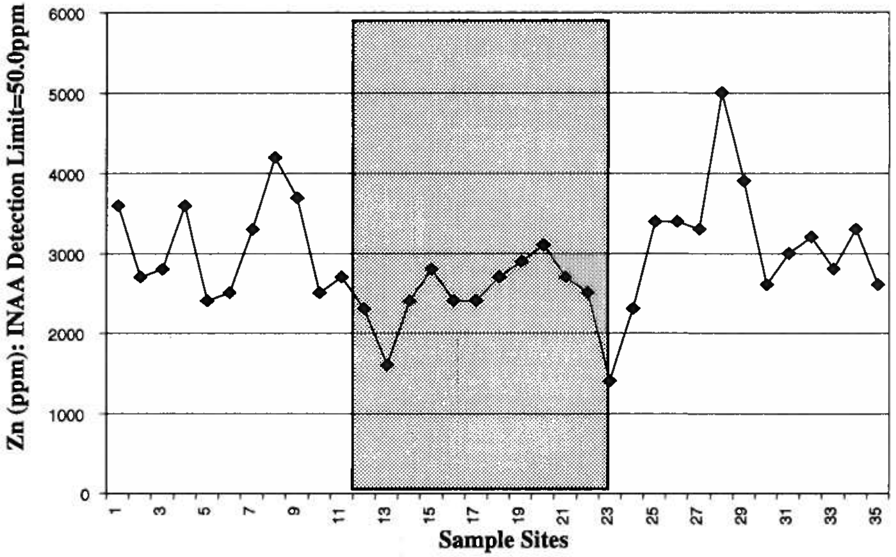


Mountain Lake Biogeochemistry Profiles Yb, Zn and Zr (samples RE-ML97-001 to REML97-035). Shading represents the approximate surface expression of the pipe.

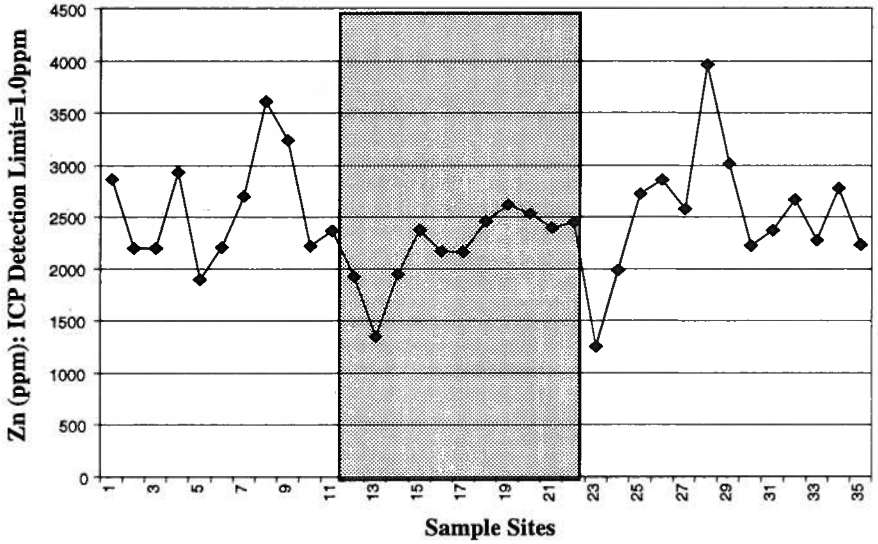
Yb in Stems



Zn in Stems (#1: By INAA)



Zn in Stems (#2: By ICP)



Zr in Stems