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Chemistry of the Springs of the Ozark Mountains, Northwestern Arkansas

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CHEMISTRY OF THE SPRINGS OF THE OZARK MOUNTAINS, NORTHWESTERN ARKANSAS

by
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Research Project Technical Completion Report A-055-ARK

Arkansas Water Resources Research Center
University of Arkansas
Fayetteville, Arkansas 72701

Arkansas Water Resources Research Center

Prepared for
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ABSTRACT

Three lead-zinc mineralized areas of northern Arkansas were selected to study the effect of mineralization on ground water chemistry. The Ponca area has the largest amount of lead sulfide mineralization, the Zinc area has a significant amount of zinc silicate and zinc sulfide; whereas, the Rush area has zinc carbonate and zinc sulfide. A total of 143 samples were collected from these areas and analyzed for general water chemistry parameters including heavy metals.

The water quality of the area is generally good; however, a few springs exceed the drinking water standards for ammonia, nitrate, iron, manganese and lead. The surface temperatures and subsurface temperatures (determined from silica geothermometry) do not indicate any significant geothermal heating of these spring waters. Geochemical exploration using ground water chemistry, especially lead, appears to be very useful in outlining these lead-zinc mineralized areas; however, location of individual deposits using ground water chemistry does not appear to be promising.

ACKNOWLEDGEMENTS

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Much of the field and laboratory work was carried out by John Bales, T. F. Dilday,III and Lawrence Smith.

The cooperation and assistance of the National Park Service for work in the Ponca and Rush areas is also gratefully acknowledged.

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INTRODUCTION

The north-central part of the Ozark Mountains, Arkansas is highly mineralized with potentially commercial amounts of zinc, and associated lead and cadmium. Significant amounts of zinc and lead have been produced in the Ponca, Rush and Zinc areas of Arkansas in the past. There is a paucity of published ground water chemical (especially trace metals) data for this region, especially considering the number of people dependent upon ground water for home use. The ground water of this region issuing from springs, flows through fractures and solution-enlarged fractures in the carbonate rocks. Springs were sampled in this study (Fig. 1 and Table 1) because they represent ground water uncontaminated by plumbing which is not the case for well water samples.

The purpose of this study was threefold:

(1) To obtain baseline ground water quality (especially trace metal) data for the area and evaluate the usefulness of the water for homes.

(2) To determine the potential of hydrogeochemical prospecting for the Mississippi-Valley Type zinc and lead deposits in the Ozark Region.

(3) To use silica geothermometry to obtain subsurface temperatures of the ground water that issues as springs in the mineralized areas.

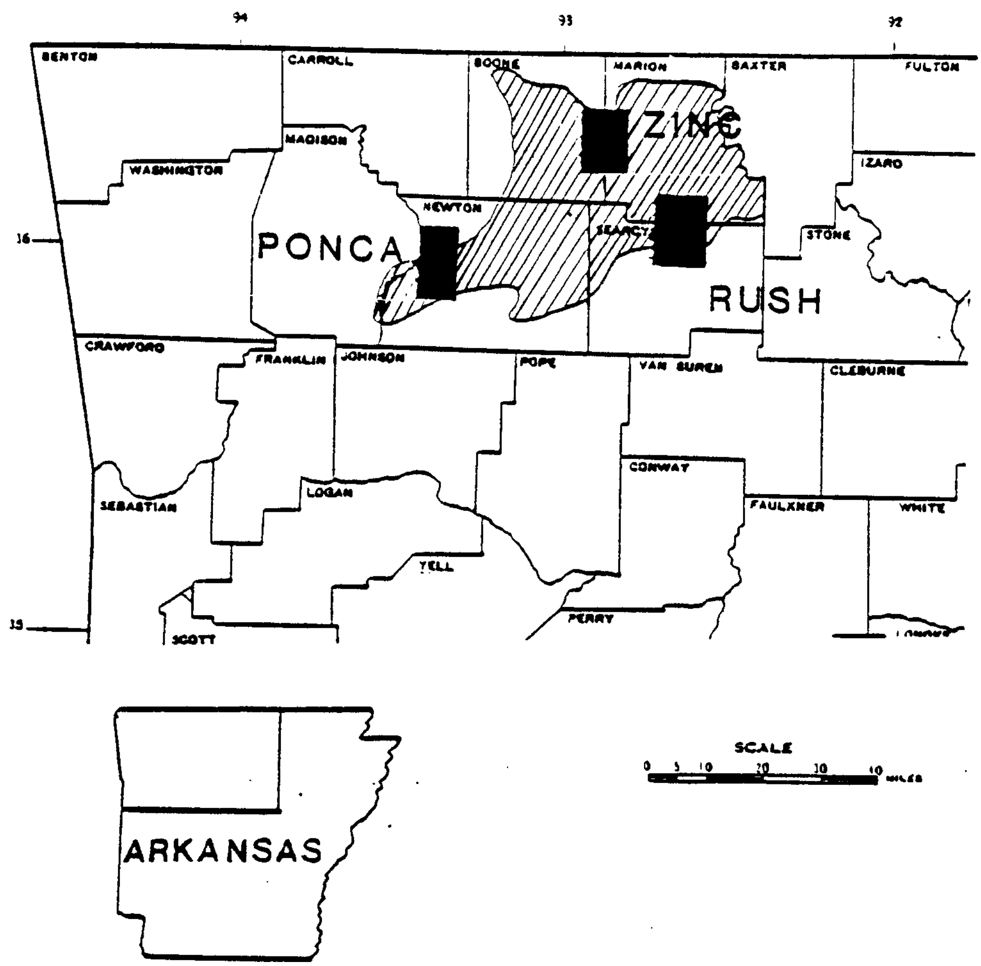

Figure 1. Location of the lead-zinc mineralized area of northwestern Arkansas (lined area). Springs were sampled from the three dark rectangular areas -- Ponca, Rush and Zinc.

Table 1. Sample location, distance to nearest mineralization, major types of ore, and formation from which the spring issues.

