The Distribution of MVT-related Metals in Acid-insoluble Residues of Paleozoic Rocks in the Ozark Plateaus Region of the United States

by Lopaka Lee and Martin B. Goldhaber[1]

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THE DISTRIBUTION OF MVT-RELATED METALS IN ACID-INSOLUBLE RESIDUES OF ROCKS IN THE OZARK PLATEAUS REGION OF THE UNITED STATES

by Lopaka Lee and Martin B. Goldhaber

INTRODUCTION

This report is a compilation of figures and tables that show the spatial and statistical distribution of elemental concentrations of As, Cd, Co, Cu, Cr, Ni, Pb, and Zn in acid-insoluble residues of rocks from the Ozark Plateaus region of the United States.

The figures and graphs of this report are based on a database that contains over 17,500 rock samples from 285 different boreholes scattered throughout the Ozark region. Collectively, this dataset contains samples representative of almost every Paleozoic rock unit in the Ozark region.

This report is part of a USGS parent project that is focused on characterizing the effects of MVT mineralization on the background groundwater chemistry of the Ozark Plateaus region of the United States (Lee, 2000). The first phase of the parent study involved the investigation of spatial and statistical relationships between MVT-related metals in rocks and groundwater. The figures and tables of this report are centered on characterizing, on a regional level, the spatial and statistical distribution of MVT-related metals in aquifer rocks. A companion open-file report that shows the spatial and statistical distribution of MVT-related metals in groundwater of the Ozark region is concurrently being published under the title *The distribution of dissolved MVT-related metals in groundwater of the Ozark Plateaus region of the United States.*

A minimal amount of interpretations of the figures and tables of this report are provided within the text. A detailed interpretation of this data, as it relates to the effects of MVT mineralization on the natural-background groundwater chemistry of the Ozark region, is available in available in Lee (2000).

The scope of this report is regional. Summaries of this report's dataset that focus on local-scale variations, such as metal variation along individual borehole lengths, are included in other USGS reports (Erickson and others 1978a, 1981, 1985, 1988a, 1990).

DESCRIPTION OF THE DATASET

The dataset that this report is based upon was generated during the USGS Conterminous U.S. Mineral Assessment Program (CUSMAP) of the Ozark region. This program evaluated the mineral resource potential of selected 1x2 degree quadrangles within the Ozarks (Erickson and others 1978b, 1988b, 1991).

A sub-project of the CUSMAP program was centered on identifying MVT-mineralizing fluid pathways, and highly mineralized ground throughout the Ozark region (Erickson and others 1978b). The primary research approach of this project was to chemically isolate and analyze the acid (HCl)-insoluble residues of borehole rock samples. The acid-insoluble residues of rocks were isolated and analyzed because MVT sulfides, and therefore MVT-related metals are concentrated within this rock fraction (Erickson and others, 1981).

The rock samples from which the acid-insoluble residues are derived were obtained from boreholes distributed throughout the Ozarks (Figure 1.0). Individual rock samples are composites representative of every 10ft of borehole interval.

The chemical analyses performed on the insoluble residues are semi-quantitative, elemental-abundance analyses. Thirty-two chemical elements were determined using a DC-arc spectrometer (Grimes and Marranzino, 1968). Elemental concentrations are reported as classed values in six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, and 0.15). Thus, elemental determinations can have values of 3, 5, 7, 10, 15, 20,… parts per-million (ppm). Concentration determinations range from 3 to 20,000 ppm, with specific element ranges and detection limits set to encompass distributions typical to the region.

The precision of the chemical determinations is within one adjoining step on each side of the reported value 83 percent of the time, and within two adjoining steps on each side of the reported value 96 percent of the time (Grimes and Marranzino, 1968).

The CUSMAP data used in this report were obtained from the USGS National Geochemical Database.

DATA COMPILATION

This report utilizes 17,703 acid-insoluble residues of rock samples from 285 different boreholes of the original CUSMAP dataset. Most of these boreholes are contained within the Joplin, Springfield, Harrison, and Rolla 1 by 2 degree quadrangles (Figure 1.0).

Eight MVT-related metals were chosen for investigation: arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn). These elements were chosen because: 1) they represent a metal suite characteristic of MVT mineralization that differs from elements intrinsic to the lithology of the region, and 2) all were determined in both the rock and water chemical analyses used within the parent project with which this report is associated.

The data were compiled by first obtaining the digital records from the USGS National Geochemical Database and checking the dataset for data-entry errors. Latitudes and longitudes were checked against published maps and paper records on file. The analytical values reported within the dataset were also compared to paper records.

The geologic formation names of samples were then reclassified according to the standard stratigraphic code developed by the USGS and adopted and published by the Association of America Petroleum Geologists (AAPG) (Cohee, 1967, 1974). The AAPG standard stratigrahic code is used in the USGS Water Resource Division's ground-water information databases, and therefore geologic comparisons between rock and water-chemistry could be easily made between rock and groundwater databases.

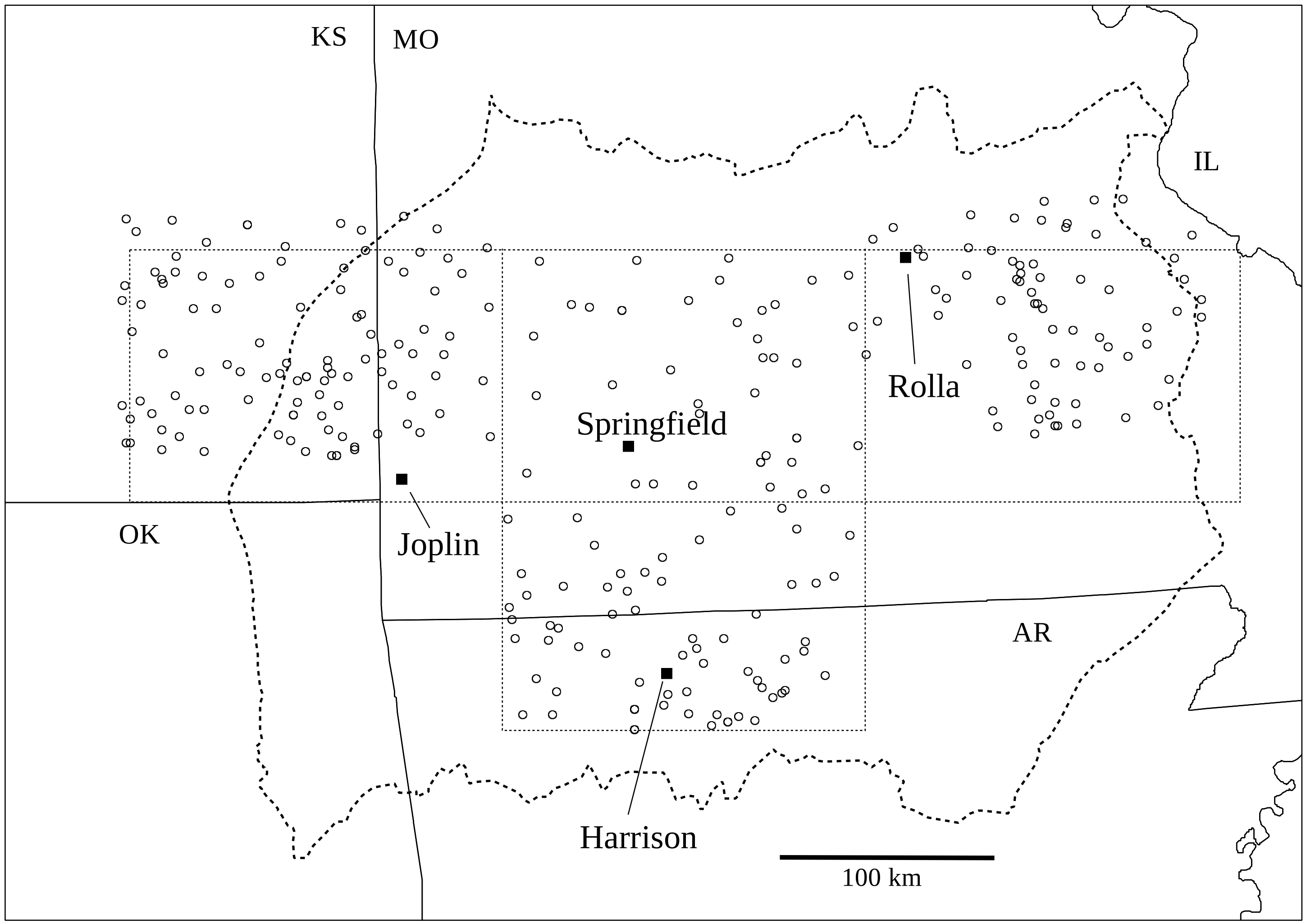

Figure 1.0 The Ozark Plateaus physiographic province and the location of USGS CUSMAP boreholes.
Shown are the cities of Joplin, Springfield, Harrison, and Rolla within their respective 1 by 2 degree quadrangles.

THE SPATIAL DISTRIBUTION OF MVT-RELATED METALS ROCKS OF THE OZARK REGION

The spatial distribution of MVT-related metals in rocks was investigated through 2-D mapping and 3-D geologic modeling. The following sections discuss these methods.

TWO-DIMENTIONAL MAPS OF THE CONCENTRATIONS OF METALS IN OZARK REGION ROCKS

Figures 2.0 through 2.7 show the 2-D spatial distribution of As, Cd, Co, Cu, Cr, Ni, Pb and Zn in the acid-insoluble residues of rock samples. The figures are elemental-concentration maps that show the sites at which MVT-related metals were detected in insoluble residues.

