

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

**Partitioning of Elements Between Two Size  
Sediment Fractions in Samples from Nineteen Areas  
of the Western United States**

by

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## CONTENTS

	Page
Abstract.....	1
Introduction.....	1
Field Sampling.....	1
Sample Preparation.....	3
Analytical Techniques.....	3
Thirty-five Element Scan .....	3
Mercury.....	3
Uranium and Thorium.....	3
Arsenic and Selenium.....	5
Hot-Water Extractable Boron.....	5
Results and Discussion.....	5
References Cited.....	14

## ILLUSTRATIONS

Figure 1.--Map showing the general locations of the nineteen study areas in the western United States.....	2
Figure 2.--Flow diagram showing the sample preparation procedure..	4
Figures 3-32.--Scatter diagrams showing the relation between elements in coarse and fine fractions of sediment samples from the western United States.....	7
3.--Aluminum .....	7
4.--Arsenic .....	7
5.--Boron .....	7
6.--Barium .....	7
7.--Calcium .....	7
8.--Cerium .....	7
9.--Cobalt .....	8
10.--Chromium .....	8
11.--Copper .....	8
12.--Iron .....	8
13.--Gallium .....	8
14.--Mercury .....	8
15.--Potassium .....	9
16.--Lanthanum .....	9
17.--Lithium .....	9
18.--Magnesium .....	9
19.--Manganese .....	9
20.--Sodium .....	9
21.--Neodymium .....	10
22.--Nickel .....	10
23.--Phosphorus .....	10
24.--Lead .....	10
25.--Scandium .....	10

26.--Selenium .....	10
27.--Strontium .....	11
28.--Titanium .....	11
29.--Thorium .....	11
30.--Vanadium .....	11
31.--Yttrium .....	11
32.--Zinc .....	11

**TABLES**

Table 1.--Determination limits for elements reported.....	15
Table 2.--Detection ratios for trace elements in coarse and fine sediment fractions from the present study.....	16
Table 3.--Geochemical baselines for soils from the western United States and observed ranges for coarse and fine sediment fractions from the present study.....	17
Table 4.--Regression equations between elements in coarse and fine fractions of sediments from nineteen areas of the western United States based on the model $Y = mX + b$ ....	18

## **ABSTRACT**

The Department of Interior Task Group on Irrigation Drainage conducted reconnaissance studies at U.S. Bureau of Reclamation irrigation projects associated with wildlife refuges in the western United States to evaluate potential adverse effects of irrigation drainage on fish, wildlife, and other water uses. Nine areas were included in the studies during 1986-1987 and an additional ten areas in 1987-1988. In the 19 areas, about 255 samples of bottom material from streams, rivers, marshes, ponds, lakes, and drainage ditches were collected. The samples were sieved into two size fractions--less than 230 mesh (0.063 mm) and less than 10 mesh (2 mm with the less than 0.063 millimeter material included). Samples were analyzed for total content of major, minor, and trace elements, and water-soluble boron. Comparisons are made between the two fractions to show enrichment or depletion of various elements, and recommendations are made for future reconnaissance type sediment-sampling programs.

## **INTRODUCTION**

The Department of Interior (DOI) formed a multi-agency Task Group on Irrigation Drainage in 1985 in response to Congressional requests for examination of potential damage to land affected by DOI irrigation projects. As a result, the Task Group has conducted reconnaissance-level studies in 19 areas in the western United States (fig. 1). The overall objective of the studies was to determine whether or not irrigation practices have potential to cause or are responsible for harmful effects on human health, fish and wildlife, or other water uses.

The studies were conducted by personnel from the U.S. Geological Survey, U.S. Bureau of Reclamation, and U.S. Fish and Wildlife Service, and other Federal and State agencies. Water, bottom material, plant tissue, and animal tissue were sampled. Bottom material is the focus of this report and refers to the uppermost 5 to 10 cm of material obtained from sediment deposited in streams, rivers, marshes, ponds, lakes, and drainage ditches. The objective of the bottom material sampling and analysis was to examine the relationship between elements in two size fractions, determine whether or not element enrichment predominates in one size fraction, and make recommendations for sampling and analysis of bottom sediment in future reconnaissance studies. In addition, the range of element concentrations measured in the two sediment size fractions are compared to baseline concentrations for soils of the western United States.

## **FIELD SAMPLING**

Bottom material samples were collected from the nineteen study areas (fig. 1) between 1986 and 1988. The number of samples collected from each area ranged from 6 to 15. At all sampling locations, sediment collection consisted of the uppermost 5 to 10 cm of material available. Samples consisted of a composite of bottom material from a number of subsamples (6-8) collected from the stream channel. Samples from lakes or ponds were composited from within a small area. The subsamples were mixed in a non-contaminating container (glass, enamel, or stainless steel pan). Samples from Salton Sea and Tulare Lake study areas were wet sieved in the field using stainless steel or nylon sieves and native water, whereas all other samples were dry sieved in the laboratory after air drying and mechanical disaggregation.

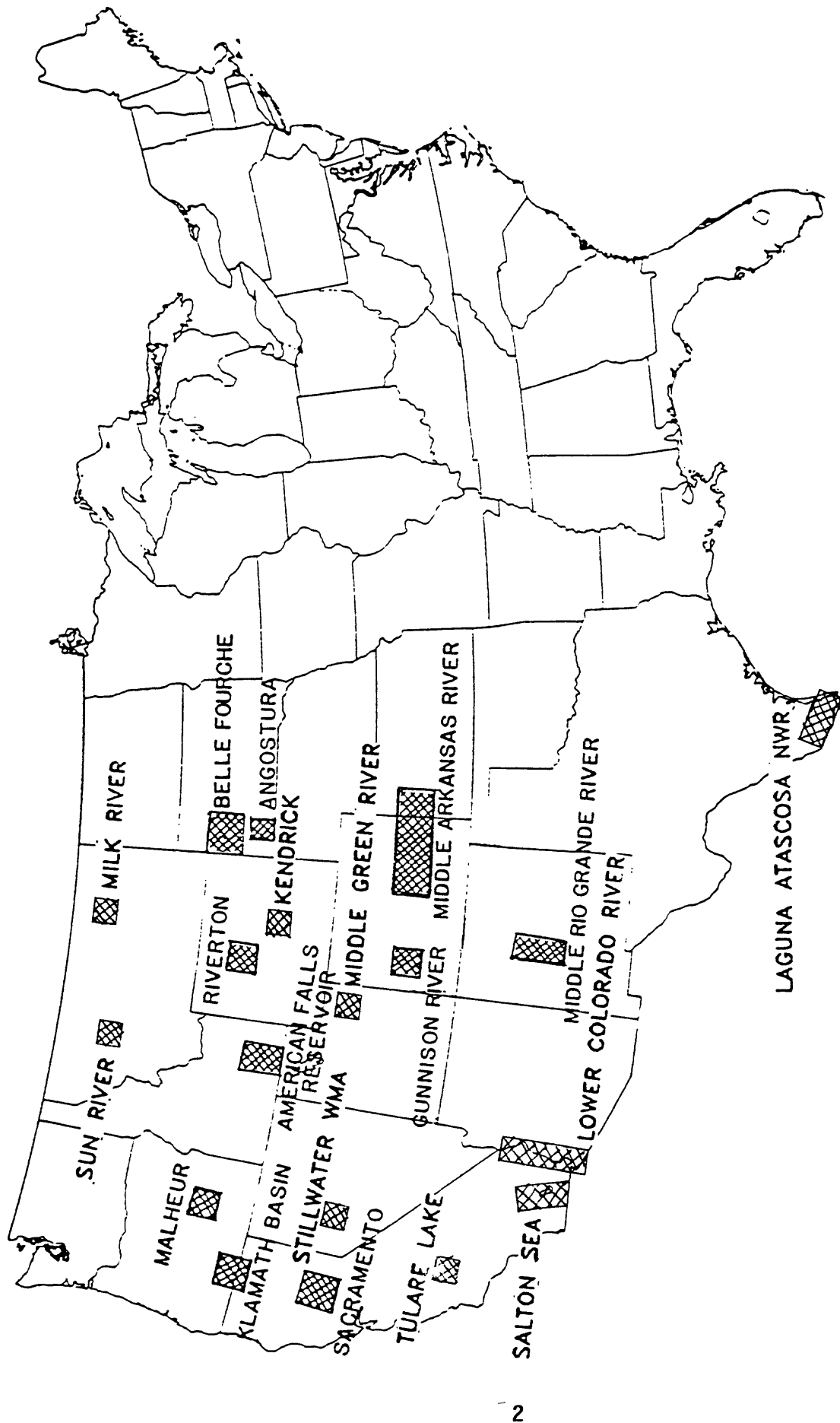


Figure 1. Map showing the general locations of the nineteen study areas in the western United States.