Sample Number	Location: Quarter Secs.	Sec.	Township	Range	Quad	County	Min.* in ft.	Type of ore	Formation
NA 1	SE¼SE¼SW¼NW¼	27	17N	15W	Cozahome	Marion	8300	Zn-S	Everton
NA 2	SE¼NW¼SW¼SE¼	29	17N	15W	Cozahome	Marion	1000	Zn-S	Boone
NA 3	NW¼NE¼NW¼NE¼	15	17N	15W	Cozahome	Marion	2000	Zn-S	Everton
NA 4	SW¼NE¼NE¼SW¼	10	17N	15W	Rea Valley	Marion	1200	Zn-S, CO_3	Everton
NA 5	NW¼SW¼NW¼NE¼	11	17N	15W	Rea Valley	Marion	1000	Zn-S	Everton
NA 6	NE¼SW¼NE¼SE¼	10	17N	15W	Rea Valley	Marion	1500	Zn-S, CO_3	Everton
NA 7	SE¼SE¼SE¼NE¼	9	17N	15W	Cozahome	Marion	1500	Zn-S, CO_3	Everton
NA 8	NE¼SE¼NE¼NE¼	9	17N	15W	Cozahome	Marion	1500	Zn-S, CO_3	Everton
NA 9	NE¼SE¼SE¼NE¼	4	17N	15W	Cozahome	Marion	1000	Zn-S	Everton
NA10	SE¼SW¼SE¼NE¼	4	17N	15W	Cozahome	Marion	1500	Zn-S	Everton
NA11	NE¼NE¼SW¼NE¼	6	17N	15W	Cozahome	Marion	5000	Zn-S	Powell
NA12	NE¼SW¼SE¼SE¼	36	18N	16W	Cozahome	Marion	2500	Zn-S	Everton
NA13	NE¼NW¼SW¼SE¼	15	17N	15W	Cozahome	Marion	4500	Zn-CO_3	Boone
NA14	NW¼SW¼NE¼NW¼	20	17N	15W	Cozahome	Marion	2700	Zn-S	Everton
NA15	NW¼NW¼SW¼SE¼	28	18N	16W	Yellville	Marion	18500	Zn-S	Everton
NA16	SW¼SE¼SE¼NW¼	8	16N	22W	Ponca	Newton	4900	Pb-S	Boone
NA17	NE¼NW¼SE¼NW¼	8	16N	22W	Ponca	Newton	5300	Pb-S	Boone
NA18	SW¼SE¼NE¼NW¼	8	16N	22W	Ponca	Newton	5600	Pb-S	Boone
NA19	SE¼SE¼SE¼SE¼	6	16N	22W	Ponca	Newton	5800	Pb-S	Hale
NA20	SE¼SE¼SW¼SE¼	24	16N	23W	Ponca	Newton	2000	Pb-S Zn-CO_3	Everton
NA21	SW¼NE¼SE¼SE¼	23	16N	23W	Osage	Newton	2000	Pb-S Zn-CO_3	Cane Hill
NA22	SE¼NE¼NW¼NW¼	25	16N	23W	Ponca	Newton	1000	Pb-S Zn-CO_3	Cane Hill
NA23	SW¼NW¼NE¼SW¼	24	16N	23W	Ponca	Newton	1700	Pb-S Zn-CO_3	Everton
NA24	SE¼SW¼NW¼SE¼	24	16N	23W	Ponca	Newton	2000	Pb-S Zn-CO_3	Everton
NA25	NW¼NW¼SW¼SE¼	24	16N	23W	Ponca	Newton	1500	Pb-S Zn-CO_3	Everton
NA26	NE¼NE¼SW¼SE¼	24	16N	23W	Ponca	Newton	2500	Pb-S Zn-CO_3	Everton
NA27	SW¼SW¼SE¼SW¼	25	16N	23W	Ponca	Newton	2500	Pb-S Zn-CO_3	Boone
NA28	SW¼SE¼NE¼SE¼	25	16N	23W	Ponca	Newton	4500	Pb-S Zn-CO_3	Everton

Table 1 (Continued)

Sample Number	Location: Quarter Sec.	Sec.	Town-ship	Range	Quad	County	Min.* in ft.	Type of ore	Formation
NA29	NW¼SE¼NE¼NE¼	25	16N	23W	Ponca	Newton	3200	Pb-S Zn-CO_3	Everton
NA30	SE¼SE¼NE¼NE¼	25	16N	23W	Ponca	Newton	3600	Pb-S Zn-CO_3	Everton
NA31	SE¼SW¼NW¼NE¼	18	16N	22W	Ponca	Newton	1000	Pb-S	Cane Hill
NA32	NE¼NW¼NE¼NW¼	25	16N	23W	Ponca	Newton	1500	Pb-S Zn-CO_3	Boone
NA33	SE¼NW¼SW¼NW¼	30	16N	22W	Ponca	Newton	4500	Pb-S Zn-CO_3	Everton
NA34	SE¼SE¼SW¼NE¼	3	15N	23W	Boxley	Newton	8000	Pb-S Zn-CO_3, Si	Everton
NA35	NW¼NW¼SW¼NE¼	3	15N	23W	Boxley	Newton	7500	Pb-S Zn-CO_3, Si	Everton
NA36	NE¼SE¼NW¼NE¼	3	15N	23W	Boxley	Newton	6500	Pb-S Zn-CO_3, Si	Everton
NA37	NE¼SW¼NW¼NE¼	3	15N	23W	Boxley	Newton	7000	Pb-S Zn-CO_3, Si	Everton
NA38	NW¼SE¼NW¼NE¼	3	15N	23W	Boxley	Newton	6500	Pb-S Zn-CO_3, Si	Everton
NA39	SE¼NW¼NW¼SE¼	23	19N	18W	Pyatt	Marion	10300	UNK	Everton
NA40	SW¼SW¼SE¼NE¼	23	19N	18W	Pyatt	Marion	8800	UNK	Everton
NA41	SE¼SW¼SW¼NW¼	24	19N	18W	Pyatt	Marion	7200	UNK	Everton
NA42	NW¼NW¼NW¼SW¼	24	19N	18W	Pyatt	Marion	7400	UNK	Everton
NA43	SW¼NE¼SE¼SW¼	13	19N	18W	Pyatt	Marion	6700	UNK	Everton
NA44	SE¼NW¼SE¼NE¼	27	19N	18W	Pyatt	Marion	14300	UNK	Everton
NA45	NW¼SE¼SE¼NW¼	21	19N	18W	Zinc	Boone	3900	UNK	Everton
NA46	NE¼NE¼NE¼NE¼	21	19N	18W	Zinc	Boone	3500	Zn-S, Si	Everton
NA47	NE¼NW¼SW¼NW¼	16	19N	18W	Zinc	Boone	0	Zn-Si	Everton
NA48	SE¼SE¼NW¼NE¼	20	19N	18W	Zinc	Boone	2000	Zn-S	Everton
NA49	SE¼SW¼SW¼NE¼	35	16N	23W	Osage	Newton	2500	Zn-Si, CO_3 Pb-S	Everton
NA50	SE¼NW¼NW¼SW¼	6	15N	22W	Murray	Newton	11700	Pb-S Zn-CO_3	Fayetteville
NA51	SE¼SE¼NW¼SW¼	6	15N	22W	Murray	Newton	12000	Pb-S Zn-CO_3	Fayetteville
NA52	SE¼SE¼SE¼NE¼	22	15N	23W	Boxley	Newton	8500	Pb-S	Boone
NA53	SW¼NE¼NE¼SW¼	36	16N	23W	Ponca	Newton	5500	Pb-S Zn-CO_3	Everton
NA54	NE¼NW¼NE¼SW¼	24	16N	23W	Ponca	Newton	2000	Pb-S Zn-CO_3	Everton
NA55	NE¼NW¼SW¼NE¼	24	16N	23W	Ponca	Newton	2800	Pb-S Zn-CO_3	Everton
NA56	SE¼SE¼SE¼SE¼	25	16N	23W	Osage	Newton	2300	Pb-S Zn-CO_3	Boone
NA57	SE¼SE¼SW¼SW¼	10	15N	23W	Boxley	Newton	4000	Pb-S	Boone
NA58	SE¼NE¼SW¼SW¼	17	16N	22W	Ponca	Newton	5000	Pb-S	Everton

Table 1 (Continued)