INTERPRETATIONS OF 2-D MAPS

In general, elevated concentrations of MVT metals in rocks form trends that coincide with the major structural zones of the Ozark region. Elevated concentrations of MVT metals are associated with the St. Francois Mountains, Central-Missouri Tectonic Zone, Bolivar-Mansfield Tectonic Zone, and the Chesapeake Tectonic Zone.

High Zn concentrations (up to 10,000ppm) are clustered within the northern-Arkansas Chesapeake Tectonic Zone (Figure 2.7). High Cd concentrations (up to 500ppm) are also associated with this area (Figure 2.1). Cd is the most abundant minor constituent of Ozark region sphalerite (Hagni, 1983), and the correlation of Zn and Cd in this area suggests that sphalerite may make up a significant proportion of insoluble residues. Binocular examinations of the insoluble residues tend confirm this; residues with high Zn and Cd content commonly contain visible sphalerite (R. Erickson, unpub. data).

High Pb concentrations (2000ppm) occur scattered throughout the Ozark region, but are consistently higher along structural trends (Figure 2.6). Many sites with high Pb are also high in As (Figure 2.0). Clusters of high Pb and As concentrations are associated with the southern extent of the Bolivar-Mansfield Tectonic zone and the northern-Arkansas Chesapeake Tectonic Zone. Very high Cu concentrations (>7000ppm) occur scattered throughout the Ozark region (Figure 2.4). Co, Cr, and Ni distributions show that these metals are frequently detected low concentrations (Figures 2.2, 2.3, 2.5). However, throughout the Ozarks high concentrations of Co, Cr, and Ni are associated with the major structural zo nes of the Ozark region.

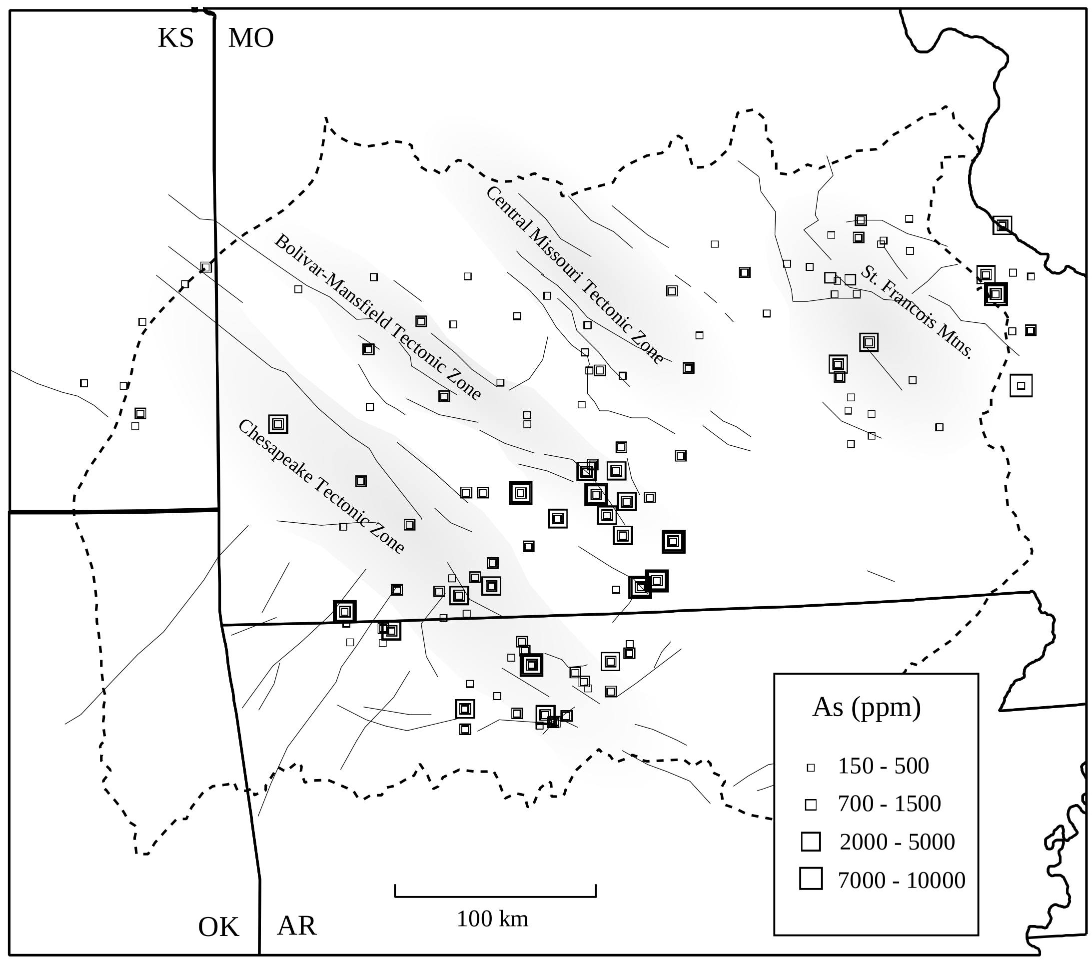

Figure 2.0 Plan-view distribution of As in acid-insoluble residues of borehole rock samples. Plot shows sites at which As was detected in concentrations greater than 150ppm. Multiple values at individual sites are overprinted.

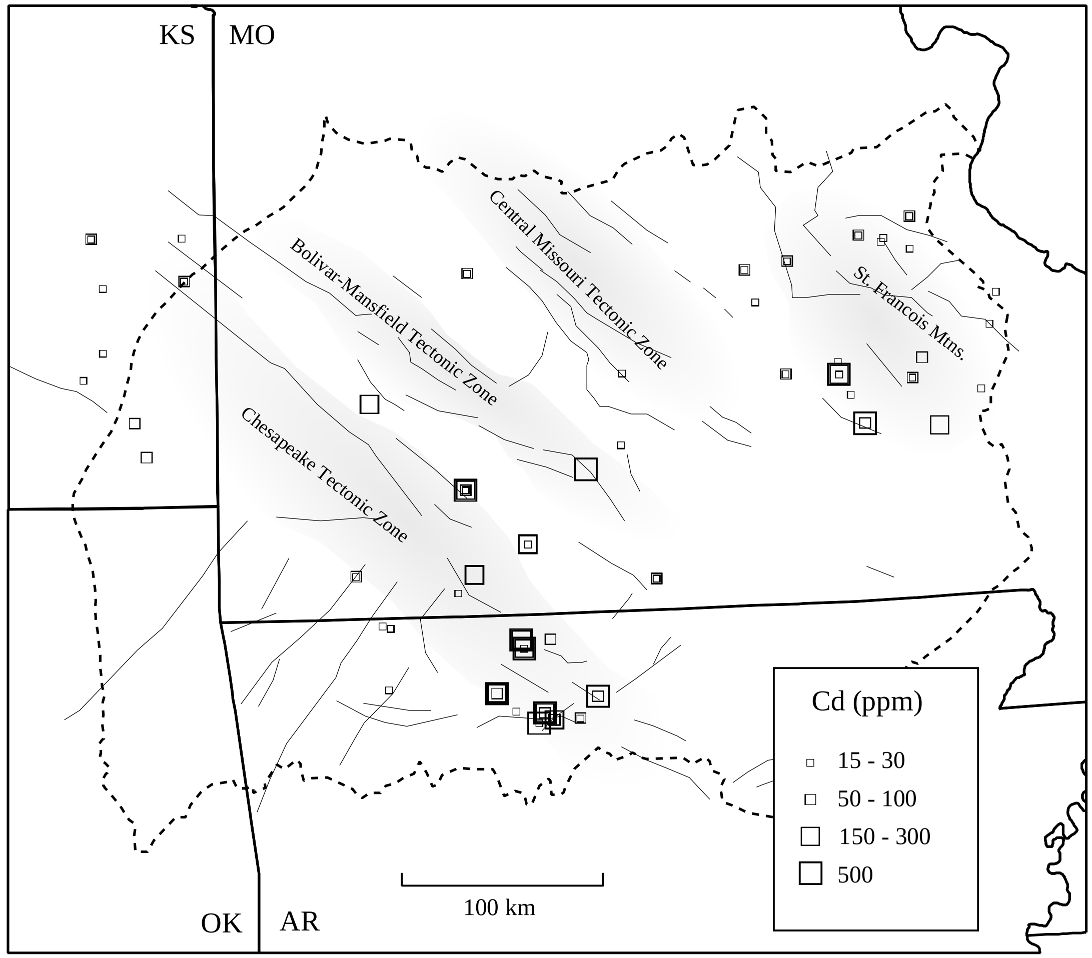

Figure 2.1 Plan-view distribution of Cd in acid-insoluble residues of borehole rock samples. Plot shows sites at which Cd was detected in concentrations greater than 15ppm. Multiple values at individual sites are overprinted.