## **SAMPLE PREPARATION**

Samples of wet sediment were mailed to the Geologic Division Analytical Laboratories of the U.S. Geological Survey in Denver. Samples of field wet-sieved material consisted of a slurry of sediment and water. All samples were air dried at ambient temperature under forced air. The field-sieved samples, after drying, were disaggregated and received no further preparation before analyses. The bulk samples were disaggregated and the minus 10 mesh (2 mm) material (coarse fraction) was saved. A split of the minus 10 mesh material was split into two parts. One part was ground to minus 100 mesh and the other part was dry sieved through a 230 mesh (0.063 mm) sieve (fine fraction). The material passing the sieve was saved for analyses. Hereafter, the two size fractions are referred to as coarse and fine fractions. A flow diagram (fig. 2) illustrates the sample preparation procedure.

## **ANALYTICAL TECHNIQUES**

Abbreviated descriptions of the analytical techniques used in this study are given below. In addition to the references cited under each method, detailed descriptions of the methods, except those for Se and U, are given in Baedecker (1987).

### Thirty-five Element Scan

Samples were analyzed using induction-coupled plasma (ICP) for the determination of 35 elements simultaneously (table 1). Each sample (0.200 g) was digested at low-temperature in a mixture of concentrated hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock and others, 1983). The acidic sample solution was taken to dryness and the residue was dissolved with 1 mL of aqua regia and then diluted to 10 g with deionized water. Reagent blanks, reference materials, and sample replicates were all digested by the same procedure and analyzed with the samples. The limits of determination (analytical reporting limits) are shown in table 1. Elements not detected in one or more samples are listed in table 2. The relative standard deviation (RSD) for replicate determinations of most elements is about five percent.

### Mercury

Cold vapor atomic-absorption spectroscopy was used to determine Hg (Kennedy and Crock, 1987). A 0.1 g sample was digested with nitric acid and sodium dichromate and then mixed with hydroxylamine hydrochloride and stannous chloride to produce a vapor of elemental Hg. The Hg was determined with a flameless atomic absorption spectrophotometer. The determination limit is given in table 1. Not all samples contained Hg concentrations above the limit of determination (table 2). The RSD for the method is about ten percent.

### Uranium and Thorium

Uranium and Th were determined by delayed neutron activation analysis (DNAA) for sediment collected during 1986-1987. After activation of a 10 g sample with thermal neutrons, the delayed neutrons from U-235 were measured. The sample was then re-irradiated with fast neutrons and the delayed neutrons from U-235, U-238, and Th-232 were measured (Millard, 1976). Using the natural U-238/U-235 isotopic ratio and

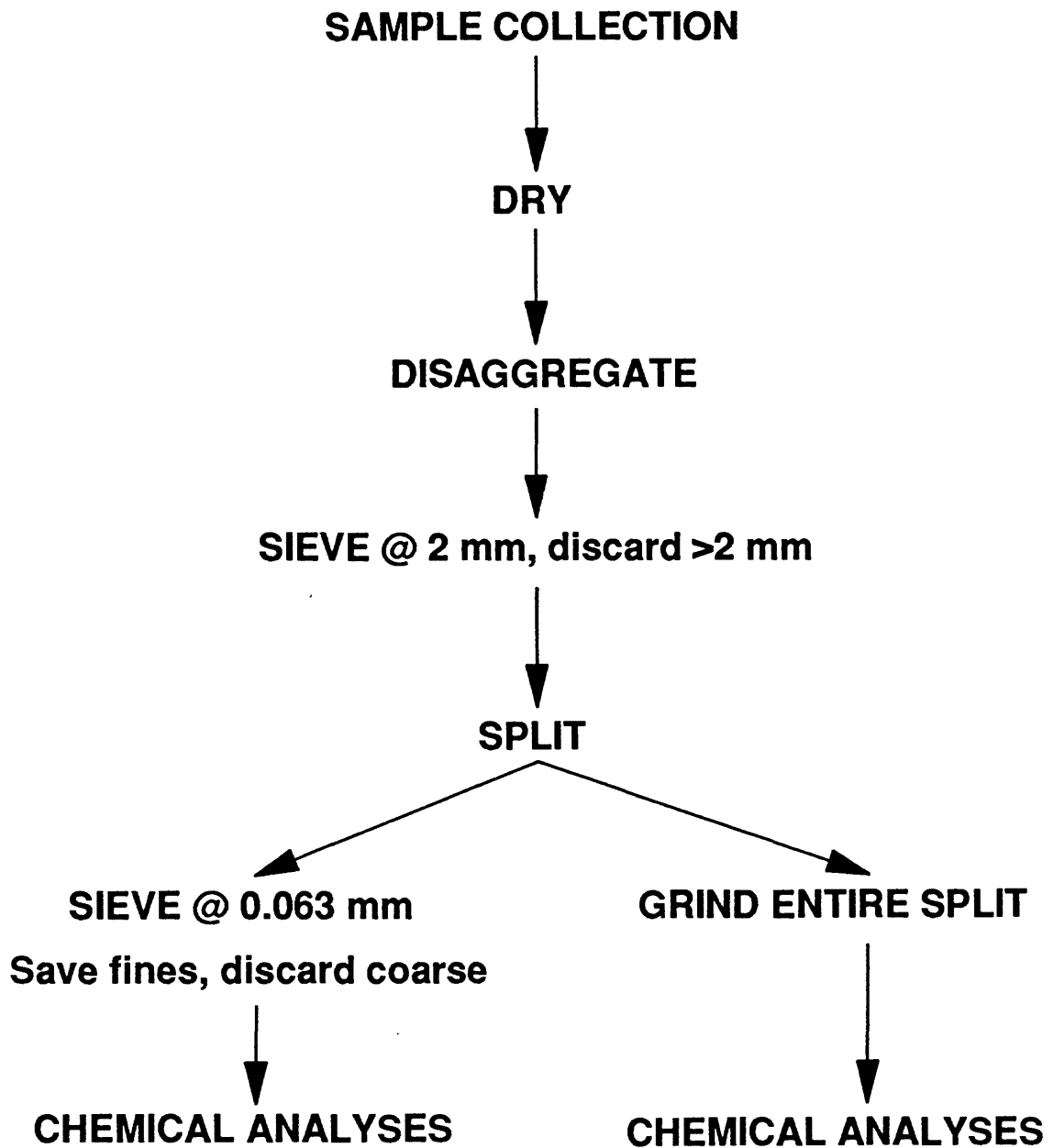


Figure 2. Flow diagram showing the sample preparation procedure.

the two delayed neutron measurements, Th was calculated by difference. For concentrations of at least 1 and 10 ppm U and Th, respectively, and a Th/U ratio greater than 3, the RSD for the U determination is about five percent. The determination limits for U and Th are given in table 1, but not all samples contained concentrations of U and Th above the limits of determination (table 2).

Uranium and Th were not determined by DNAA for the samples collected during 1987-1988, but data for Th were obtained from ICP. Therefore, data for uranium is not presented in this report and the data for Th represent analyses by two methods.

#### Arsenic and Selenium

Arsenic and Se were determined by continuous flow hydride generation and atomic absorption spectroscopy (Briggs and Crock, 1986; Crock and Lichte, 1982). One gram of sample was digested with a mixture of nitric, perchloric, sulfuric, and hydrofluoric acids. After digestion, the sample was diluted to 100 mL with 10% HCl. The sample solution was reacted with sodium borohydride in order to generate the gaseous hydrides which were swept into the heated quartz furnace of an atomic absorption spectrometer. Arsenic concentrations were read using a calibration curve and Se was determined using the method of standard additions. Determination limits for As and Se are shown in table 1, but for Se, not all samples contained concentrations above the limit of determination (table 2). The RSD for the determination of both elements was about ten percent.