Sample Number	Location: Quarter Secs.	Sec.	Township	Range	Quad	County	Min.* in ft.	Type of ore	Formation
NA59	NE¼NE¼NE¼NE¼	29	15N	23W	Boxley	Newton	8500	Pb-S	Atoka
NA60	NE¼SW¼NE¼SE¼	32	15N	23W	Boxley	Newton	17000	Pb-S	Atoka
NA61	NW¼NW¼SE¼SE¼	15	15N	23W	Boxley	Newton	5500	Pb-S	Boone
NA62	SE¼SE¼SW¼SE¼	24	16N	23W	Ponca	Newton	2000	Pb-S Zn-CO_3	Boone
NA63	SW¼SE¼NE¼NW¼	8	16N	22W	Ponca	Newton	6100	Pb-S	Everton
NA64	SW¼SE¼SE¼NW¼	8	16N	22W	Ponca	Newton	4900	Pb-S	Boone
NA65	NE¼NW¼NW¼NW¼	16	19N	18W	Zinc	Boone	1000	Zn-S, Si	Everton
NA66	SE¼SE¼NW¼SW¼	9	19N	18W	Zinc	Boone	2800	Zn-S, Si	Everton
NA67	NE¼SW¼SW¼NE¼	9	19N	18W	Zinc	Boone	5000	Zn-S, Si	Everton
NA68	SE¼SE¼SW¼SE¼	29	19N	18W	Zinc	Boone	700	Zn-S, CO_3	Everton
NA69	NE¼NE¼SE¼SE¼	29	19N	18W	Zinc	Boone	1000	Zn-S, CO_3	Everton
NA70	SW¼SW¼NW¼NW¼	33	20N	18W	Zinc	Boone	11100	Zn-CO_3	Everton
NA71	SE¼SE¼NE¼NE¼	33	20N	18W	Zinc	Boone	8500	Pb-S	Cotter
NA72	NE¼SE¼NE¼NE¼	5	19N	18W	Zinc	Boone	10000	Zn-CO_3	Boone
NA73	SE¼SE¼NW¼SW¼	4	19N	18W	Zinc	Boone	7500	Zn-S	Boone
NA74	NW¼SE¼NW¼SW¼	4	19N	18W	Zinc	Boone	8000	Zn-S	Boone
LS 1	NE¼NE¼NW¼NW¼	13	16N	16W	Maumee	Searcy	2300	Zn-S	Everton
LS 2	NW¼SW¼SE¼SE¼	17	16N	15W	Cozahome	Searcy	500	Zn-S	Boone
LS 3	SE¼SE¼NW¼NW¼	1	16N	16W	Maumee	Searcy	4000	Zn-Si	Boone
LS 4	NE¼NE¼SW¼SW¼	36	17N	16W	Maumee	Marion	5300	Zn-Si	Everton
LS 5	NE¼NE¼SE¼NW¼	1	16N	16W	Maumee	Searcy	3000	Zn-Si	Everton
LS 6	NE¼SE¼NW¼SE¼	36	17N	16W	Maumee	Marion	3000	Zn-Si	Boone
LS 7	SE¼NW¼NE¼SE¼	31	17N	15W	Cozahome	Marion	2500	Zn-S	Everton
LS 8	NE¼NE¼SW¼SW¼	32	17N	15W	Cozahome	Marion	2500	Zn-S	Boone
LS 9	NW¼SE¼NW¼NW¼	30	17N	15W	Cozahome	Marion	7000	Zn-S	Boone
LS10	SE¼SE¼NW¼NW¼	30	17N	15W	Cozahome	Marion	6800	Zn-S	Boone
LS11	NW¼SE¼NW¼SE¼	19	17N	16W	Maumee	Marion	1700	Zn-S	Everton
LS12	SE¼NE¼SW¼SW¼	21	17N	16W	Maumee	Marion	1000	Pb-S	Boone

Table 1 (Continued)

Sample Number	Location				Quad	County	Min.* in ft.	Type of ore	Formation
	Quarter Secs.	Sec.	Town-ship	Range					
LS13	NW¼NE¼SW¼NE¼	6	16N	15W	Cozahome	Searcy	500	Zn-S	Everton
LS14	NW¼SE¼SW¼NE¼	6	16N	15W	Cozahome	Searcy	0	Zn-S	Everton
LS15	SW¼NE¼SW¼SE¼	17	17N	16W	Maumee	Marion	6700	Zn-S	Everton
LS16	SW¼NE¼NW¼NE¼	20	17N	16W	Maumee	Marion	5800	Pb-S	UNK
LS17	SW¼SW¼SE¼SE¼	24	17N	17W	Maumee	Marion	2200	UNK	Boone
LS18	SE¼SW¼NE¼NE¼	23	17N	17W	Maumee	Marion	2000	UNK	Boone
LS19	NW¼SW¼NW¼NE¼	11	17N	15W	Rea Valley	Marion	1000	Zn-S	Everton
LS20	SE¼SE¼NW¼SW¼	9	19N	18W	Zinc	Boone	2800	Zn-S, Si	Everton
LS21	SE¼SE¼SE¼NE¼	22	15N	23W	Boxley	Newton	8500	Pb-S	Everton
LS22	SW¼NE¼SW¼SE¼	24	16N	23W	Ponca	Newton	2000	Pb-S Zn-CO_3	Boone
LS23	SW¼NW¼NE¼SW¼	24	16N	23W	Ponca	Newton	1700	Pb-S Zn-CO_3	Everton
LS24	SE¼SE¼SE¼SE¼	6	16N	22W	Ponca	Newton	5800	Pb-S	Everton
LS25	NE¼NE¼SW¼SE¼	24	16N	23N	Ponca	Newton	2500	Pb-S Zn-CO_3	Everton
LS26	SE¼NE¼SW¼SW¼	17	16N	22W	Ponca	Newton	5000	Pb-S	Hale
LS27	SE¼SW¼SW¼NE¼	35	16N	23W	Osage	Newton	2500	Zn-Si, CO_3 Pb-S	Everton
LS28	SW¼SE¼SW¼SW¼	18	19N	17W	Pyatt	Marion	3000	UNK	Boone
LS29	NW¼SE¼SW¼NW¼	19	19N	17W	Pyatt	Marion	1000	UNK	Everton
LS30	SE¼NE¼SW¼NE¼	19	19N	17W	Pyatt	Marion	2000	UNK	Everton
LS31	NE¼NE¼NW¼SW¼	20	19N	18W	Zinc	Marion	700	Zn-S	Everton
LS32	SE¼SW¼SE¼SE¼	19	19N	18W	Zinc	Marion	1500	Zn-S	Everton
LS33	SE¼NE¼SE¼SE¼	19	19N	18W	Zinc	Marion	700	Zn-S	Everton
LS34	SW¼NW¼NE¼SE¼	24	19N	19W	Zinc	Marion	2000	Zn-S	Boone
LS35	NW¼NE¼NW¼SW¼	19	19N	18W	Zinc	Marion	300	Zn-S	Everton
LS36	NE¼NW¼NW¼NW¼	13	19N	18W	Pyatt	Marion	8200	Zn-S, Si	Everton
LS37	NW¼SE¼SW¼SW¼	12	19N	18W	Pyatt	Marion	7600	Zn-S, Si	Everton
LS38	SE¼SW¼SE¼NW¼	5	19N	17W	Pyatt	Marion	4300	Zn-S	Boone
LS39	SW¼SE¼NE¼SW¼	32	20N	17W	Pyatt	Marion	1100	Zn-S Pb-S	Everton