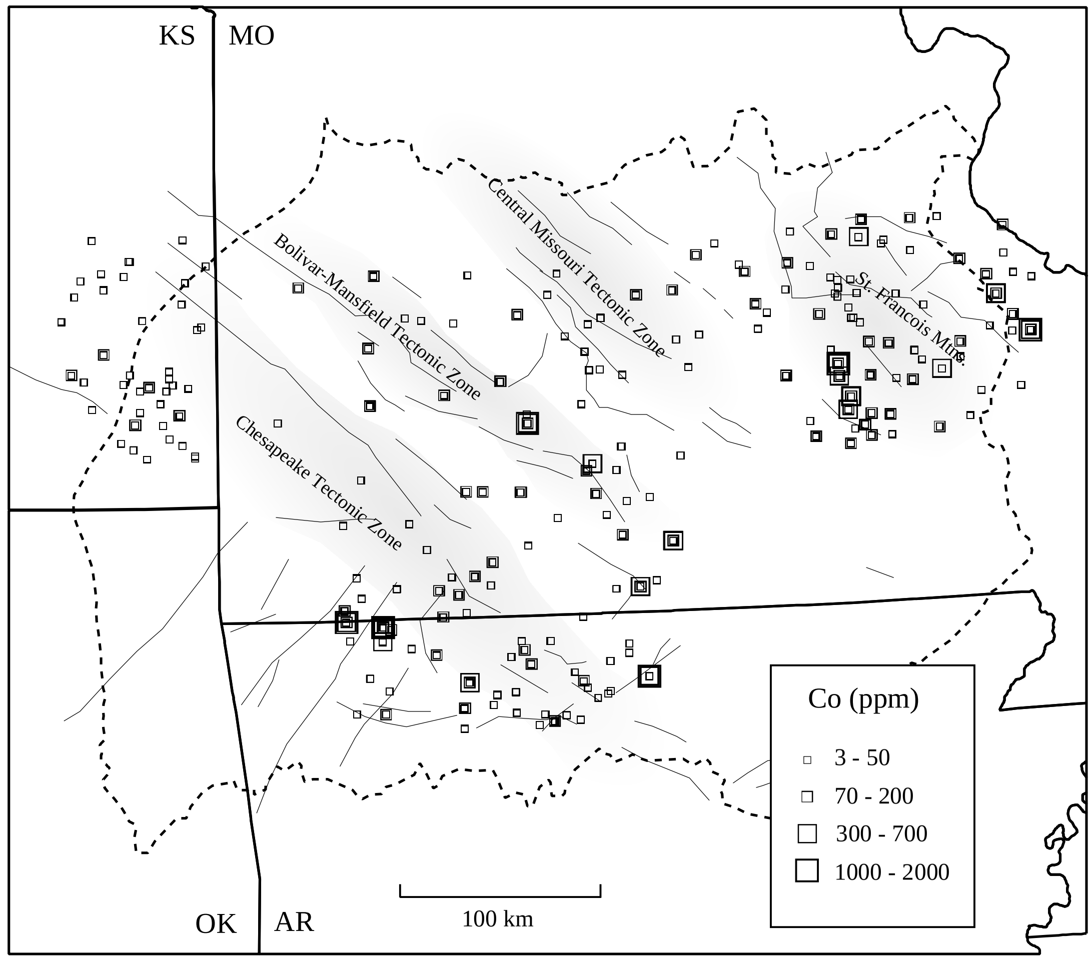

Figure 2.2 Plan-view distribution of Co in acid-insoluble residues of borehole rock samples. Plot shows sites at which Co was detected in concentrations greater than 3ppm. Multiple values at individual sites are overprinted.

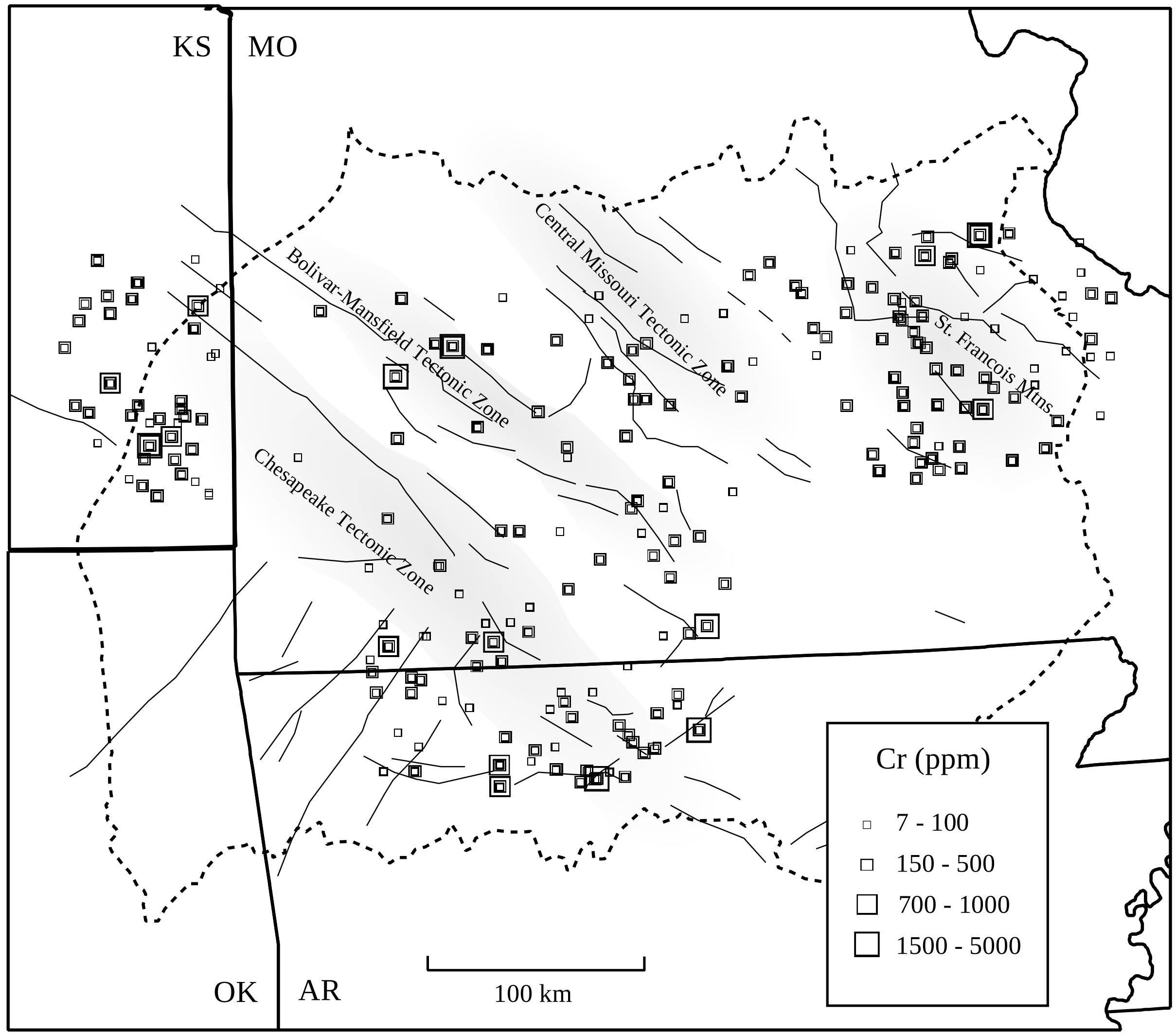

Figure 2.3 Plan-view distribution of Cr in acid-insoluble residues of borehole rock samples. Plot shows sites at which Cr was detected in concentrations greater than 7ppm. Multiple values at individual sites are overprinted.