#### Hot-Water Extractable Boron

Boron was determined by a hot-water extraction (Crock and Severson, 1980). A 10 g sample was placed in a 50 mL polyethylene centrifuge tube. Each sample was then wetted with 20 mL of deionized water, capped, and shaken to wet the entire sample. The tubes were placed in a boiling water bath for approximately one hour. After the extraction was complete, the samples were centrifuged at 1500 rpm to separate the sample from the solution. The supernatant solution was decanted, acidified with 1 mL of concentrated nitric acid, and lutetium was added as an internal standard. The solution was analyzed for B on a Jarrell Ash model 1160 simultaneous ICP instrument. The precision (RSD) was about 7% for the samples and standards tested. The determination limit for the method was 0.4 % in the solid sample, but not all samples contained B in concentrations above the limit of determination (table 2).

### **RESULTS AND DISCUSSION**

Results of bottom material analysis included in this report are from reconnaissance level studies. The studies were designed as limited-sampling investigations whose purpose was to provide data that could be used to recognize potential element-related problems, but not to characterize any irrigation-drainage project area in detail. Sample locations were selected to represent either background levels outside the project area or areas with the potential for element enrichment due to irrigation and drainage practices. Some bottom material samples were collected to represent background values "upstream" of the project area; other samples were collected from streams and drainage canals within the irrigation project areas to represent possible elevated element levels related to agricultural irrigation and drainage; still other bottom material samples were collected from the delta areas of "downstream" ponds and lakes within wildlife refuges receiving irrigation-drainage or "drainwater". A wide range in element concentrations both within any project area and among all project areas was expected. This wide range can be observed (table 3) by comparing the baseline values for soils from the



western United States (Shacklette and Boerngen, 1984) with the ranges measured in both the coarse and fine sediment fractions from the present study. For most elements, the observed ranges for coarse and fine sediments are wider than the baseline range for soils. Results of analysis for individual samples are presented in Severson and others (1987) and in Harms and others (1990). In this report, data from the 19 study areas in the western United States (fig. 1) are combined.

X-Y plots are used to visually evaluate the enrichment of elements in either the fine (X) bottom material or the coarse (Y) bottom material fractions (figs. 3-32). In all figures a 1:1 line is drawn to aid in visualization of relative enrichment in either the coarse or fine fractions. Data points above the 1:1 line indicate relative enrichment in the coarse fraction, while data points below the line indicate relative enrichment in the fine fraction. A simple linear regression model ( $Y = mX + b$ ) was also used to examine element relationships between the two bottom material size fractions and to compute the amount of variation explained by the model ( $r^2$ , the coefficient of determination) (Table 4). Perfect agreement in element concentrations between the two size fractions would result in a slope ( $m$ ) of one, an intercept ( $b$ ) of zero and a coefficient of determination ( $r^2$ ) of one.

One group of elements (Al, B, Hg, Na, and Se) have slopes near one. Of these, only Hg (fig. 14) approaches the three ideal conditions. Aluminum (fig. 3), Se (fig. 26), and Na (fig. 20) have slopes near one and intercepts near zero but coefficients of determination smaller than one. Boron (fig. 5) has a coefficient of determination near one and an intercept near zero but the slope is less than one. Most of the 255 data points for B, Hg, and Se are clustered near the origin and therefore, the slope and coefficient of determination are influenced largely by only 10 to 15 data points. In contrast, Al and Na data points are distributed throughout the data range, and the slope and coefficient of determination reflect all the data points. The X-Y plots for Se and Hg suggest only minimal enrichment differences between either the coarse or fine fractions, while the plot for Na suggests a weak enrichment in the coarse fraction. The plot for Al suggests a weak enrichment in the fine fraction, and the plot for B suggests enrichment in the fine fraction at concentrations greater than about 80 ppm. From the plots and the predicted relations between these five elements in coarse and fine bottom sediments, it is concluded that sampling and analyzing either fraction would result in no differences in interpretation of the resulting data for a reconnaissance-type investigation where the main concern is distinguishing between low, normal, or high concentrations.

Another group of ten elements have slopes between 0.8 and 0.9 (except Ca with a slope of 0.74), coefficients of determination between 0.5 and 0.8, and variable intercepts. The data points for Ba (fig. 6), Ca (fig. 7), Co (fig. 9), Ga (fig. 13), Li (fig. 17), Mg (fig. 18), K (fig. 15), Sc (fig. 25), Sr (fig. 27), and V (fig. 30) are distributed throughout their ranges. These elements exhibit a large amount of scatter about the 1:1 line. Plots for Ba, Ca, K, and Sr suggest no consistent enrichment between fractions. Plots for the remaining six elements (Co, Ga, Li, Mg, Sc, and V) show enrichment in the fine sediment fraction. The large amount of scatter in the data for these ten elements suggests that predicting relations between the two sediment size fractions would tend to be unreliable. Because of this uncertainty, sampling and analyzing only one fraction would result in over or under estimation of the element concentration in the other fraction, depending on the geochemical character of the specific sample. In general analyzing the coarse

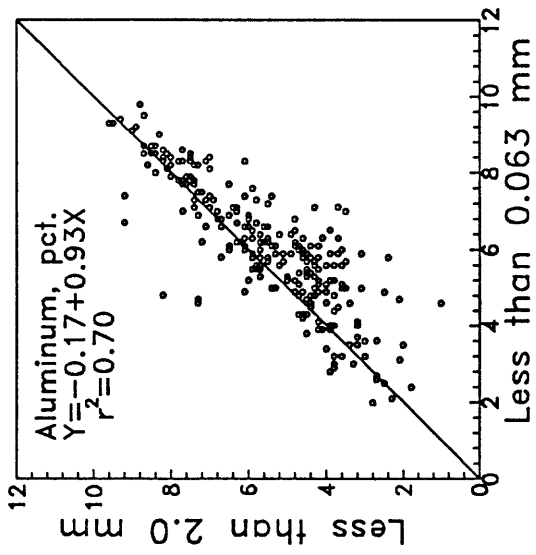


Figure 3. Aluminum.

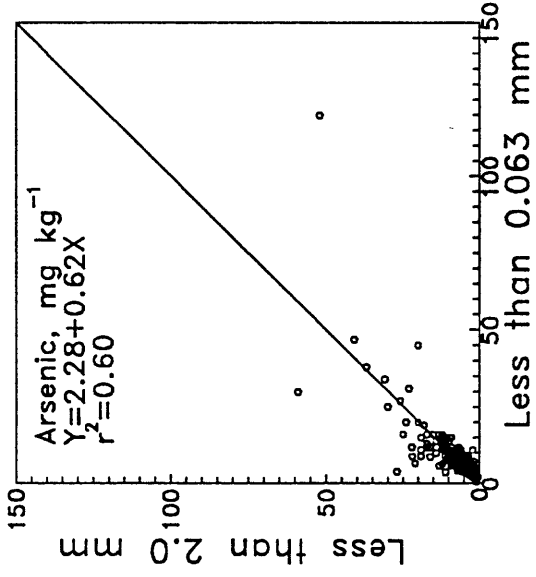


Figure 4. Arsenic.

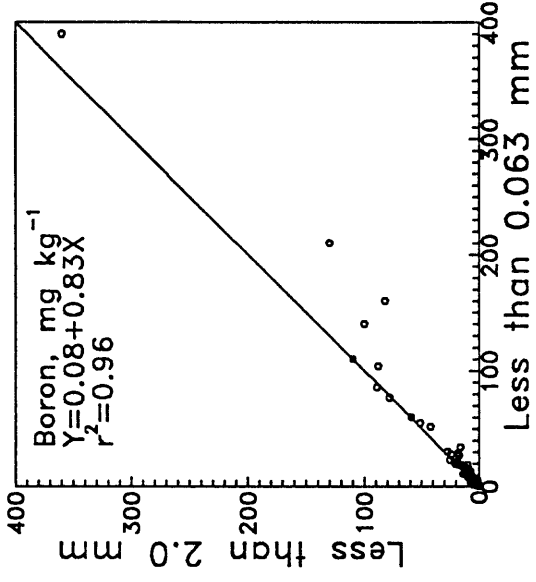


Figure 5. Boron.