Table 1 (Continued)

Sample Number	Quarter Secs.	Sec.	Town-ship	Range	Quad	County	Min.* in ft.	Type of ore	Formation
LS40	SE¼SE¼SW¼SE¼	32	20N	17W	Pyatt	Marion	2000	Zn-S	Everton
LS41	SW¼NW¼NW¼NW¼	4	19N	17W	Pyatt	Marion	3600	Pb-S, CO_3	Everton
LS42	SE¼SE¼SW¼NW¼	4	19N	17W	Pyatt	Marion	5000	Zn-S	Boone
LS43	NW¼SE¼SW¼NE¼	29	20N	17W	Pyatt	Marion	1700	Zn-CO_3	Everton
LS44	NW¼NE¼SW¼NW¼	28	20N	17W	Pyatt	Marion	4000	Zn-CO_3	Everton
LS45	NW¼SE¼NW¼SW¼	28	20N	17W	Pyatt	Marion	3600	Zn-CO_3	Everton
LS46	NW¼NW¼NE¼SW¼	29	20N	17W	Pyatt	Marion	1000	Zn-S,Si,CO_3 Pb-S	Powell
LS47	SW¼SE¼SW¼SW¼	26	20N	18W	Pyatt	Marion	3000	Pb-S	Cotter
LS48	NW¼SW¼NE¼NE¼	36	20N	19W	Zinc	Boone	1500	Zn-CO_3	Powell
LS49	SW¼SW¼NE¼NE¼	36	20N	19W	Zinc	Boone	1500	Zn-CO_3	Cotter
JB50	SE¼NE¼SE¼SE¼	2	16N	16W	Maumee	Searcy	1500	Zn-S	Boone
JB51	NE¼SE¼NE¼NE¼	11	16N	16W	Maumee	Searcy	500	Zn-S	Everton
JB52	NW¼SE¼SW¼SE¼	4	17N	16W	Yellville	Marion	3300	UNK	Boone
JB53	NW¼NW¼SW¼SE¼	4	17N	16W	Yellville	Marion	2300	UNK	Boone
JB54	NE¼SW¼SE¼NW¼	9	17N	16W	Yellville	Marion	1800	UNK	Boone
JB55	SW¼SW¼NE¼NE¼	9	17N	16W	Yellville	Marion	3600	UNK	Boone
JB56	NW¼SE¼SE¼NE¼	15	17N	16W	Maumee	Marion	7200	UNK	Everton
JB57	NW¼SE¼SE¼NE¼	15	17N	16W	Maumee	Marion	7200	UNK	Everton
JB58	NW¼NW¼NW¼SW¼	24	17N	16W	Maumee	Marion	6300	UNK	Everton
JB59	NE¼NW¼NE¼NE¼	25	17N	16W	Maumee	Marion	7600	UNK	Boone
JB60	NW¼SE¼SE¼NW¼	24	17N	16W	Maumee	Marion	8100	UNK	Boone
JB61	NW¼SE¼NE¼NE¼	3	16N	16W	Maumee	Searcy	3000	Zn-Si, CO_3	Powell
JB62	NW¼SW¼NE¼SW¼	21	16N	16W	Maumee	Searcy	7600	Zn-S	Boone
JB63	NE¼NW¼SW¼SW¼	30	17N	16W	Maumee	Marion	6600	UNK	Boone
JB64	NW¼NE¼SE¼NW¼	25	17N	17W	Maumee	Marion	7500	UNK	Everton
JB65	SW¼SW¼SE¼SE¼	24	17N	17W	Maumee	Marion	2100	UNK	Boone
JB66	NE¼NW¼NW¼SW¼	24	17N	17W	Maumee	Marion	3000	UNK	Everton

Table 1 (Continued)

Sample Number	Location: Quarter Secs.	Sec.	Town-ship	Range	Quad	County	Min. in ft.*	Type of ore	Formation
JB67	SE¼NE¼NE¼NW¼	24	17N	17W	Maumee	Marion	3600	UNK	Boone
KS68	NE¼SW¼NE¼NW¼	10	15N	23W	Boxley	Newton	7800	Pb-S	Boone
KS69	SE¼SW¼NE¼NW¼	15	15N	23W	Boxley	Newton	3800	Pb-S	Boone
KS70	NE¼NE¼SE¼SE¼	4	15N	23W	Boxley	Newton	9600	Pb-S	Cane Hill
KS71	NW¼NW¼SE¼SE¼	25	16N	23W	Ponca	Newton	3200	Pb-S $Zn-CO_3$	Everton
KS72	SE¼NW¼NW¼NE¼	18	16N	22W	Ponca	Newton	600	Pb-S	Everton

* Distance to known mineralization

GENERAL GEOLOGY

The rocks of northern Arkansas are mainly horizontal limestone, dolostone, shale and sandstone, and range in age from Pennsylvanian to Ordovician. Figure 2 shows the stratigraphic columns for the region; however, the oldest exposed rocks in the area are the Cotter and Jefferson City Dolomites. Springs in this area are usually located in the carbonate rocks. A brief summary of each of the three mineralized areas studied in this project are given below.

Ponca Area

Spring samples collected from the Ponca-Boxley mining district are simply referred to as from the Ponca area in this report. The Ponca-Boxley district lies in the valley of the upper Buffalo River in northwestern Newton County, Arkansas. Most of the deposits occur in the northwest side of the river and line up in a general northeast-southwest direction along the Ponca lineament (Smith, 1978 and McKnight, 1935). The ores are chiefly zinc carbonate and limestone. Some galena deposits also occur in the basal clay of the Batesville sandstone. Zinc silicate is present but rare. Most of the deposits are localized along fractures or faults. The production of the district has been about 2,500 tons of zinc concentrates and 1,500 tons of galena concentrates.

System		Formation	Member
PENNSYLVANIAN		Hartshorne ss. Atoka fm.	
	Morrow Group	Bloyd sh. (undiff.)	Kessler ls. Brentwood ls.
		Hale fm. (undiff.)	Prairie Grove Cane Hill
MISSISSIPPIAN		Pitkin ls. Fayetteville sh. Batesville ss. Ruddell sh. Moorefield fm. Boone fm. Chattanooga sh.	Wedington ss. Hindsville ls. Sylamore ss.
DEVONIAN		Penters chert	
SILURIAN		Lafferty ls. St. Clair ls. Brassfield ls.	
ORDOVICIAN		Cason sh.	
		Fernvale ls.	
		Kimmswick ls.	
		Plattin ls.	
		Joachim dol.	
		St. Peter ss.	
		Everton fm.	
		Powell dol.	
		Cotter dol.	
		Jefferson City dol.	
		Roubidoux fm.	
		Gasconade-Van Buren fm. (undiff.)	Gunter
CAMBRIAN		Eminence-Potosi fm. (undiff.)	
		Pre-Potosi (undiff)	
PRE-CAMBRIAN			

Figure 2. Generalized stratigraphic column for northwestern Arkansas. From Caplan (1957).