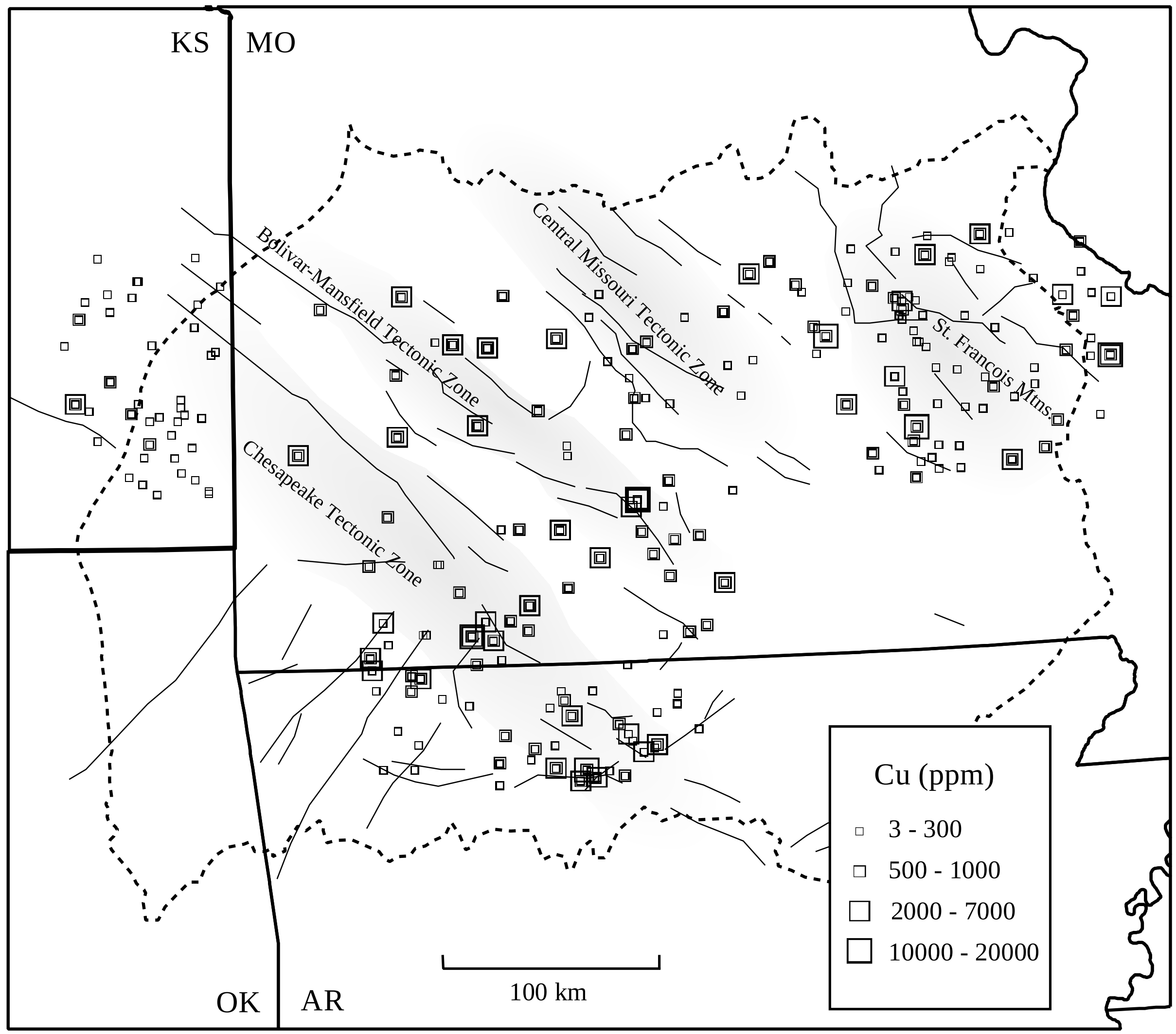

Figure 2.4 Plan-view distribution of Cu in acid-insoluble residues of borehole rock samples. Plot shows sites at which Cu was detected in concentrations greater than 3ppm. Multiple values at individual sites are overprinted.

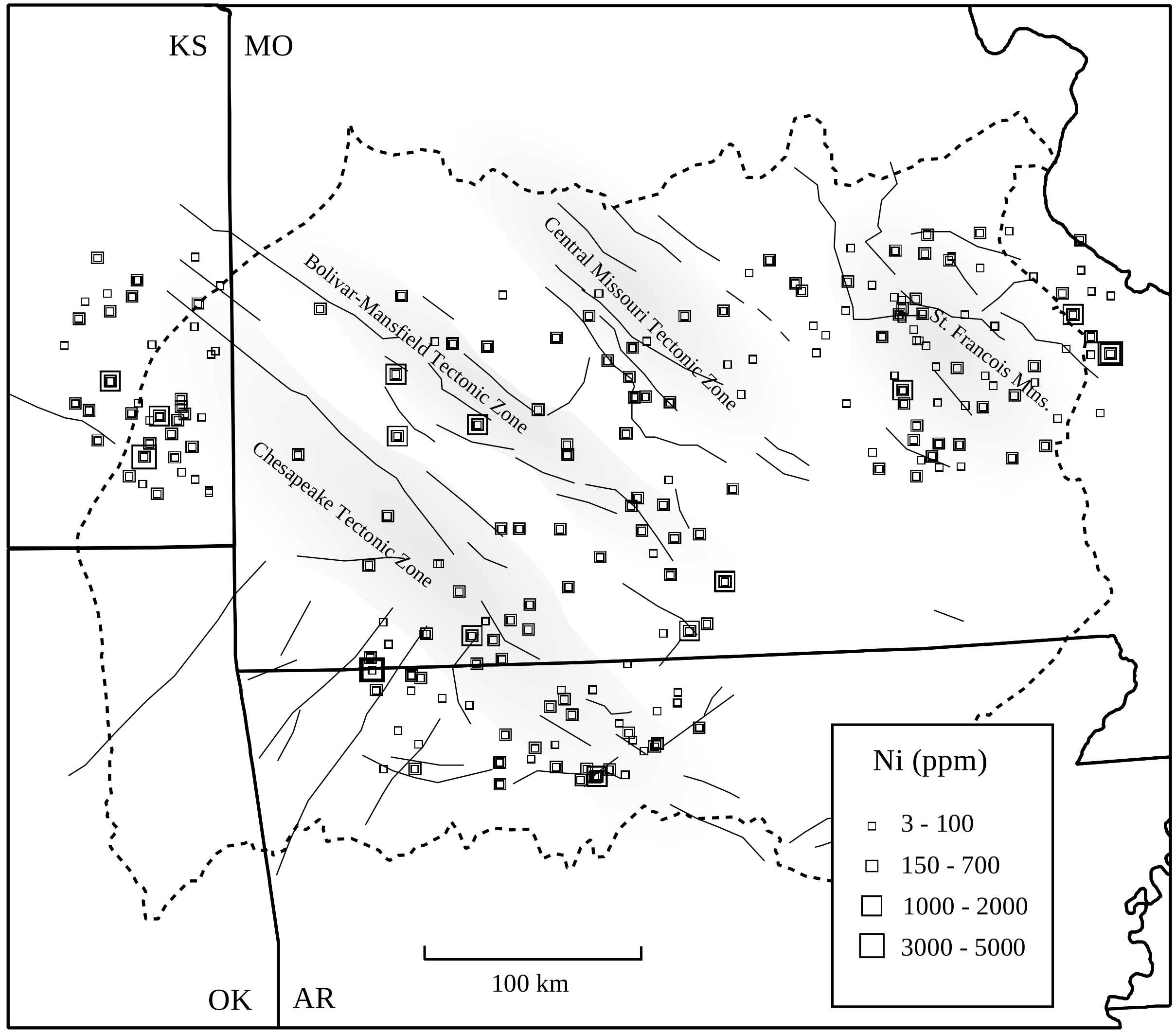

Figure 2.5 Plan-view distribution of Ni in acid-insoluble residues of borehole rock samples. Plot shows sites at which Ni was detected in concentrations greater than 3ppm. Multiple values at individual sites are overprinted.

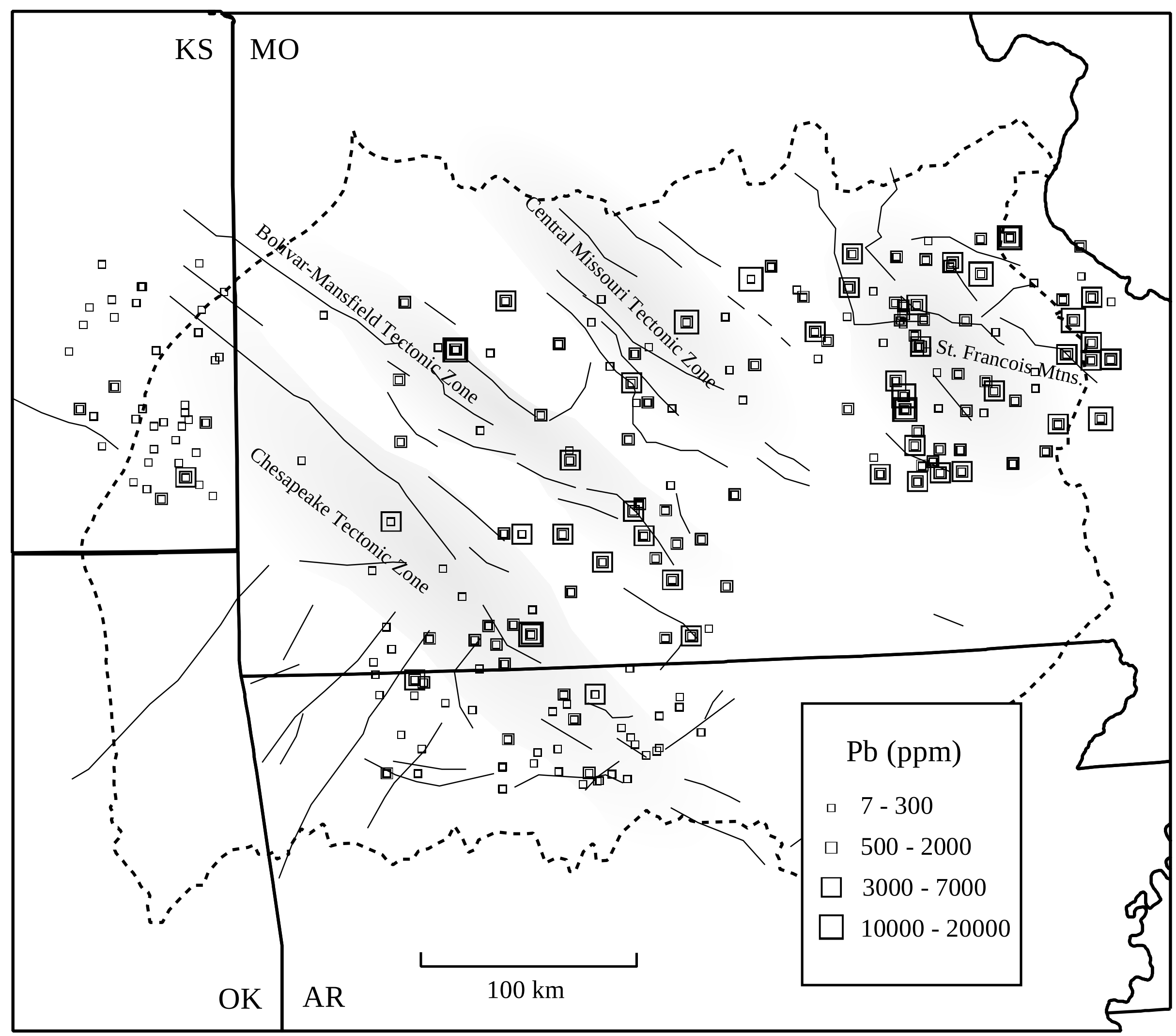

Figure 2.6 Plan-view distribution of Pb in acid-insoluble residues of borehole rock samples. Plot shows sites at which Pb was detected in concentrations greater than 7ppm. Multiple values at individual sites are overprinted.