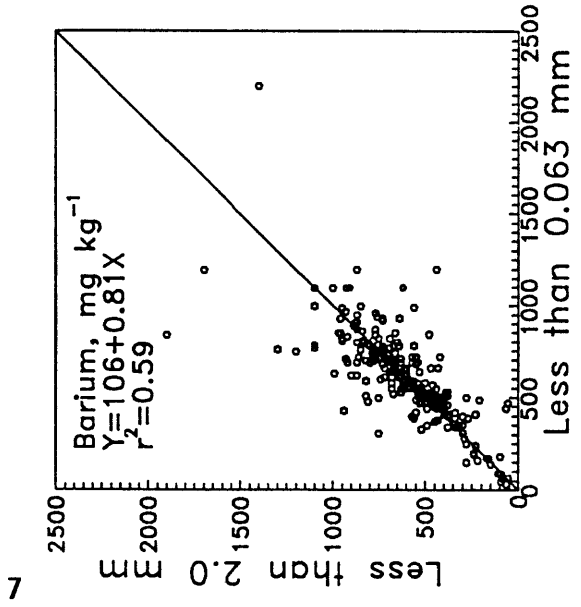


Figure 6. Barium.

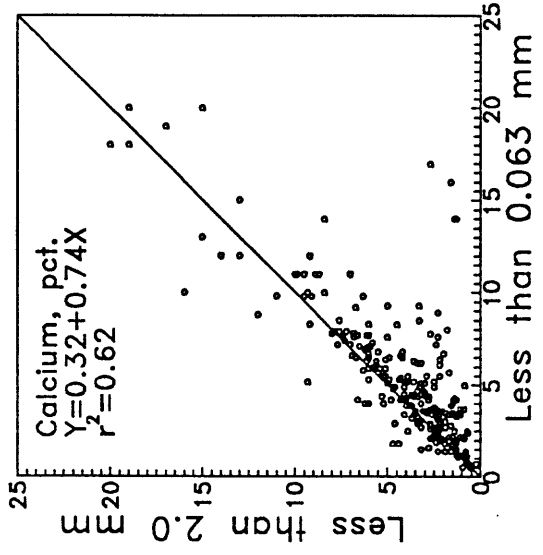


Figure 7. Calcium.

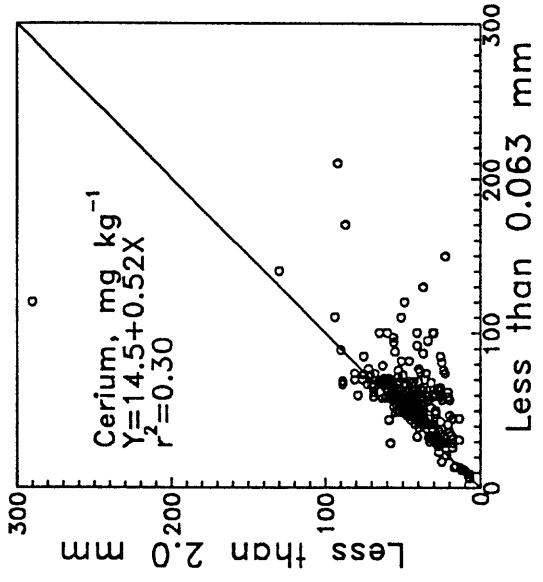


Figure 8. Cerium.

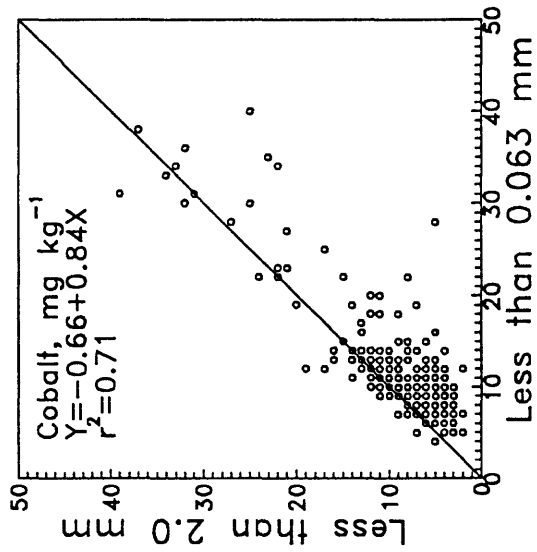


Figure 9. Cobalt.

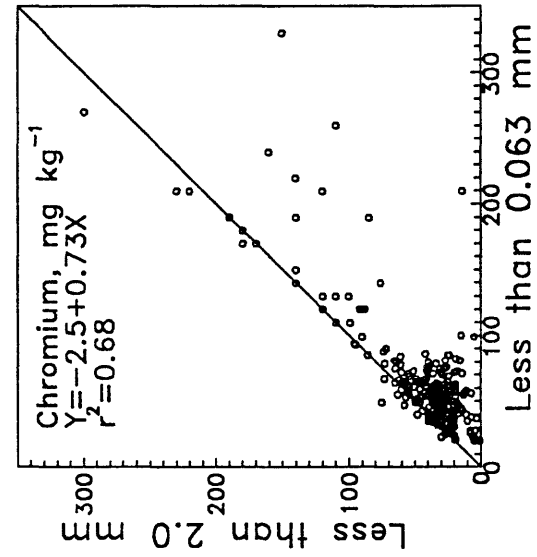


Figure 10. Chromium.

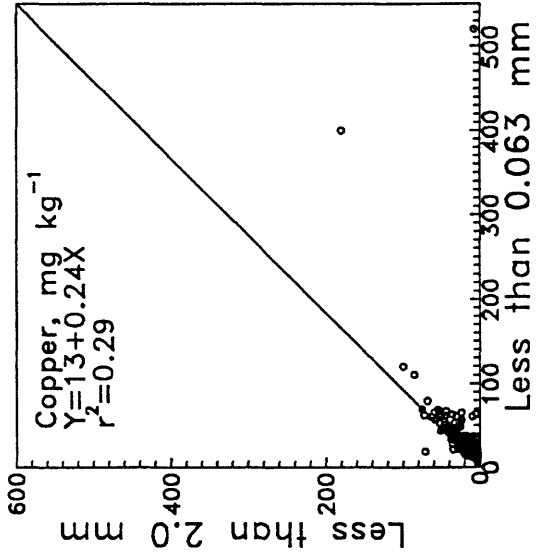


Figure 11. Copper.

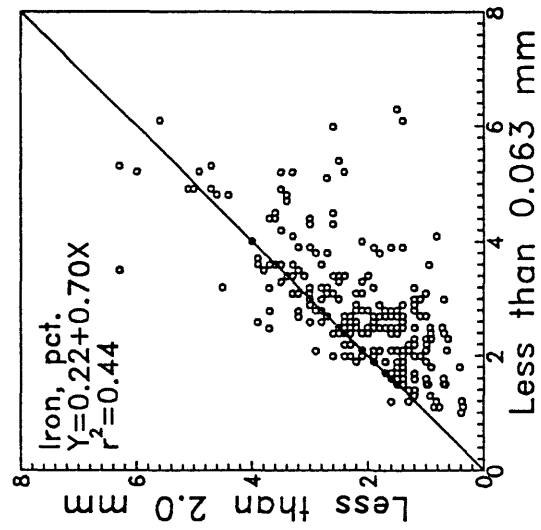


Figure 12. Iron.

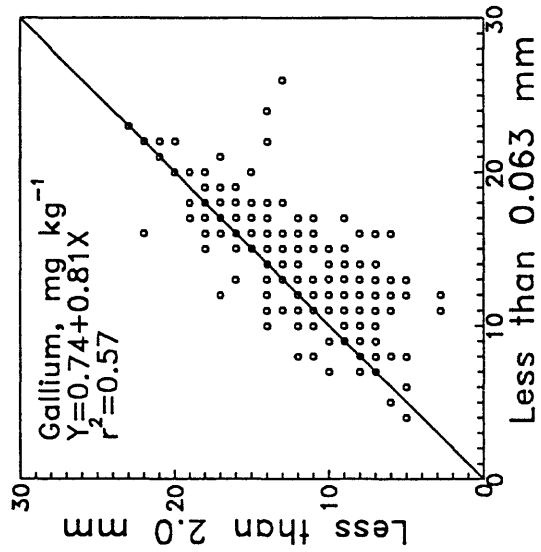


Figure 13. Gallium.