Rush Area

The Rush area described here includes the Maumee-Water Creek and Rush Creek districts which are located in Marion and Searcy counties. The Rush Creek district has been the most productive district in northern Arkansas. Most of the ores in the Rush area are the oxidized ore smithsonite and primary sphalerite. About 75-80% of more than 29,500 tons of concentrates being carbonates and the remainder sphalerite. The ore occurs in limestone, dolomite and dolomitic sandstone in the Everton Formation and in the Rush district ore also occurs in a discontinuously dolomitized limestone whose top is 160 feet below the St. Peter sandstone. The mineralization is thought to be generally associated with faulting (McKnight, 1935).

Zinc Area

The Zinc area includes the Zinc, Dodd City and West Sugarloaf Creek - Malden Creek districts located in Boone and Marion Counties. Most of the mineralization occurs in a silicified limestone and dolomite of the Everton, some in the Cotter and Powell dolomites and rare mineralization in the St. Joe limestone. In the Zinc district most of the ore is zinc silicate instead of carbonate and some sphalerite. The Dodd City district ores include sphalerite, smithsonite, calamine and some galena. Although the West Sugarloaf - Malden Creek area ores are only zinc sulfide and carbonate located in the Powell and Cotter dolomites, only two springs were located in this district. Thus, the unique aspect of the Zinc area is the preponderance of zinc silicate mostly located in the Everton.

METHODOLOGY

Temperature, pH, conductivity and total alkalinity as mg/l $CaCO_3$ were determined in the field on raw water samples. A one liter sample and a 500 milliliter sample were filtered through a 0.45 micron pore-size membrane using a freon-pressurized unit. The one liter sample was acidified with three milliliters of 1:1 nitric acid for cation analyses in the laboratory. The 500 milliliter sample was refrigerated for anion, silica and ammonia analyses also at the laboratory.

U.S. Environmental Protection Agency (EPA, 1974) Standard Methods (APHA, 1971) and Hach Chemical Company (1976) methods were used for analyses. See Table 2 for summary of the analytical methods used. Several springs were sampled two times. The analytical results for these samples include not only analytical variability but also collection and natural variability as well. The replicate samples are listed below.

NA 16 = NA 64
NA 18 = NA 63
NA 20 = NA 62

NA 5 = LS 19
NA 19 = LS 24
NA 26 = LS 25
NA 29 = LS 22

Table 2. Summary of analytical methods. The method used is indicated in ( ). If no ( ), then the method is the same as or slightly modified EPA method.

Parameter	Method	
Temperature	thermometer	
pH	pH meter	
Specific Conductivity	conductivity meter	
Total alkalinity	titration to methyl red end point with 0.02N sulfuric acid (APHA)	
NO_3	colorimetry	cadmium reduction (HACH)
NH_4	colorimetry	phenate and nesslerization during early analyses*(APHA)
PO_4 (ortho, dissolved)	colorimetry	ascorbic acid (APHA)
SO_4	colorimeter	turbidimetric (APHA)
Cl	colorimetry	Mercuric nitrate (APHA)
F	colorimetry	SPADNS
SiO_2	colorimetry	heteropoly blue (APHA)

*Nesslerization method used for samples collected on or before 11/1/1981.

Table 2 (Continued)

Parameter	Method	
Ca, Mg, Ba	AAS*	C_2H_2-N_2O flame, CsCl added
Sr	flame emission	C_2H_2-N_2O flame, CsCl added
Na, K, Li	flame emission	H_2-air flame, CsCl added
Hg	flameless	AAS
Zn, Pb, Fe, Cu, Ni, Co, Mn, ± 10%	C_2H_2-air flame	chelation - extraction method of Nix and Goodwin, 1974.

*ASS = atomic absorption spectrometry

NA 49 = LS 27
NA 52 = LS 21
NA 58 = LS 26
NA 66 = LS 20
LS 17 = JB 65

Many of these samples have values mostly within analytical error. In a few cases, however, significantly different values are obtained. Considering that the samples were usually collected in different seasons, it is possible that the differences are simply natural variability.

Data for the individual samples are presented in Tables 3-8. Selected samples were selected for Ba, F and Hg determinations (Table 9). A total of 47 spring samples including one well sample were collected in the Ponca area, 52 spring samples were collected in the Rush area and 42 spring samples were collected in the Zinc area. The one well sample was collected for comparative purposes and is not used for any interpretations or included in any discussions.

WATER QUALITY

The ground water from the springs of the northern part of Arkansas is classed as calcium bicarbonate water with a total hardness value of about 170 mg/l as $CaCO_3$ on the average. Generally the spring water of this area is of good quality; however, several springs do exceed drinking water limits (see Table 10) for the

Table 3. General Water Chemistry of Ponca Area

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
NA 16	3/29/81	13	257	160	7.6	.07	3.0	.04	6.7	< 5.0	.11
NA 17	3/29/81	14	327	190	7.6	<.01	3.0	.15	4.9	17.2	.75
NA 18	3/29/81	14	305	190	7.6	<.01	2.7	.08	5.2	9.0	.60
NA 19	3/29/81	12	208	125	7.8	.02	4.3	1.56	6.4	19.0	.51
NA 20	3/29/81	12	126	80	7.5	<.01	2.4	1.08	3.1	9.0	.17
NA 21	5/ 9/81	16	182	135	7.2	.06	2.4	<.01	5.1	< 5.0	1.30
NA 22	5/ 9/81	15	202	110	6.6	<.01	3.8	<.01	4.6	21.0	.06
NA 23	8/29/81	18	410	310	7.6	<.01	1.9	.97	4.6	12.0	.11
*NA 24	8/29/81	21	441	255	7.1	<.01	2.4	.31	4.9	23.5	.09
NA 25	8/29/81	18	271	70	7.5	.07	1.1	.24	5.2	< 5.0	<.02
NA 26	8/29/81	18	376	110	7.2	.12	1.2	.17	5.3	< 5.0	.30
NA 27	8/29/81	18	373	260	7.4	<.01	1.6	.22	5.2	8.0	.45
NA 28	8/29/81	17	400	300	7.3	<.01	1.2	.20	5.8	< 5.0	.04
NA 29	8/29/81	17	313	220	7.3	<.01	2.3	.22	5.4	5.5	.35
NA 30	8/29/81	16	366	240	7.7	<.01	1.1	.02	5.4	< 5.0	.40
NA 31	8/30/81	26	361	220	8.0	<.01	2.2	.75	6.8	12.0	.02
NA 32	8/30/81	19	336	200	7.5	<.01	0.8	.28	5.3	< 5.0	.04
NA 33	8/30/81	17.5	316	205	7.2	<.01	1.3	.18	5.7	< 5.0	.17
NA 34	8/30/81	19	291	215	7.7	<.01	1.6	.13	6.0	< 5.0	<.02
NA 35	8/30/81	21	346	215	7.4	.47	0.6	.05	5.7	< 5.0	<.02
NA 36	8/30/81	19.5	231	150	7.1	<.01	1.2	<.01	6.1	< 5.0	<.02
NA 37	8/30/81	17	215	130	7.1	<.01	2.1	.04	6.3	< 5.0	<.02
NA 38	8/30/81	16.5	216	140	7.1	<.01	1.8	.04	6.4	< 5.0	.02