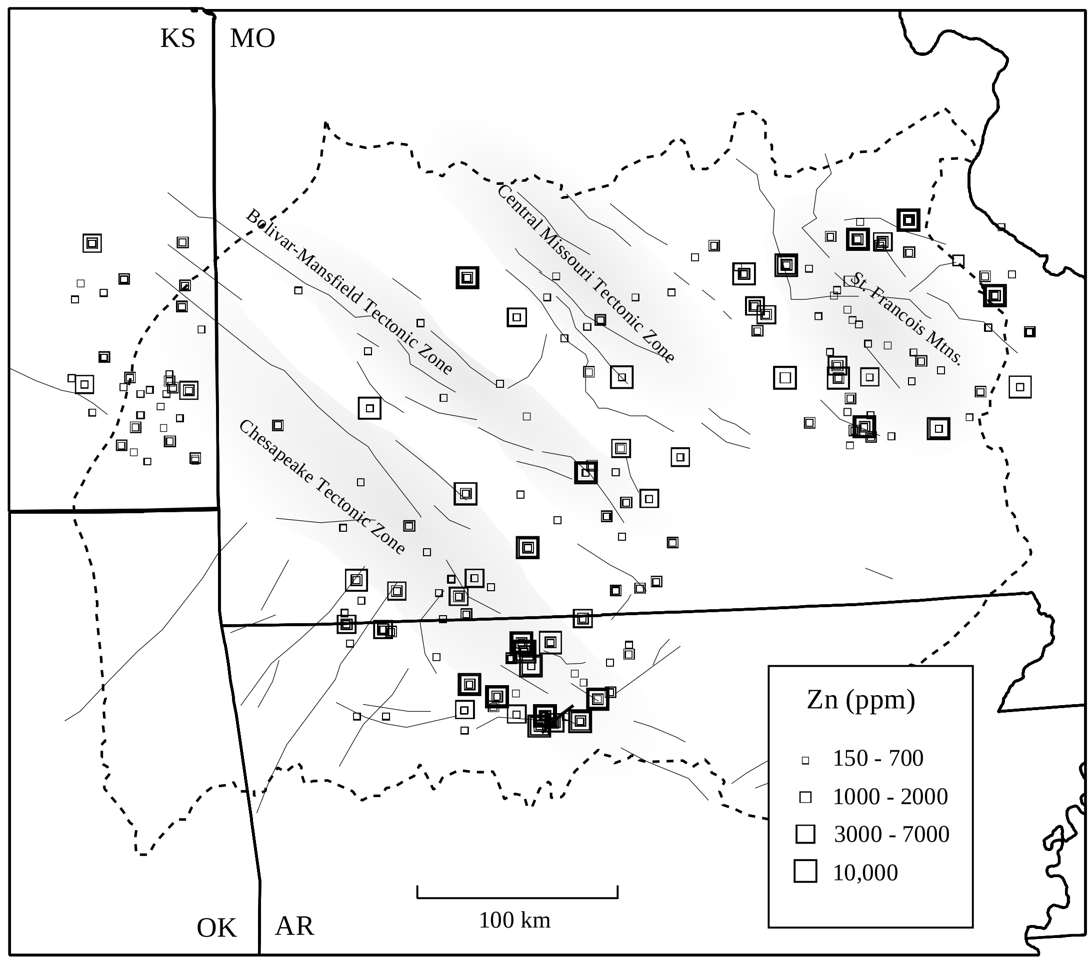

Figure 2.7 Plan-view distribution of Zn in acid-insoluble residues of borehole rock samples. Plot shows sites at which Zn was detected in concentrations greater than 150ppm. Multiple values at individual sites are overprinted.

THREE-DIMENSIONAL VISUALIZATIONS OF THE CONCENTRATIONS OF METALS IN ROCKS OF THE CENTRAL OZARKS REGION

The spatial occurrence of MVT-related metals was also investigated through 3-D geologic modeling. A 3-D hydrogeologic model of the central portion of the Ozark region was used to characterize the 3-dimentional distribution of metals within the context of hydrostratigraphy. The central Ozarks area was chosen for 3-D visualization because a significant dissolved-metal anomaly existed in groundwater of this area (Lee, 2000).

Figures 2.8 and 2.9 show the 3-D distribution of Zn and Pb within the hydrostratigraphy the Ozarks. Each figure is a 3-D cross-sectional view of the central portion of the Ozark Uplift. The surfaces of the model are the tops of the regional aquifers made semi-transparent. Vertical exaggeration is approximately 40x. The enlarged red blocks within the model are the locations of insoluble residues that contain greater than a specified cut-off concentration. Cut-off concentrations were used because they simplify the visualizations by reducing the number of points displayed, and therefore more clearly show where high concentrations of metals occur and their associated trends.

In this report, Zn and Pb are the only MVT metals displayed in 3-D figures. The 3-D distribution of other metals may be inferred from the 2-D maps of section 2.1.0, and the statistics of section 3.0.

INTERPRETATION OF 3-D VISUALIZATIONS

Figure 2.8 shows that the high concentrations of Zn in rocks of northern Arkansas (defined in Figure 2.7) occur in the *upper* Ozark aquifer unit. Specifically, high Zn concentrations occur in the near surface to surface rocks of southern Missouri/ northern Arkansas. Similar 3-D visualizations showed that Cd concentrations have distribution patterns almost identical to Zn.

Figure 2.9 shows that the high Pb concentrations in rocks are also associated with the upper Ozark aquifer unit in the same area containing high Zn concentrations. However, overall, high Pb concentrations tend to occur lower in the section. For example, the high lead concentrations associated with the Bolivar-Mansfield Tectonic Zone (defined in figure 2.6) occur low in the hydrologic section of northern Arkansas/southern Missouri. The remaining MVT metals have 3-D distribution patterns similar to lead.

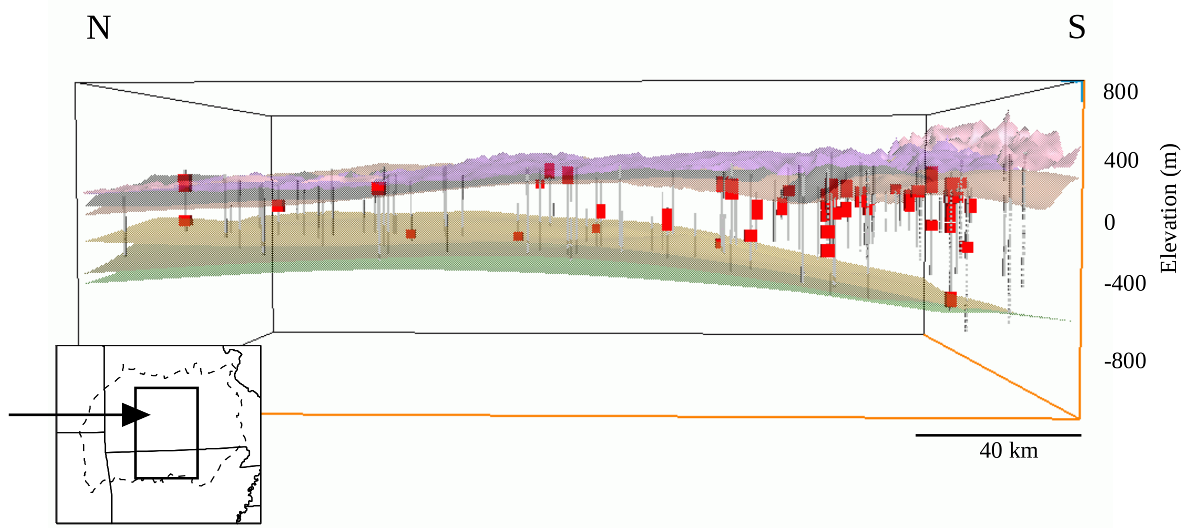

Figure 2.8 3D cross-sectional view of the central portion of the Ozark Uplift. Inset box shows the areal extent of the 3D model and view direction. The view is looking to the east, down the axial crest of the Ozark uplift. The Boston Mountains and the edge of the Arkoma Basin can be seen to the south. The surfaces of the model are the tops of the regional aquifer units of the Ozark Aquifer System. Vertical exaggeration is approximately 40X. The large space in the interior of the model is the Ozark aquifer unit. The location of insoluble residue samples is shown along the trace of boreholes which form vertical drop lines.

The enlarged red blocks are the locations of insoluble residues that contain >10,000ppm Zn. High concentrations of Zn occur in the *upper* portions of the Ozark aquifer system. The surface and near-surface rocks of northern Arkansas contain an abundance of zinc and cadmium, indicating the presence of sphalerite in rocks.