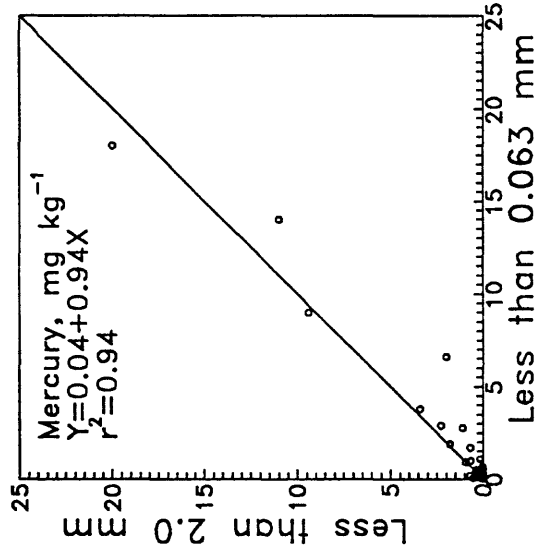


Figure 14. Mercury.

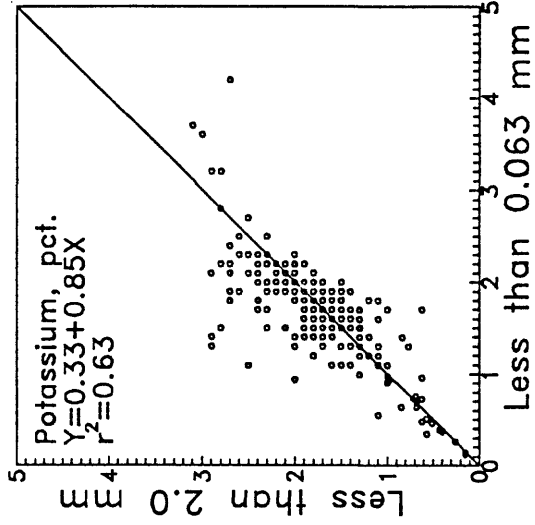


Figure 15. Potassium.

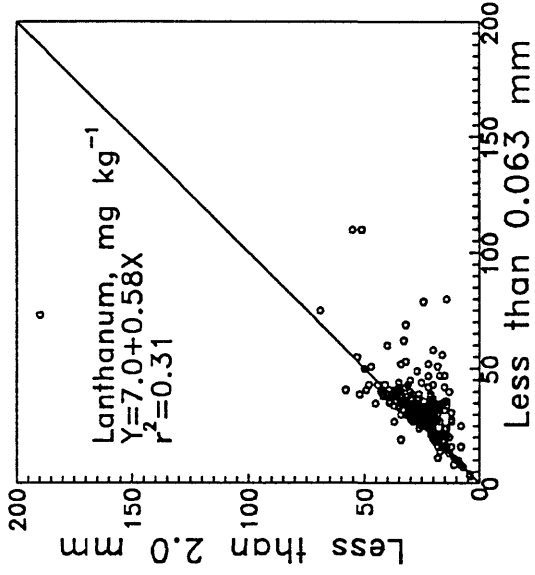


Figure 16. Lanthanum.

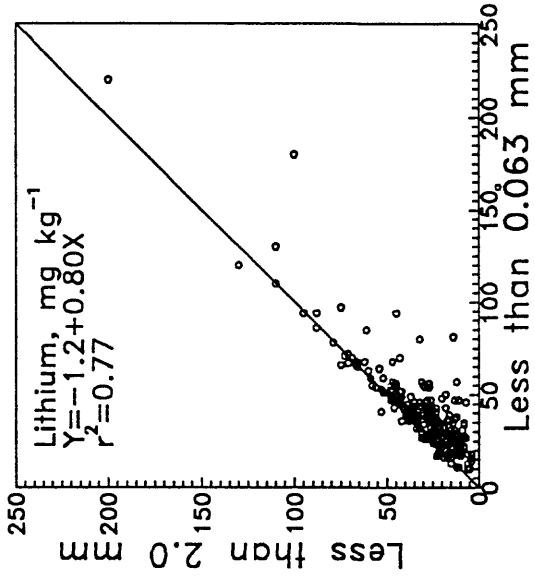


Figure 17. Lithium.

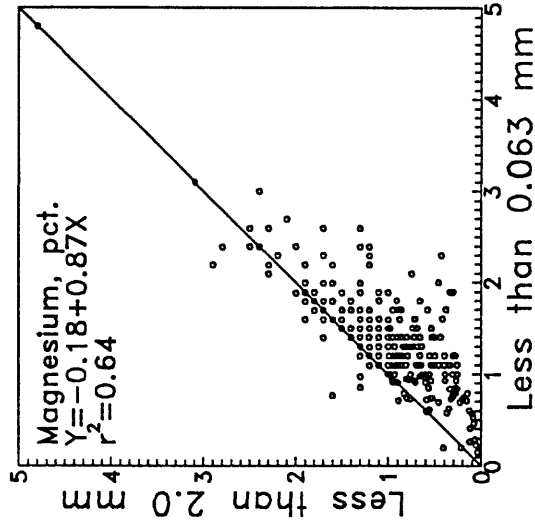


Figure 18. Magnesium.

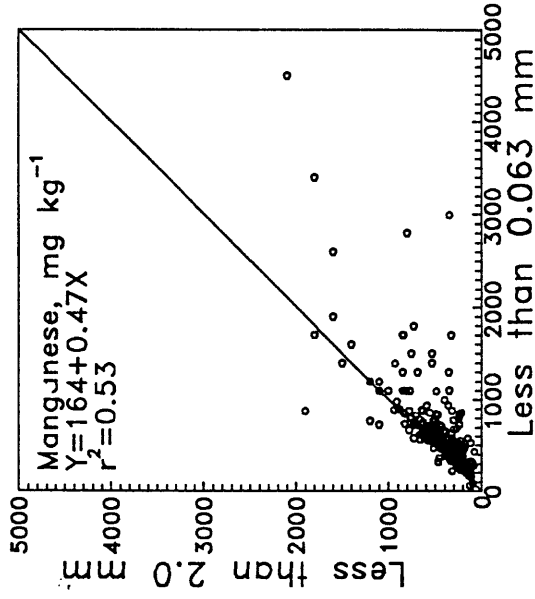


Figure 19. Manganese.

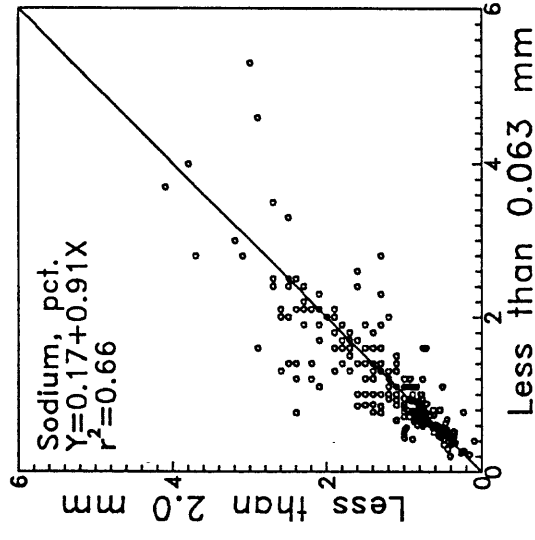


Figure 20. Sodium.

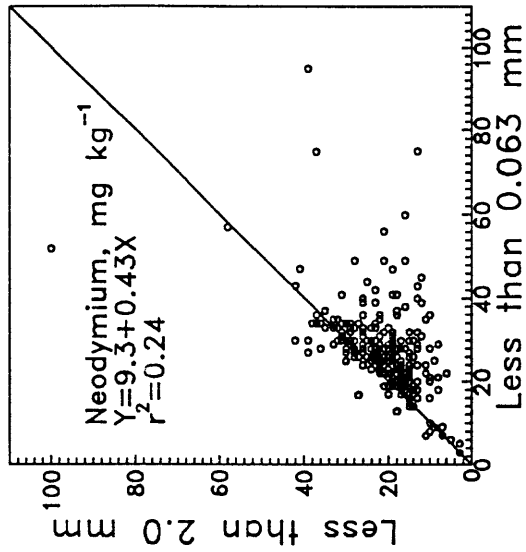


Figure 21. Neodymium.