Table 3 (Continued)

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
NA 49	9/19/81	16	297	170	7.3	.09	1.1	.02	6.0	< 5.0	.02
NA 50	9/19/81	16.5	412	240	7.2	.01	0.9	.18	5.8	6.7	.04
NA 51	9/19/81	15	372	205	7.6	.01	1.0	.24	6.4	13.5	.04
NA 52	9/20/81	14	275	145	7.1	.01	1.4	.14	7.6	5.2	.13
NA 53	9/20/81	15	312	165	7.7	.02	0.9	.07	5.7	< 5.0	.04
NA 54	9/20/81	16	372	215	7.6	.01	0.8	.03	6.0	< 5.0	.10
NA 55	9/20/81	17.5	428	260	7.7	.01	1.5	.07	5.6	< 5.0	.07
NA 56	9/20/81	18	447	250	7.2	.04	0.8	<.01	6.5	< 5.0	.15
NA 57	9/20/81	17.5	359	210	7.4	<.01	1.5	<.01	7.6	< 5.0	.14
NA 58	9/20/81	15	218	135	7.3	<.01	1.3	<.01	7.1	< 5.0	.14
NA 59	10/ 9/81	18	43	25	5.5	<.01	1.6	.19	7.8	< 5.0	.90
NA 60	10/ 9/81	16.5	12	15	5.2	<.01	1.1	.12	6.7	5.0	.06
NA 61	10/ 9/81	15	358	200	7.3	<.01	1.2	<.01	5.4	5.0	.34
NA 62	10/ 9/81	15.5	383	220	7.2	<.01	0.9	.07	5.3	17.7	.38
NA 63	10/ 9/81	14.5	394	230	7.6	<.01	1.4	.07	6.2	16.0	.20
NA 64	10/ 9/81	15.5	259	165	7.0	<.01	1.5	.02	7.1	< 5.0	.05
LS 21	5/24/82	14.0	257	120	7.2	.05	2.5	<.01	4.9	18.2	.56
LS 22	5/24/82	15.5	298	175	7.7	.02	1.6	<.01	4.5	9.0	.46
LS 23	5/24/82	14.0	239	130	7.8	.01	0.9	<.01	4.7	8.5	.08
LS 24	5/24/82	16.0	358	150	7.5	.02	2.1	.07	4.4	14.8	.91
LS 25	5/24/82	15.0	350	190	7.6	.04	0.7	<.01	4.4	17.2	.51
LS 26	5/24/82	17.0	219	110	7.7	.05	1.7	.03	5.7	6.2	.23
LS 27	5/24/82	15.0	254	130	7.5	.26	2.5	.05	4.6	12.2	.20

Table 3 (Continued)

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
KS 68	1/27/83	12.0	139	70	6.9	.19	2.8	<.01	4.6	18.2	.01
KS 69	1/27/83	12.0	220	155	7.5	.01	2.8	<.01	3.4	12.5	.24
KS 70	1/27/83	12.0	288	230	7.0	.17	1.8	<.01	5.8	9.5	.04
KS 71	1/27/83	12.0	316	250	7.8	.14	0.7	<.01	4.4	8.5	.06
KS 72	1/27/83	8.0	147	85	-	<.01	1.8	.02	4.8	9.5	.14

* Well Sample

Table 4. General Water Chemistry of Rush Area

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
NA 1	3/18/81	10	254	180	7.9	.04	3.5	.06	6.0	< 5.0	.33
NA 2	3/18/81	13	151	100	7.9	.03	5.5	.04	5.8	< 5.0	.41
NA 3	3/18/81	11	259	175	8.3	.02	4.4	.06	5.6	8.5	.08
NA 4	3/18/81	11	310	215	7.7	<.01	4.5	.09	5.4	< 5.0	.13
NA 5	3/19/81	15	422	280	8.2	.04	2.4	.18	5.1	10.0	.08
NA 6	3/19/81	16	472	305	7.6	.03	2.5	.10	5.4	< 5.0	.04
NA 7	3/19/81	13.5	194	130	7.9	.16	2.9	.05	6.3	< 5.0	.13
NA 8	3/19/81	13	546	410	7.8	<.01	2.4	.50	4.4	6.7	.16
NA 9	3/19/81	11	397	295	7.8	<.01	4.2	.16	4.4	10.0	.29
NA 10	3/19/81	11.5	445	300	7.6	.03	3.3	.18	4.5	12.2	.31
NA 11	3/19/81	11.5	432	270	7.4	.10	4.2	.16	5.9	< 5.0	.20
NA 12	3/19/81	14	348	200	7.4	.10	4.0	.08	7.4	< 5.0	1.20
NA 13	3/19/81	8.5	146	90	8.1	<.01	4.9	.09	6.0	< 5.0	.35
NA 14	3/19/81	13	136	70	7.2	<.01	10.2	.09	5.9	< 5.0	.40
NA 15	3/19/81	13.5	351	225	7.6	.11	3.7	.09	7.7	< 5.0	.60
LS 1	5/ 6/82	14.0	344	190	7.0	<.01	2.0	.02+	6.1	8.5	.43
LS 2	5/ 6/82	14.0	293	170	7.2	<.01	1.6	.04+	6.7	10.6	<.03
LS 3	5/ 6/82	15.0	326	170	7.6	<.01	1.6	.02+	5.9	8.5	.36
LS 4	5/ 6/82	14.0	368	205	7.1	<.01	2.5	.02+	5.5	12.0	--
LS 5	5/ 6/82	14.5	218	95	7.1	<.01	2.0	.02+	6.4	10.6	--
LS 6	5/ 6/82	14.0	323	190	7.3	<.01	6.0	.02+	5.7	8.5	.43
LS 7	5/ 6/82	14.0	427	210	6.9	<.01	22.5	.02+	6.7	6.2	.12
LS 8	5/ 6/82	14.0	293	165	6.8	<.01	7.3	.02+	6.9	7.5	.13

Table 4 (Continued)