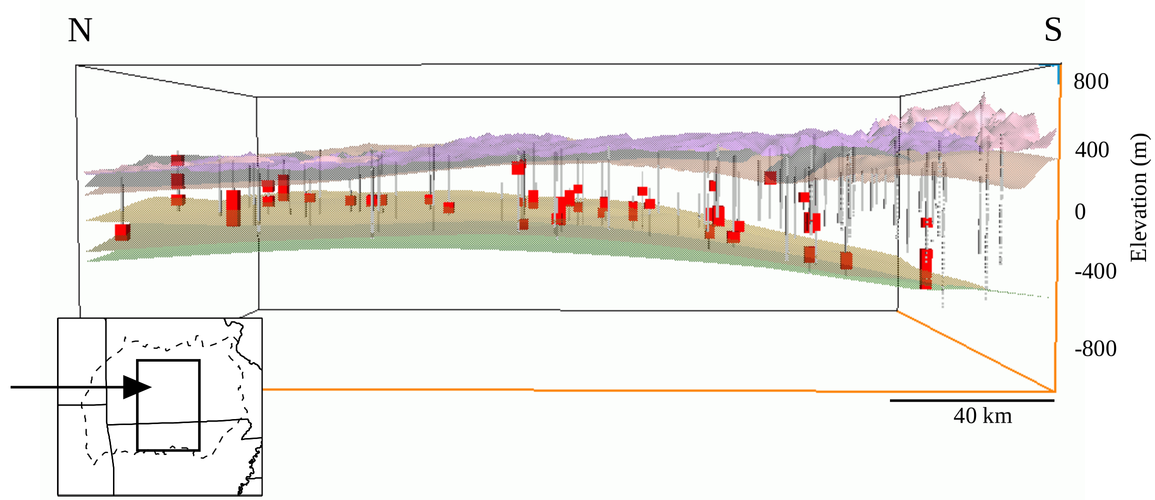

Figure 2.9 3D cross-sectional view of the central portion of the Ozark Uplift. Inset box shows the areal extent of the 3D model and view direction. The view is looking to the east, down the axial crest of the Ozark uplift. The Boston Mountains and the edge of the Arkoma Basin can be seen to the south. The surfaces of the model are the tops of the regional aquifer units of the Ozark Aquifer System. Vertical exaggeration is approximately 40X. The large space in the interior of the model is the Ozark aquifer unit. The location of insoluble residue samples is shown along the trace of boreholes which form vertical drop lines.

The enlarged red blocks are the locations of insoluble residues that contain >700ppm Pb. High concentrations of Pb and most other MVT-related metals are concentrated in the *lower* portions of the Ozark Aquifer System.

THE STATISTICAL DISTRIBUTION OF MVT-RELATED METALS IN ACID-INSOLUBLE RESIDUES OF OZARK REGION ROCKS

The statistical distribution of MVT-related metals by geologic and hydrologic unit was characterized through concentration-detection frequency grids. These grids are unique to this study and were designed to visually define the ranges and central tendencies of semi-quantitative element concentrations throughout the stratigraphic column. They are a method of statistically describing semi-quantative determinations without transforming or reducing the original dataset. The following section describes the attributes and use of these grids.

CONCENTRATION-DETECTION FREQUENCY GRIDS

Table 1.0 is a generalized stratigraphic column of the Ozark Plateaus sedimentary section. Shown are the geologic and hydrogeologic units of the Ozark region along with their corresponding AAPG code. The AAPG code of geologic units is used as a formational key for the following concentration-detection frequency grids. Note that some samples were assigned to combined or undifferentiated formational codes and therefore, some units occupy more vertical space than others. Consequently, the verticality of the section does not correspond to relative stratigraphic thickness.

Tables 1.1 through 1.8 are frequency grids for As, Cd, Co, Cr, Cu, Ni, Pb, and Zn. The far left column of the grids are the sampled formations arranged in the general stratigraphic order that corresponds to that of Table 1.0. The bold horizontal lines of the grid between certain geologic formations delineate the boundaries of hydrogeologic units that are shown on Table 1.0

The uppermost row of the grids are the semi-quantitative concentration bins. The numbers within the colored cells of the grid are the total number of detections within a concentration bin for a given formational unit; in other words, these numbers represent the number of times an element-concentration was detected within a geologic formation. For example, in Table 1.1, within Pennsylvanian rocks (AAPG code = 320PSLV) arsenic was detected once at a concentration of 150 ppm.

The last two columns on the far right of the grids show the total number of times an element was detected within a geologic unit, and the total number of samples representative of a geologic unit. These columns display the overall stratigraphic occurrence of metals and can serve as an aid in making cross-formational comparisons.

As a visual aid, the total distribution of frequency values, for each element, was logarithmically color scaled. The total distribution of frequencies, and assigned color codes is displayed below the grid. **In summary, darker colors within the concentration-detection frequency grids represent a higher frequency of detections (higher frequency of metal occurrence), while the lighter colors represent lower frequencies of detection (lower frequency of metal occurrence). Approximate**

concentrations modes for each formation are defined by a horizontal clustering of darker cells.

INTERPRETATION OF THE CONCENTRATION-DETECTION FREQUENCY GRIDS

Tables 1.1 through 1.8 show that high-concentration detections of MVT metals occur most frequently lower in the section, specifically within Cambrian rocks of the *lower* Ozark aquifer unit and St. Francois aquifer and confining units. In these aquifer units, the Potosi and Eminence Dolomites, the Derby-doerun, and the Bonnterre Formation host the highest concentrations and occurrences of metals.

Zn and Cd are exceptional in their distribution. High concentrations of Zn and Cd are detected most frequently in the *upper* Ozark aquifer unit and the Springfield Plateau aquifer unit. Within the upper Ozark aquifer unit, the Everton Formation, St. Peter Sandstone, and Jefferson City-Cotter & Powell dolomites contain high concentrations of Zn and Cd. In the Springfield Plateau aquifer unit, the Boone Formation hosts high concentrations of Zn and Cd.

Table 1.0 Generalized regional stratigraphy and hydrogeology of the Ozark Plateaus

Geologic Age	AAPG Code	Geologic Formation	Hydrologic Unit	Hydrologic System
Pennsylvanian	320PSLV	Pennsylvanian, undifferentiated	*Western Interior Plains confining units*	*Western Interior Plains confining system*
	330MSSP	Mississippian, undifferentiated		
	338KKKB	Keokuk-burlington Limestones, undiff.		
	338BRLG	Burlington Limestone		
	338ELSY	Elsey Formation		
	333WRSW	Warsaw Formation		
Mississippian	330BOON	Boone Formation	*Springfield Plateau aquifer unit*	
	337STJO	St. Joe Limestone		
	338FRGL	Fern Glen Limestone		
	338RSPG	Reeds Spring Limestone		
	338PRSN	Pierson Formation		
	338GDFL	Grand Falls Formation		
	339NRTV	North View Shale		
	337CMPN	Compton Formation	*Ozark confining unit*	
	330CTNG	Chattanooga Shale		
	360ODVC	Ordovician, undifferentiated		
	364STPR	St. Peter Sandstone		
	364EVRN	Everton Formation		
	368PWLL	Powell Dolomite		*Ozark aquifer system*
	367CTTR	Cotter Dolomite		
Ordovician	367CRJF	Cotter-Jefferson City Dolomites, undiff.		
	368JFRC	Jefferson City Dolomite		
	367RBDX	Roubidoux Formation	*Ozark aquifer unit*	
	367GSCD	Gasconade Dolomite		
	367GSCDU	upper Gasconade Dolomite		
	367GSCDL	lower Gasconade Dolomite		
	367GNTR	Gunter Sandstone		
	370CMBR	Cambrian, undifferentiated		
	371EMNC	Eminence Dolomite		
	371POTS	Potosi Dolomite		
Cambrian	371DRBD	Derby-Doerun Formation		
	371DVIS	Davis Shale	*St. Francois confining unit*	
	371BDDD	Bonneterre-Davis undifferentiated		
	371BNTR	Bonneterre Formation	*St. Francois aquifer unit*	
	371LMTT	Lamotte Sandstone		
Precambrian	400PCMB	Precambrian, undifferentiated	*Precambrian confining unit*	

Table 1.1 Concentration-detection frequency grid for Arsenic

Geologic Formation (AAPG_CODE)	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000	Total Detections	Total Samples
											Arsenic semi-quantitative concentration (ppm)															
320PSLV											1														1	407
330MSSP											2	1	1	2		1									7	883
338KKKB																										83
338BRLG																										35
338ELSY																										31
333WRSW																										35
330BOON																										16
337STJO																										11
338FRGL																										19
338RSPG											1														1	117
338PRSN																										62
338GDFL																										12
339NRTV																										30
337CMPN																										31
330CTNG																										23
360ODVC											2														2	82
364STPR																										34
364EVRN											2	2		2	2	1									9	327
368PWLL											5	3													6	374
367CTTR											6	7	2	2	2	1									20	1181
367CRJF											8	15	12	9	2										46	908
368JFRC											5	5	3	3	1	5									22	1178
367RBDX											14	8	10	6	7	4	1	1		1					52	1200
367GSCD											21	18	6	7	6	4		1	1						64	1630
367GSCDU													3												3	109
367GSCDL											6	3	13	2											24	471
367GNTR											1			1											2	305
370CMBR											11	6	2	4	4	3			1						31	216
371EMNC											46	46	37	46	37	24	10	15	6	7	3	2			279	2021
371POTS											22	33	23	30	18	26	16	15	8	2	3	2			178	1547
371DRBD											8	19	11	8	8	6	3								63	786
371DVIS											4	6	2	2		6			2	3	2	1			28	988
371BDDD																										45
371BNTR											19	20	8	10	9	11	5	10	3	1		1			97	2098
371LMTT																										344
400PCMB																										64