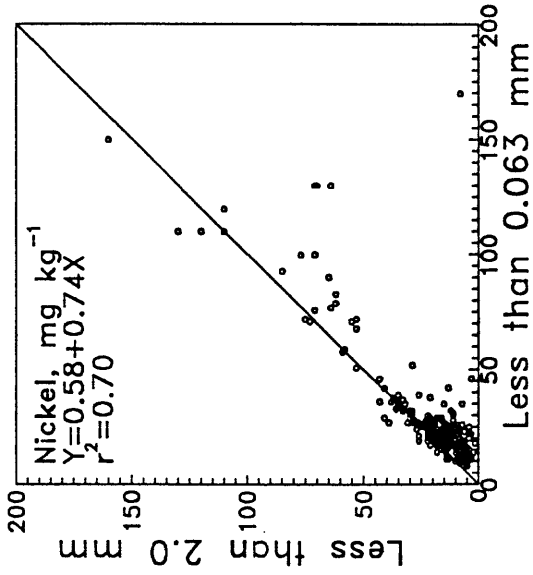


Figure 22. Nickel.

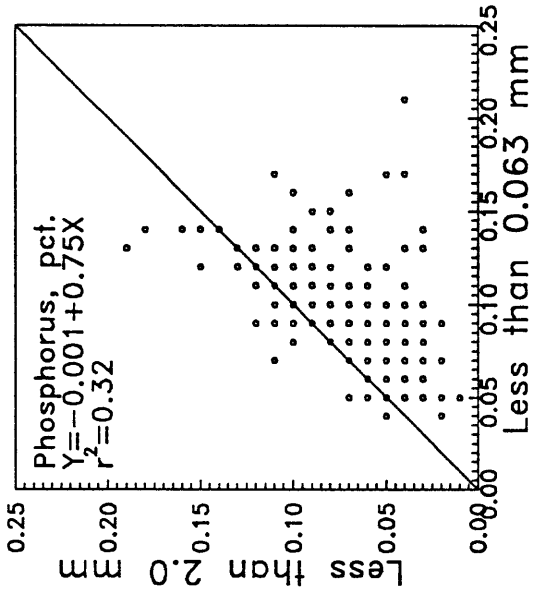


Figure 23. Phosphorus.

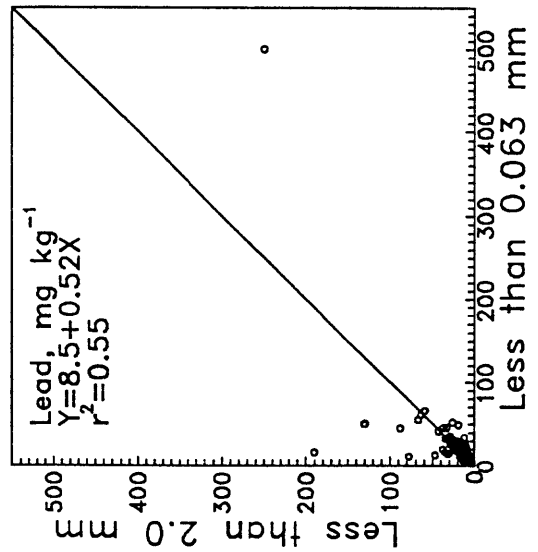


Figure 24. Lead.

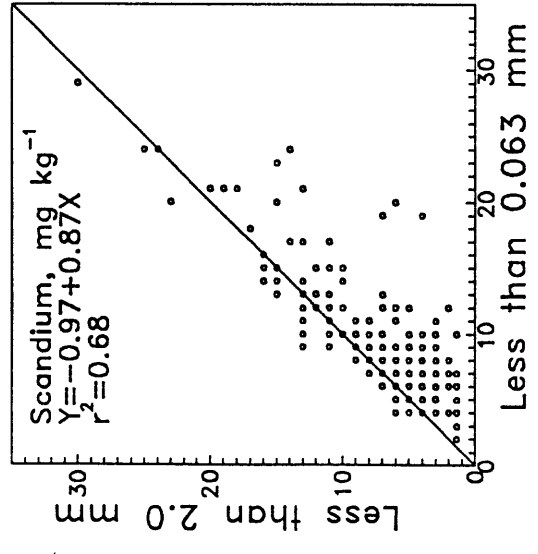


Figure 25. Scandium.

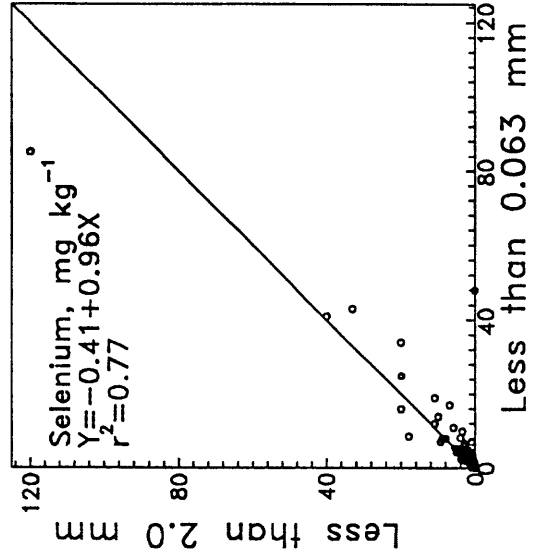


Figure 26. Selenium.

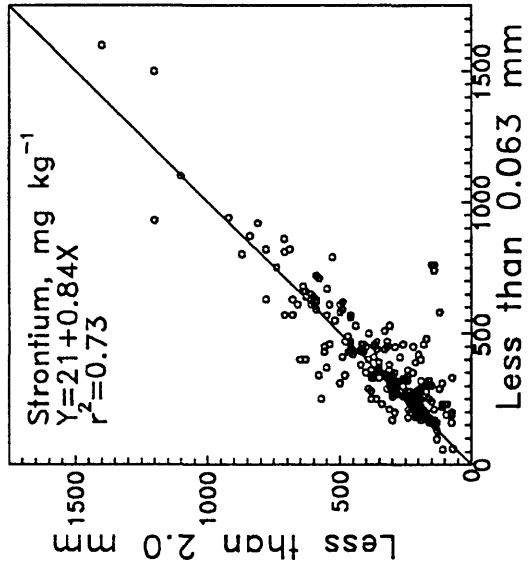


Figure 27. Strontium.

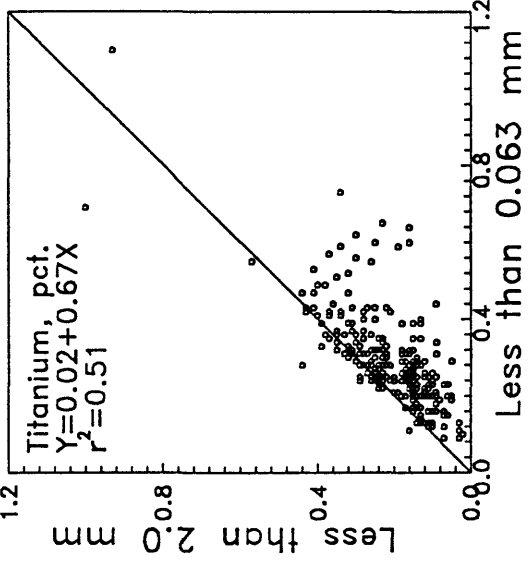


Figure 28. Titanium.

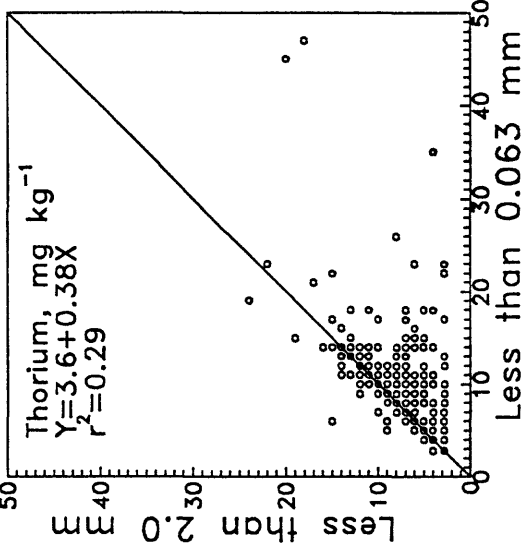


Figure 29. Thorium.