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as Mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
LS 9	5/ 7/82	12.5	250	115	7.5	<.01	9.1	$.02^+$	6.2	11.2	.30
LS 10	5/ 7/82	13.5	320	105	7.9	<.01	34.9	$.02^+$	6.9	12.0	--
LS 11	5/ 7/82	14.0	427	210	7.4	<.01	4.7	$.02^+$	6.5	8.5	.41
LS 12	5/ 7/82	10.5	222	100	7.6	<.01	3.3	$.02^+$	7.1	10.6	--
LS 13	5/ 7/82	14.5	348	160	7.4	<.01	10.9	$.01^+$	6.2	13.5	<.03
LS 14	5/ 7/82	15.0	342	140	7.6	<.01	1.1	$.02^+$	5.5	16.4	<.03
LS 15	5/ 7/82	14.5	460	240	7.3	<.01	2.0	$.03^+$	6.7	10.6	.36
LS 16	5/ 7/82	16.0	446	180	7.6	<.01	1.6	$.02^+$	6.1	4.3	.20
LS 17	5/ 7/82	14.5	489	235	7.1	<.01	13.1	$.04^+$	7.9	14.8	--
LS 18	5/ 7/82	17.0	476	210	7.3	<.01	15.8	$.04^+$	6.9	6.2	.48
LS 19	5/ 7/82	15.5	490	235	7.8	<.01	1.1	$.04^+$	5.7	10.6	.03
JB 50	1/ 8/83	11.0	281	210	6.9	.05	1.6	.16	4.9	9.5	.16
JB 51	1/ 8/83	7.0	204	105	8.0	.05	1.4	.06	4.7	8.5	.06
JB 52	1/15/83	11.0	377	270	7.2	<.01	3.0	<.01	5.8	7.6	.03
JB 53	1/15/83	12.0	287	230	7.0	<.01	9.1	<.01	6.0	4.2	.23
JB 54	1/15/83	12.0	402	275	7.3	<.01	0.9	<.01	5.6	10.1	--
JB 55	1/15/83	14.0	359	240	7.3	<.01	3.0	<.01	6.2	6.2	1.36
JB 56	1/15/83	10.0	150	105	8.2	<.01	4.2	<.01	4.2	4.2	.16
JB 57	1/15/83	11.0	146	105	8.0	<.01	4.9	.03	5.0	6.2	.40
JB 58	1/15/83	12.0	173	135	7.7	<.01	4.4	<.01	4.6	8.5	.29
JB 59	1/16/83	9.0	277	185	7.3	<.01	9.1	<.01	-	7.6	.45
JB 60	1/16/83	9.0	218	155	8.2	<.01	3.3	<.01	-	12.5	.13

Table 4 (Continued)

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as Mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
JB 61	1/16/83	11.0	356	280	7.8	<.01	3.5	<.01	–	4.2	2.66
JB 62	1/16/83	12.0	313	265	7.9	.02	2.1	<.01	–	9.5	.39
JB 63	1/16/83	13.0	177	130	7.4	<.01	2.6	<.01	–	6.2	--
JB 64	1/16/83	13.0	304	200	7.6	.05	6.5	<.01	–	8.5	1.68
JB 65	1/16/83	14.0	337	175	7.4	<.01	9.1	<.01	–	9.5	2.91
JB 66	1/16/83	13.0	530	205	7.1	.17	45.1	<.01	–	55.0	20.23
JB 67	1/16/83	13.0	426	255	7.3	<.01	27.9	.05	–	8.5	1.93

[+]Analysis on acidified (HNO_3) samples.

Table 5. General Water Chemistry of Zinc Area.

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
NA 39	9/ 7/81	19.5	438	220	7.2	.03	2.2	1.53	6.1	9.0	.04
NA 40	9/ 7/81	19	394	220	7.4	.03	6.2	.42	6.4	< 5.0	.20
NA 41	9/ 7/81	16	389	220	7.3	.02	2.1	.14	6.0	< 5.0	1.10
NA 42	9/ 7/81	17	348	190	7.0	.03	1.5	.14	6.3	< 5.0	1.90
NA 43	9/ 7/81	18.5	350	200	7.8	<.01	1.1	.04	6.4	< 5.0	.30
NA 44	9/ 7/81	17	510	280	7.1	<.01	1.1	.87	6.4	< 5.0	.40
NA 45	9/ 7/81	17	429	235	7.0	<.01	4.1	.66	7.5	< 5.0	2.20
NA 46	9/ 7/81	16.5	385	230	7.0	<.01	1.5	.98	7.0	< 5.0	.70
NA 47	9/ 7/81	17	284	150	7.1	<.01	2.0	2.34	6.7	< 5.0	.70
NA 48	9/ 7/81	15.5	286	165	7.6	<.01	2.8	1.48	7.5	< 5.0	1.40
NA 65	10/31/81	15	294	150	7.7	<.01	1.3	.29	7.1	< 5.0	.23
NA 66	10/31/81	15	294	170	7.4	<.01	2.0	.32	6.4	< 5.0	.04
NA 67	10/31/81	15	168	90	7.7	.01	1.3	.32	6.0	< 5.0	<.02
NA 68	11/ 1/81	15.5	428	240	6.8	.01	1.8	.39	6.4	< 5.0	.60
NA 69	11/ 1/81	16	443	250	7.1	<.01	2.2	.44	7.1	< 5.0	<.02
NA 70	11/ 1/81	15	240	145	7.4	<.01	2.5	.33	6.2	< 5.0	.47
NA 71	11/ 1/81	15	422	250	7.3	<.01	1.4	.44	7.0	10.5	.05
NA 72	11/ 1/81	15.5	240	130	7.3	<.01	2.0	.46	5.8	< 5.0	.03
NA 73	11/ 1/81	15	312	135	7.3	<.01	1.5	.26	5.8	< 5.0	<.02
NA 74	11/ 1/81	14	264	140	7.3	.05	1.7	.15	5.5	< 5.0	.04
LS 20	5/ 7/82	13.0	229	120	7.3	<.01	2.0	$.02^+$	6.1	7.6	.06

Table 5 (Continued)

Sample Number	Collection Date	Temperature of Sample °C	Spec. Cond. Normal'd to 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm
LS 28	8/28/82	17.0	357	210	7.3	.02+	3.8	<.01*	7.6*	4.2+	--
LS 29	8/28/82	18.0	410	290	7.3	.01+	4.0	<.01*	8.2*	6.2+	--
LS 30	8/28/82	17.0	486	285	7.2	.01+	3.3	<.01*	8.5*	7.6+	--
LS 31	8/28/82	17.0	290	215	6.5	.01+	2.0	<.01*	7.9*	7.6+	--
LS 32	8/28/82	16.0	340	205	6.7	.01+	3.5	.01*	7.6*	8.5+	--
LS 33	8/28/82	15.0	414	260	6.7	.02+	6.5	.03*	7.6*	6.2+	--
LS 34	8/28/82	16.0	313	150	6.8	.02+	3.0	.03*	6.6*	7.6+	--
LS 35	8/28/82	16.0	307	185	7.0	.02+	3.3	<.01*	6.8*	11.2+	--
LS 36	8/28 82	15.0	362	210	7.1	.01+	2.5	.02*	7.3*	4.2+	--
LS 37	8/28/82	15.0	330	175	7.4	.01+	3.8	<.01*	6.8*	4.2+	--
LS 38	8/28/82	15.0	374	220	6.5	--	3.3	<.01*	7.3*	--	--
LS 39	8/28/82	15.0	313	165	6.8	.01+	2.0	.01*	4.6*	6.2+	--
LS 40	8/28/82	16.5	415	235	6.8	.01+	4.3	<.01*	7.6*	8.5+	--
LS 41	8/28/82	17.0	394	235	7.3	.02+	3.0	<.01*	7.6*	6.2+	--
LS 42	9/25/82	15.5	383	250	6.8	.02+	3.0	<.01*	7.3*	4.2+	--
LS 43	9/26/82	15.5	321	160	7.4	.07+	4.3	.07*	7.0*	7.6+	--
LS 44	9/26/82	15.0	258	150	7.4	.01+	4.3	.01*	6.6*	7.6+	--
LS 45	9/26/82	14.0	238	150	7.8	.01+	0.8	.03*	6.0*	<4.2+	--
LS 46	9/26/82	17.5	301	195	7.4	.01+	2.3	.03*	7.0*	6.2+	--
LS 47	9/26/82	15.0	552	315	7.0	<.01+	1.3	.03*	6.8*	11.9+	
LS 48	9/26/82	16.0	236	130	7.3	.01+	4.0	.02*	7.0*	8.5+	--
LS 49	9/26/82	16.0	425	265	6.8	<.01+	2.0	.04*	7.6*	4.2+	--

* Analysis exceeded EPA holding time by several days   + Analysis on acidified (HNO_3) Samples

Table 6. Metal analyses for Ponca area.