COLOR KEY

# of As Detections

# of As Detections
1
2
3 to 5
6 to 8
9 to 18
> 18

Table 1.2 Concentration-detection frequency grid for Cadmium

Geologic Formation (AAPG_CODE)	Cadmium semi-quantitative concentration (ppm)																								Total Detections	Total Samples
	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000		
320PSLV					2	1	1		1																5	407
330MSSP					12	3		2		3	1														21	883
338KKKB					2	2																			4	83
338BRLG					3				1		1														5	35
338ELSY					4																				4	31
333WRSW																										35
330BOON																										16
337STJO																										11
338FRGL																										19
338RSPG					3			1																	4	117
338PRSN						1					1			1											3	62
338GDFL																										12
339NRTV											1														1	30
337CMPN					5		1																		6	31
330CTNG																										23
360ODVC																										82
364STPR								1			1	3		1											6	34
364EVRN					2	1			1					1											5	327
368PWLL										1				1											2	374
367CTTR					6	1		2			1			1											11	1181
367CRJF					1			1		2	1	1	1	3											10	908
368JFRC					5																				5	1178
367RBDX					1				1																2	1200
367GSCD					3	2		1				1													7	1630
367GSCDU																										109
367GSCDL					1																				1	471
367GNTR					1																				1	305
370CMBR												1													1	216
371EMNC					12		3	2	1	2			1												21	2021
371POTS					3		1																		4	1547
371DRBD					3	1		1																	5	786
371DVIS																										988
371BDDD																										45
371BNTR					4	8		1		1			1	1											16	2098
371LMTT																										344
400PCMB																										64

COLOR KEY

# of Cd Detections
1
2
3
4 to 5
6 to 8
>8

Table 1.3 Concentration-detection frequency grid for Cobalt

Geologic Formation (AAPG_CODE)	Cobalt semi-quantitative concentration (ppm)																								Total Detections	Total Samples
	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000		
320PSLV	6	17	48	132	111	55	10	6	4	2															391	407
330MSSP	82	82	38	65	45	27	13	10	3	3		2	1	1		1									373	883
338KKKB	10	9	1	1	3	2																			26	83
338BRLG	5	16																							21	35
338ELSY	7	4		1	1				1																14	31
333WRSW	2	4	2	4	1																				13	35
330BOON	1	2	1	1		2																			7	16
337STJO	2				1	2	1	1																	7	11
338FRGL	4	2	1		2	4	3																		16	19
338RSPG	18	15	4	3	2	1																			43	117
338PRSN	5	14	6	6	7	6	2				1														47	62
338GDFL		1																							1	12
339NRTV	3	3	3	4	1	7	5																		26	30
337CMPN	1	7	3	5	5	5	2	1																	29	31
330CTNG				4	6	7		2	1																20	23
360ODVC	6	3	2	3	2	1	2																		19	82
364STPR		2	2	2	1																				7	34
364EVRN	40	23	10	16	12	1	2			2															106	327
368PWLL	27	75	55	52	27	16	6	1		2		2	1	1											264	374
367CTTR	190	169	80	88	71	30	5	3	1	1		2	1	1	1			1							644	1181
367CRJF	175	168	58	54	33	26	1	4	1	3		2	2												527	908
368JFRC	157	152	44	38	19	11	4	2	3	1		2	3	1				1							438	1178
367RBDX	154	75	26	21	17	8	4	2		1		1		1											310	1200
367GSCD	167	108	40	31	23	15	5	5	1	2			1					1							399	1630
367GSCDU	15	5	1	5	2	1						1													30	109
367GSCDL	44	15	9	5	7	8	2	1				1													92	471
367GNTR	26	6	8	3	2																				45	305
370CMBR	5	21	26	36	19	19	16	14	6	1			1												164	216
371EMNC	152	163	88	137	96	116	58	33	10	8	2	2	1	1											867	2021
371POTS	80	170	74	99	74	70	48	40	14	6		1					1								625	1547
371DRBD	35	90	91	112	102	76	21	6	9	2	1	1	1												547	786
371DVIS	30	107	157	205	202	173	40	5	2	6	2														929	988
371BDDD	2	5		8	7	5	2																		29	45
371BNTR	99	398	313	321	198	123	38	43	20	15	6	2	2	4	2	2									1586	2098
371LMTT	26	29	7	5	5	2		1		1	1														77	344
400PCMB	4	4	8	9	3	1		1	6	1		1													38	64

COLOR KEY

# of Co Detections

1
2 to 3
4 to 6
7 to 19
20 to 71
> 71

Table 1.4 Concentration-detection frequency grid for Chromium

Geologic Formation (AAPG_CODE)	Chromium semi-quantitative concentration (ppm)																							Total Detections	Total Samples
	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000		
320PSLV					4	11	2	20	27	166	109	50	9	7	1	1									407	407
330MSSP			51	82	60	86	42	48	47	75	38	17	2	5	2	1	1								557	883
338KKKB			8	3	1	7	3	4	1	1	2		2												32	83
338BRLG			4	2	2																				8	35
338ELSY			1	3	1	1	1		1																8	31
333WRSW			1	3	1	3	4	6	1	4	1	1	1												26	35
330BOON			7	1		7									1										16	16
337STJO			4		2	1					3	1													11	11
338FRGL			5	4	2	1	1	1	1	2	1														18	19
338RSPG			21	24	1	1		1	2	8															58	117
338PRSN			8	9	3	4	4	6	3	5		1	1												44	62
338GDFL				4	2																				6	12
339NRTV				1	1		2	5	2	6	7	4	2												30	30
337CMPN			5	4	1	1		2	4	5		2													24	31
330CTNG				3		3	1	2	5	8	1														23	23
360ODVC				8	36	10	1	4	1	3	3	1													67	82
364STPR			9	5	8	5		6																	27	34
364EVRN			98	66	49	42	5	20	6	11	16	5													318	327
368PWLL			5	15	18	63	33	86	55	76	19	2													361	374
367CTTR			78	129	95	246	84	170	64	84	24	13	1	4	1	3									996	1181
367CRJF			53	90	151	176	80	139	51	83	13	2													838	908
368JFRC			123	160	106	172	57	93	33	46	26	14	3	5		2									840	1178
367RBDX			179	220	121	130	32	53	13	15	6	6	1	5	1										782	1200
367GSCD			233	223	108	125	36	59	22	31	15	9	3	3						2					869	1630
367GSCDU			32	16	14	9		6	1	3	2	1		1		1			1						87	109
367GSCDL			103	86	68	28	3	17	6	10	6	9	2	1		3									342	471
367GNTR			52	67	24	20	3	12	2	1	1														182	305
370CMBR			19	45	10	12	9	16	11	33	12	13	2	4						1					187	216
371EMNC			184	309	123	188	80	135	80	85	35	17	7	7		2	2								1254	2021
371POTS			82	241	56	94	47	71	43	53	14	4	3												662	1547
371DRBD			20	103	45	95	85	127	88	83	36	11	1	1											695	786
371DVIS			14	20	30	59	111	185	158	227	128	35	3												970	988
371BDDD			2	5	3	8	2	15	1	4															40	45
371BNTR			49	339	198	351	324	331	208	119	37	4													1960	2098
371LMTT			36	87	13	12	7	9	4																168	344
400PCMB			3	10	5	7	3	2	1	1	2			1		2	3								40	64

COLOR KEY
# of Cr Detections

1
2 to 3
4 to 8
9 to 30
31 to 84
> 84

Table 1.5 Concentration-detection frequency grid for Copper

Copper semi-quantitative concentration (ppm)

Geologic Formation (AAPG_CODE)	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000	Total Detections	Total Samples
320PSLV	10	11	8	22	40	134	102	46	13	11	7	1				1									406	407
330MSSP	328	99	40	64	51	56	33	27	14	14	3	5	1	1	1		1								738	883
338KKKB	19	13	3	4	6	1	2			1															49	83
338BRLG	17	2	1	1																					21	35
338ELSY	12	5	2	1	1	1																			22	31
333WRSW	8	4	3	4	3	3	2	3																	30	35
330BOON	12		1	1		1		1																	16	16
337STJO	2	3		2	1	1	2																		11	11
338FRGL	4		3	5	2	2	1				1														18	19
338RSPG	68	14	1	3	1		1	2		1	1														92	117
338PRSN	16	9	7	7	2	3	6	2	2	1	1							1							57	62
338GDFL	3	2			1																				6	12
339NRTV		2	1	8	5	8	3	1	1	1															30	30
337CMPN		4	3	4	4	3	7	2			3						1								31	31
330CTNG	2			1	1	2	4	5	4	2	1		1												23	23
360ODVC	33	10	12	8	2	5	5	3	1			1									1				81	82
364STPR	15	1	1	3	2	3		1	2	2		2		1											27	34
364EVRN	83	50	30	37	28	24	19	24	7	8	2	4	2	2	1		1	1		1					324	327
368PWLL	9	10	11	22	53	66	67	69	23	24	10	7		2		1									363	374
367CTTR	135	115	106	161	155	188	82	110	37	40	16	7	3		1	2	1	2							1161	1181
367CRJF	109	90	76	124	124	123	78	69	19	42	24	12	5	6	1		1	1		1					905	908
368JFRC	214	187	136	147	135	120	65	46	30	13	11	6	3	2			1								1116	1178
367RBDX	421	170	101	100	61	61	26	36	11	16	12	6	2	1										1	1025	1200
367GSCD	584	227	127	151	93	98	44	51	18	32	14	12	3	7		1	1						1	1	1465	1630
367GSCDU	25	21	6	9	8	11	4	6	5	3	2	2	2												104	109
367GSCDL	144	82	45	33	34	29	10	17	13	12	5	3	3	1	1										432	471
367GNTR	165	35	11	19	8	6	4	1		1	1		2												253	305
370CMBR	12	10	11	10	9	20	20	38	15	27	16	15	7	3	1		1		1						216	216
371EMNC	268	218	145	200	124	177	123	139	97	154	89	86	48	30	22	15	8	4	3	2	2				1954	2021
371POTS	305	174	99	95	77	134	89	130	58	95	62	53	39	31	15	8	3	2	1	1		1			1411	1547
371DRBD	74	63	61	43	37	85	92	118	59	53	31	28	15	15	5	1			1						781	786
371DVIS	33	67	100	118	115	213	140	107	33	31	17	6	1	1	2	1			1						986	988
371BDDD	4		2	3		8	4	14	1	5	1	2	1												45	45
371BNTR	450	275	184	182	134	201	160	168	112	96	46	27	7	10	2	2				2				1	2059	2098
371LMTT	157	48	33	30	15	17	4	8	5	1	2		1	2	1										324	344
400PCMB	24	4	6	5	7	2	1	3	1	1										1					55	64