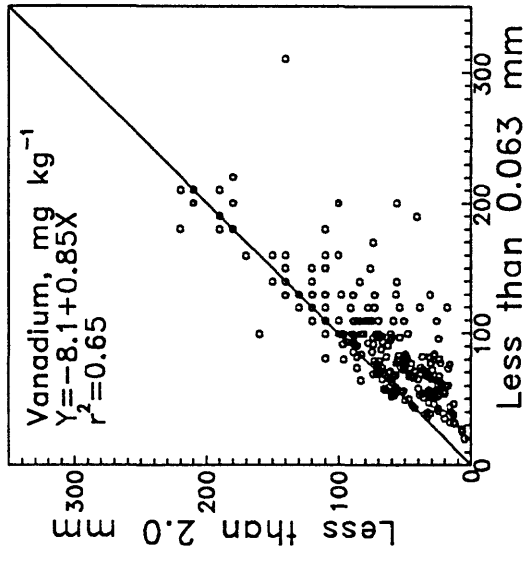


Figure 30. Vanadium.

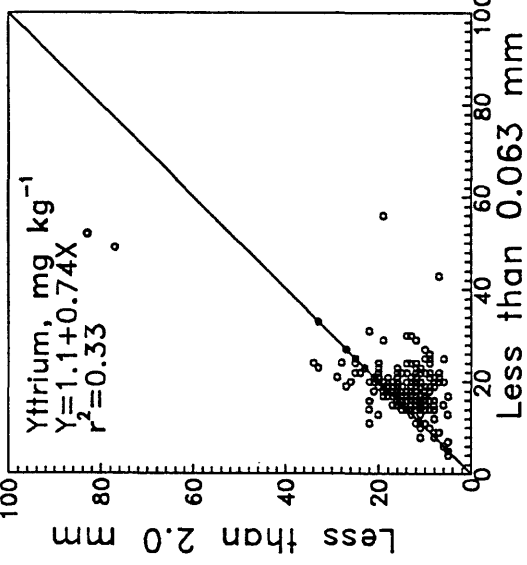


Figure 31. Yttrium.

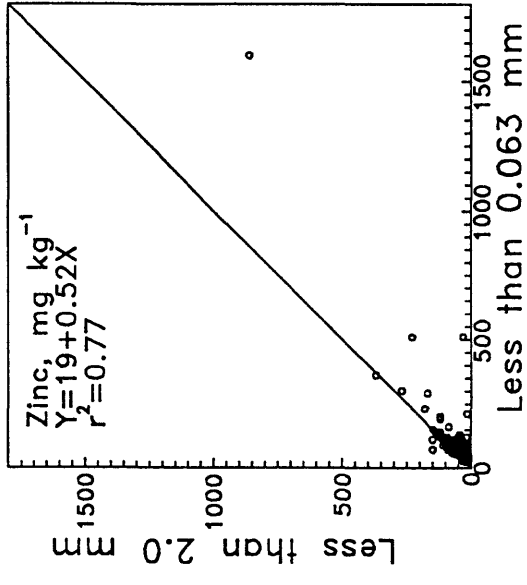


Figure 32. Zinc.

fraction would result in an under estimation of the fine fraction by 15 to 20 percent, based on the regression equations for these ten elements (Table 4).

Three elements (Fe, fig. 12; P, fig. 23; and Ti, fig. 28) show the same trends between coarse and fine sediment fractions as the ten elements discussed in the previous paragraph, but exhibit even more scatter in their data points. This results in lower coefficients of determination which range from about 0.3 to 0.5. Point plots for these three elements show enrichment of most samples in the fine sediment fraction. Enrichment varies for individual samples and a few samples show enrichment in the coarse fraction. Similar to the group of ten elements discussed previously, the large amount of scatter for these three elements results in uncertainty in collecting and analyzing either size fraction for purposes of predicting the element concentration in the other size fraction. In general, analyzing the coarse fraction would result in an underestimation of the fine fraction by 25 to 35 percent, based on the prediction equations for Fe, P, and Ti.

A group of eleven elements (As, fig. 4; Ce, fig. 8; Cr, fig. 10; Cu, fig. 11; La, fig. 16; Mn, fig. 19; Nd, fig. 21; Ni, fig. 22; Th, fig. 29; Y, fig. 31; and Zn, fig. 32) exhibit a wide range in slope (0.2 to 0.75), coefficient of determination (0.2 to 0.8), and intercept. This group of elements tends to have a large cluster of data points near the lower 25 percent of their range, and 5 to 20 data points over the remaining 75 percent of their range. The few data points at the upper end of the range greatly influence the slope, and the data point outliers greatly reduce the coefficient of determination. The point plots suggest that the data for each element might best be represented by two separate regression lines. One group of data points clusters near the 1:1 line on the plots, while the second group of data points appears to suggest significant enrichment in the fine fraction. Plots for most of the eleven elements show enrichment in the fine sediment fraction for most of the samples, with As being an exception. The point plot for As shows most samples falling near the 1:1 line with the rest showing enrichment in the coarse fraction. In order to identify the few samples with significant enrichment, it would be necessary to collect and analyze the fine sediment fraction.

The point plot for Pb (fig. 24) shows that most data points in the lower 20 percent of the observed range are clustered along the 1:1 line. Four outliers show significant enrichment in the coarse fraction, and the single outlier with the largest Pb concentration shows approximately a 2:1 enrichment in the fine fraction. The samples representing outlying data may contain fragments of lead shot used in the past for waterfowl hunting. Ignoring the five outlying data points, the plot suggests that the slope would be near one, and sampling and analyzing either the coarse or fine sediment fraction would result in no differences in interpretation of the resulting data.

Graphs for Be, Nb, and Yb are not included because most samples for these three elements were near their lower detection limits and their observed ranges were within the background range for the western United States (Table 3). Coefficients of determination for regression equations (Table 4) for these three elements were very small, and the slopes of the equations suggest enrichment in the fine fraction. However, graphs of the data would show only a random scattering of points over a narrow range of values near the lower determination limit.

In addition to considering prediction equations and point plots of data for the two sediment fractions, some information on the practical aspects of obtaining coarse and fine sediments for analysis should be considered before making a decision as to which fraction has the most utility for a reconnaissance-level study. Coarse sediment occurs in nearly any stream, lake, pond, or drainage ditch, whereas fine sediment may not always occur or may occur as such a small percentage of the bulk sediment that a large amount of sediment would need to be processed to obtain 100 to 200 g of fine sediment. A particle-size determination of the bulk sediment would be

useful in relating the element concentration in the fine-sediment fraction to the mass of the bulk sediment.

Wet sieving of a bulk sediment sample to obtain a 100 to 200 g sample of sieved material may require four liters of water which must be reduced by 75 percent for shipment to the laboratory. Concentration is done by sedimentation and decanting. The completeness of the sedimentation depends on the particle size, organic content, and ionic strength of the native water. Where the particles are large, the organic content is high, and the ionic strength is great, sedimentation occurs rapidly because of flocculation, and nearly 100 percent of the material is recovered with a sedimentation time of a few hours. On the other hand, if the particle size is small, organic content is low, and the water is of low ionic strength, sedimentation is not practical. After the material has been allowed to settle for a few days, colloids remain in suspension and are lost in the decanting process because natural flocculation does not occur. This loss of the finest fraction could substantially reduce the element concentration of the material available for analysis if adsorption on colloids was controlling element content. Analyzing a coarse sediment fraction, which also contained fine sediments, would probably result in a lower concentration value than for the fine fraction because of dilution by unreactive coarse materials. The concentration would be higher, however, than if only the coarse fraction containing no fine materials were analyzed.

Dry sieving of a sample generally results in less than 100 percent recovery of the fine fraction because of particle aggregation and this separation can not be used as an estimate of particle-size distribution. This method seems superior compared to wet sieving because no colloids are lost.