COLOR KEY

# of Cu Detections
1
2 to 3
4 to 10
11 to 30
31 to 96
>96

Table 1.6 Concentration-detection frequency grid for Nickel

Geologic Formation (AAPG_CODE)	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000	Total Detections	Total Samples
	Nickel semi-quantitative concentration (ppm)																									
320PSLV	2	8	1	2	16	33	61	140	79	49	11	4	1												407	407
330MSSP	118	117	71	119	76	67	48	59	44	29	13	5	2	4	1	2	1	1	1	2					780	883
338KKKB	21	11	2	7	6	5	3	3	3		1														62	83
338BRLG	8	11	3	1	1																				24	35
338ELSY	7	5		3	1		2	1	2																21	31
333WRSW	5	10	2	2	2	6	2	4	1																34	35
330BOON	1	3	2	5	1		1	1		1	1														16	16
337STJO			1	1	3	1				2	3														11	11
338FRGL					3	5	2	2	1	3	2														18	19
338RSPG	20	14	7	16	19	15	7	1	1	2															102	117
338PRSN	1	3	1	9	6	7	5	5	9	6	3	2	1	2						1					61	62
338GDFL	4	1	3	2			1																		11	12
339NRTV			2	2	2	5	6	7		1	2	1	2												30	30
337CMPN	3	2	2	1	4	2	2	4	4	4	1	2													31	31
330CTNG		2		1			2	6	5	5			2												23	23
360ODVC	13	19	14	7	6	4	2	1	1	3	1	2													73	82
364STPR		4	10	13		3		1	1	1															27	34
364EVRN	44	80	51	46	29	33	11	14	7	6			1	2	1										325	327
368PWLL	1	17	31	51	41	73	58	64	25	9	3	1													363	374
367CTTR	51	132	129	269	177	168	104	71	33	19	3	1		2											1159	1181
367CRJF	25	89	135	224	136	124	61	55	16	16	6	5	3	3											898	908
368JFRC	160	179	114	244	128	122	67	37	21	3	1			1											1077	1178
367RBDX	176	206	192	223	95	52	20	16	6	6	1			1											994	1200
367GSCD	202	253	235	243	107	80	25	32	15	12	3	2		1											1210	1630
367GSCDU	7	21	13	33	16	4	1	4	1																100	109
367GSCDL	44	79	84	139	34	25	10	6	7	6	1	2													437	471
367GNTR	43	93	45	20	9	4	6	1	1		1														223	305
370CMBR	12	14	7	22	14	35	26	22	7	13	15	11	5	3		2									208	216
371EMNC	88	192	187	207	154	214	149	156	83	99	36	28	18	8	3	2									1624	2021
371POTS	36	134	83	110	89	130	105	111	54	64	44	33	9	8	2	1									953	1547
371DRBD	15	54	46	76	62	114	105	118	51	39	12	3	3	1											699	786
371DVIS	15	34	30	94	173	216	155	196	36	4	3	3	5	2											966	988
371BDDD	2	3		3	7	8	7	7	2	4	1														44	45
371BNTR	102	336	279	268	175	237	171	151	43	46	23	13	5	8	3	1	2			1					1864	2098
371LMTT	75	84	21	19	7	5		1	1	1															214	344
400PCMB	7	8	6	7	4	5		1	1	2				2	2	1									46	64

COLOR KEY
# of Ni Detections

1
2 to 3
4 to 7
8 to 25
26 to 91
> 91

Table 1.7 Concentration-detection frequency grid for Lead

Geologic Formation (AAPG_CODE)	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000	Total Detections	Total Samples
	Lead semi-quantitative concentration (ppm)																									
320PSLV			50	77	63	98	38	27	7	5	2	2	1	2											372	407
330MSSP			113	71	35	31	25	20	5	10	1	5								1					321	883
338KKKB			7	6	4	4		1	1	1		1	1	1	1	1									29	83
338BRLG			3	2																					5	35
338ELSY			7			2																			9	31
333WRSW			3	4	2	4	2						1				1								17	35
330BOON							2																		2	16
337STJO					3	1																			4	11
338FRGL			3	2	1	1																			7	19
338RSPG			7	1	3	1	2	1	1																16	117
338PRSN			4	3	4	3	2	2		2		1				1									22	62
338GDFL																										12
339NRTV			4	8	5	6	3				1	1													28	30
337CMPN			4	1	1	4	4	2																	16	31
330CTNG			1	2	1	4	6	3	1	1				1											20	23
360ODVC			8	6		1	5			1			1												22	82
364STPR			6	2	2	2			1																7	34
364EVRN			52	24	11	25	12	16	1	2	2	1													146	327
368PWLL			29	45	63	83	45	38	14	25	8	1													340	374
367CTTR			198	158	97	138	60	76	26	29	9	2	2	2	1	2	1			1					802	1181
367CRJF			203	135	82	96	55	60	34	31	12	8	1	1							1				719	908
368JFRC			247	111	58	70	35	46	17	14	8	1	2	1											610	1178
367RBDX			342	61	22	31	11	22	8	15	4	4	1		1			1							523	1200
367GSCD			445	102	43	58	33	45	19	17	7	10	7	2	1	1									790	1630
367GSCDU			14	14	1	7	4	5	1	2	1				1	1					1				52	109
367GSCDL			42	18	8	18	6	12	5	11	3	2	2												127	471
367GNTR			88	7	4	5	1	3	1	3															112	305
370CMBR			23	16	8	14	19	20	13	34	18	10	5	2	6	5	1	2							196	216
371EMNC			314	141	94	123	100	139	87	101	68	53	30	25	5	18	4	5	3	4	2	3	2		1321	2021
371POTS			188	140	68	101	63	85	57	80	49	40	21	20	7	6	4	2	1	3					877	1547
371DRBD			69	76	63	87	51	84	52	88	52	41	19	9	6	6	7	1	1		1		1		714	786
371DVIS			101	220	164	185	86	67	36	27	24	14	11	9	3	3	4	5		1		1			961	988
371BDDD			1		3	4	9	4	2	10	1	3													37	45
371BNTR			161	265	262	346	240	206	94	107	65	67	36	45	23	29	13	30	22	16	2	2	3	8	2042	2098
371LMTT			40	19	7	8	8	8	1		1	1		1	1	1		1	1						98	344
400PCMB			12	10	9	5	1		1		1	1													40	64

COLOR KEY

# of Pb Detections
1
2 to 3
4 to 8
9 to 25
26 to 67
> 67

Table 1.8 Concentration-detection frequency grid for Zinc

Geologic Formation (AAPG_CODE)	3	5	7	10	15	20	30	50	70	100	150	200	300	500	700	1000	1500	2000	3000	5000	7000	10000	15000	20000	Total Detections	Total Samples
											Zinc semi-quantitative concentration (ppm)															
320PSLV											30	40	7	16	13	9	2	1	2						120	407
330MSSP											76	30	7	21	12	6	6	2	4	4	1				169	883
338KKKB											4	3	4		1	4	1	3	1	1	1	1			24	83
338BRLG											2	1	1	1	1	1						2			9	35
338ELSY											3					1		2							7	31
333WRSW											1		3	1		1									6	35
330BOON											1														2	16
337STJO																										11
338FRGL											4			1											5	19
338RSPG											13	12	2		2		1	1		1					32	117
338PRSN											13	6	3						1			2			25	62
338GDFL											1	1													2	12
339NRTV													1	1							1				3	30
337CMPN											6	3	1		1	1		1							13	31
330CTNG											9	2	1	1											13	23
360ODVC											2	1	1												4	82
364STPR														1		1		2			1	6			11	34
364EVRN											8	9	5	4	1	2		3	2	1	3	5			43	327
368PWLL											8	3	4		1	1	1	1				2			17	374
367CTTR											51	12	13	11	8	11	8	3	5	3	1	1			127	1181
367CRJF											52	31	12	17	4	9	2	5	2	1	4	12			151	908
368JFRC											52	22	11	7	7	4	3		1	2	1	2			112	1178
367RBDX											32	11	9	3	2	1	1	2		1	1				63	1200
367GSCD											66	29	7	6	4	3		1	4	1	1	1			123	1630
367GSCDU											5	1													6	109
367GSCDL											16		2	2	1										21	471
367GNTR											9	4	1												14	305
370CMBR											14	6	2	6	1			1	1			1			32	216
371EMNC											109	57	32	34	11	7	4	1	1	5	2	1			264	2021
371POTS											56	33	15	11	5	4	3								119	1547
371DRBD											15	16	9	9	2	7		5	1			2			66	786
371DVIS											11	3		2	1										17	988
371BDDD												1													1	45
371BNTR											48	32	14	14	11	8	6	4	1	1	1	7			147	2098
371LMTT											1		2												3	344
400PCMB											3	1													4	64

COLOR KEY

# of Zn Detections
1
2 to 3
4 to 6
7 to 11
12 to 28
> 28

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