When deciding whether to analyze a coarse or fine fraction for reconnaissance studies, it is necessary to understand the behavior of elements of most interest. If the elements are largely adsorbed, then the fine fraction of the bottom material containing clays and colloidal organic matter would contain the highest proportion of adsorption sites. However, adsorption on sediment may exhibit a bimodal or other distribution where larger particles containing hydrous oxide coatings are also important adsorption sources. Some elements in sediments may be concentrated by coprecipitation processes, and they may reside in the larger sediment fractions. Data from the present reconnaissance study suggests that partitioning between coarse and fine sediment fractions is minimal for Al, B, Hg, Na, Pb (ignoring outliers), and Se. Large amounts of scatter in the data for Ba, Ca, Co, Fe, Ga, K, Li, Mg, K, Sc, Sr, Ti, and V suggest no consistent partitioning between the two sediment fractions. Plots of data for As, Ce, Cr, Cu, La, Mn, Nd, Ni, Th, Y, and Zn suggest two populations, one which shows no partitioning between sediment fractions, and another which shows enrichment in the fine fraction.

A reconnaissance study of element concentrations in sediment should consider, (1) in what sediment fraction the elements of interest are likely to occur, and (2) if the data generated are comparable to an existing data base so that unusual levels in the sediment can be identified. The existing data base of determinations for elements in the fine fraction is small. The existing data base for elements in surface soils (coarse fraction) in the western United States is large. Surface soil erosion probably contributes much material to stream and lake sediments. It seems reasonable that this readily available data base be utilized in reconnaissance studies. Although the coarse fraction of stream and lake sediment is probably not directly comparable to surface soils, the reliability should be adequate to determine whether or not bottom sediment could be considered unusual in elemental composition relative to surface soils in the reconnaissance or field-screening stage of a study.



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Table 1.--Determination limits for elements reported.

Analytical method	Determination limit	Elements
Continuous flow hydride generation	0.1 ppm	As, Se
Cold vapor atomic absorption spectroscopy	0.02 ppm	Hg
Delayed neutron activation analysis	2.0 ppm	Th
Induction coupled plasma	2.0 ppm	Ag, Cd, Eu, La, Li, Mo, Ni, Sc, Sr, V, Y, Zn
	0.05 %	Al, Ca, Fe, K, Mg, Na, P, Ti
	1.0 ppm	Ba, Be, Co, Cr, Cu, Yb
	4.0 ppm	Ce, Ga, Mn, Nb, Nd, Pb, Th
	10 ppm	Bi, Sn
Hot-water extractable	0.4 ppm	B

Table 2.--Detection ratios for trace elements in coarse and fine sediment fractions from the present study.

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed.]

Element, units	<u>Detection ratio in bottom materials</u>	
	Coarse fraction	Fine fraction
Ag, ppm	1:255	0:255
B, ppm	249:255	222:255
Be, ppm	177:255	224:255
Bi, ppm	0:255	0:255
Cd, ppm	6:255	3:255
Eu, ppm	3:255	2:255
Ga, ppm	253:255	255:255
Hg, ppm	143:255	195:255
Mo, ppm	44:255	47:255
Nb, ppm	123:255	149:255
Nd, ppm	253:255	254:255
Pb, ppm	250:255	249:255
Sc, ppm	239:255	255:255
Se, ppm	245:255	251:255
Sn, ppm	3:255	9:255
Th, ppm	212:255	237:255
Yb, ppm	217:255	247:255

Table 3.--Geochemical baselines for soils from the western United States and observed ranges for coarse and fine sediment fractions from the present study.

[Baseline, expected 95-percent range]

Element, units	Baseline <sup>1</sup>		Observed range in bottom material			
			Coarse fraction		Fine fraction	
Al, %	1.5	- 23	1.0	- 9.6	2.0	- 9.8
As, ppm	1.2	- 22	0.6	- 59	0.6	- 120
Ba, ppm	200	-1,700	56	-1,900	32	-2,200
Be, ppm	0.13	- 3.6	<1.0	- 3.0	<1.0	- 3.0
Ca, %	0.19	- 17	0.23	- 20	0.51	- 20
Ce, ppm	22	- 190	7.0	- 290	6.0	- 210
Co, ppm	1.8	- 28	2.0	- 39	4.0	- 40
Cr, ppm	8.5	- 200	1.0	- 300	20	- 330
Cu, ppm	4.9	- 90	3.0	- 180	5.0	- 520
Fe, %	0.55	- 8.0	0.36	- 6.3	1.0	- 6.3
Ga, ppm	5.7	- 45	<4.0	- 23	4.0	- 26
Hg, ppm	0.009	- 0.25	<0.02	- 20	<0.02	- 18
K, %	0.38	- 3.2	0.15	- 3.1	0.12	- 4.2
La, ppm	8.4	- 110	4.0	- 190	3.0	- 110
Li, ppm	8.8	- 55	4.0	- 200	10	- 220
Mg, %	0.15	- 3.6	0.04	- 4.8	0.15	- 4.8
Mn, ppm	97	-1,500	80	-2,100	66	-4,500
Mo, ppm	0.18	- 4.0	<2.0	- 54	<2.0	- 73
Na, %	0.26	- 3.7	0.1	- 8.5	0.2	- 5.3
Nb, ppm	2.6	- 29	<4.0	- 12	<4.0	- 15
Nd, ppm	12	- 110	<4.0	- 100	<4.0	- 95
Ni, ppm	3.4	- 66	<2.0	- 160	8.0	- 170
P, %	0.006	- 0.17	0.01	- 0.41	0.04	- 0.21
Pb, ppm	5.2	- 55	<4.0	- 250	<4.0	- 500
Sc, ppm	2.7	- 25	<2.0	- 30	2.0	- 29
Se, ppm	0.039	- 1.4	<0.1	- 120	<0.1	- 85
Sr, ppm	43	- 930	69	-1,400	59	-1,600
Ti, %	0.069	- 0.70	0.02	- 1.0	0.09	- 1.1
Th, ppm	4.1	- 20	<4.0	- 24	<4.0	- 47
V, ppm	18	- 270	5.0	- 220	20	- 310
Y, ppm	8.0	- 60	5.0	- 83	4.0	- 56
Yb, ppm	0.98	- 6.9	<1.0	- 4.0	<1.0	- 5.0
Zn, ppm	17	- 180	10	- 860	23	-1,600

<sup>1</sup>Shacklette and Boerngen, 1984

Table 4.--Regression equations between elements in coarse (dependent variable) and fine (independent variable) fractions of sediment from nineteen areas of the western United States based on the model  $Y = mX + b$ .

Variable, and units	Slope <i>m</i>	Intercept <i>b</i>	Coefficient of Determination <i>r</i> <sup>2</sup>
Aluminum, %	0.93	-0.17	0.70
Arsenic, ppm	0.62	2.28	0.60
Barium, ppm	0.81	106	0.59
Beryllium, ppm	0.50	0.48	0.10
Boron, ppm	0.83	0.08	0.96
Calcium, %	0.74	0.32	0.62
Cerium, ppm	0.52	14.5	0.30
Cobalt, ppm	0.84	-0.66	0.71
Chromium, ppm	0.73	-2.5	0.68
Copper, ppm	0.24	13.3	0.29
Gallium, ppm	0.81	0.74	0.57
Iron, %	0.70	0.22	0.44
Lanthanum, ppm	0.58	7.0	0.31
Lead, ppm	0.52	8.5	0.55
Lithium, ppm	0.80	-1.2	0.77
Magnesium, %	0.87	-0.18	0.64
Manganese, ppm	0.47	164	0.53
Mercury, ppm	0.94	0.04	0.94
Neodymium, ppm	0.43	9.3	0.24
Nickel, ppm	0.74	0.58	0.70
Niobium, ppm	0.47	1.7	0.23
Phosphorus, %	0.75	0.001	0.32
Potassium, %	0.85	0.33	0.63
Scandium, ppm	0.87	-0.97	0.68
Selenium, ppm	0.96	-0.41	0.77
Sodium, %	0.91	0.17	0.66
Strontium, ppm	0.84	21	0.73
Thorium, ppm	0.38	3.6	0.29
Titanium, %	0.67	0.02	0.51
Vanadium, ppm	0.85	-8.1	0.65
Ytterbium, ppm	0.27	0.98	0.06
Yttrium, ppm	0.74	1.1	0.33
Zinc, ppm	0.52	18.9	0.77