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
NA 16	6	13	-	28	4	3	10	3	1.9	0.80	49	2.4	0.046
NA 17	4	13	-	18	4	7	10	3	1.5	0.50	65	3.9	0.048
NA 18	<1	<5	-	8	1	3	4	2	1.5	0.64	63	4.0	0.048
NA 19	25	100	-	239	20	33	27	3	1.5	2.00	42	2.2	0.038
NA 20	6	27	-	373	17	14	15	2	1.2	1.00	25	1.7	0.022
NA 21	6	20	-	18	2	11	10	3	1.3	0.40	38	0.9	0.040
NA 22	9	7	-	58	2	7	10	2	2.7	1.20	32	4.9	0.066
NA 23	4	<5	-	<4	<1	3	4	3	1.1	0.66	90	3.7	0.048
*NA 24	275	<5	-	18	2	3	4	2	1.4	1.05	73	12.5	0.055
NA 25	63	41	-	18	2	14	15	2	0.8	0.64	37	13.1	0.024
NA 26	39	48	-	28	4	18	15	<2	1.1	0.66	73	3.6	0.036
NA 27	13	<5	-	8	2	3	3	<2	1.3	0.90	77	1.5	0.044
NA 28	11	<5	-	18	2	3	<1	<2	0.8	0.60	84	2.0	0.038
NA 29	19	27	-	38	4	18	10	<2	1.6	1.05	53	8.3	0.035
NA 30	11	20	-	8	2	11	4	3	1.6	0.64	71	3.8	0.053
NA 31	7	<5	-	18	20	11	4	3	2.2	1.40	63	7.7	0.100
NA 32	14	<5	-	<4	2	7	4	3	0.7	0.74	71	0.6	0.033
NA 33	13	7	-	8	4	11	4	2	1.5	0.66	52	9.7	0.035
NA 34	11	34	-	8	2	18	10	2	1.0	0.40	59	1.1	0.030
NA 35	9	20	-	<4	6	11	4	3	0.9	0.66	53	1.0	0.035
NA 36	17	48	-	18	8	22	15	3	1.4	1.10	43	2.7	0.035
NA 37	9	20	-	8	4	11	10	3	1.2	0.80	41	1.4	0.031
NA 38	13	41	-	58	8	18	10	3	1.2	1.00	42	1.4	0.031
NA 49	-	-	-	-	-	-	-	-	2.0	1.10	60	2.4	0.055
NA 50	17	7	-	18	15	11	4	3	1.8	0.60	87	3.0	0.145
NA 51	11	13	-	18	15	11	4	3	6.6	1.05	69	6.0	0.165

Table 6 (continued)

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
NA 52	20	34	-	28	6	18	10	3	1.3	0.47	55	1.3	0.040
NA 53	52	<5	-	90	8	7	4	13	1.1	0.74	69	1.7	0.042
NA 54	6	<5	-	<4	<1	7	<1	3	1.2	0.57	79	1.5	0.042
NA 55	4	<5	-	8	<1	7	<1	3	1.2	0.50	97	1.2	0.044
NA 56	7	7	-	8	2	11	4	3	1.5	0.70	98	2.3	0.055
NA 57	4	<5	-	38	<1	7	<1	3	1.3	0.33	80	0.7	0.033
NA 58	11	27	-	18	2	18	4	3	0.9	0.57	39	6.5	0.030
NA 59	17	13	-	38	11	14	4	3	1.8	0.50	5	1.2	0.024
NA 60	14	20	-	100	20	14	4	3	0.9	0.44	2	0.5	0.007
NA 61	7	<5	-	8	2	11	4	3	1.0	0.60	78	1.0	0.036
LS 21	8	29	2	9	<3	5	2	<3	1.9	0.56	51	1.9	0.044
LS 22	8	45	2	9	6	8	2	<3	1.9	0.82	52	7.9	0.031
LS 23	8	40	1	6	<3	3	<1	<3	-	0.50	32	11.9	0.019
LS 24	11	34	2	15	57	8	1	<3	2.2	0.68	71	3.4	0.060
LS 25	6	<4	<1	<3	<3	<3	<1	<3	1.4	0.54	72	3.1	0.036
LS 26	2	<4	<1	<3	<3	<3	<1	<3	1.4	0.48	38	6.0	0.272
LS 27	32	34	2	12	5	3	1	<3	2.4	0.96	51	2.2	0.044
KS 68	10	6	2	97	5	10	5	5	1.9	0.57	31	1.3	0.027
KS 69	7	6	2	<6	<4	10	5	5	1.9	0.70	70	1.7	0.064
KS 70	4	<6	<2	<6	<4	<5	<5	<5	2.3	0.74	84	3.4	0.165
KS 71	4	6	2	<6	<4	<5	<5	<5	1.0	0.48	93	1.6	0.047
KS 72	<2	<6	<2	<6	<4	<5	<5	<5	1.0	0.48	32	1.8	0.036

Table 7. Metal analyses for Rush area.

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
NA 1	9	14	-	10	9	<1	8	<2	1.8	0.86	60	2.0	0.041
NA 2	5	14	-	15	5	<1	8	<2	2.2	0.76	52	0.9	0.027
NA 3	9	28	-	10	2	7	13	<2	1.5	0.74	56	4.8	0.038
NA 4	8	14	-	4	3	<1	5	<2	1.7	0.80	60	11.7	0.038
NA 5	26	38	-	36	22	7	18	2	0.9	0.53	76	17.1	0.048
NA 6	41	5	-	17	2	<1	8	<2	0.8	0.66	90	14.3	0.064
NA 7	6	21	-	10	2	<1	8	<2	1.4	0.80	42	1.6	0.031
NA 8	23	<5	-	4	2	<1	8	<2	0.8	0.66	86	34.5	0.058
NA 9	6	8	-	4	2	<1	5	<2	0.8	1.00	53	30.0	0.036
NA 10	11	5	-	4	2	<1	8	<2	1.3	0.74	60	32.0	0.036
NA 11	5	<5	-	15	4	<1	2	<2	1.5	0.86	69	23.0	0.040
NA 12	8	<5	-	4	1	<1	8	<2	1.7	0.74	48	22.0	0.031
NA 13	5	<5	-	10	4	<1	10	<2	2.0	0.70	31	1.4	0.027
NA 14	4	<5	-	4	3	<1	8	<2	4.8	0.92	22	0.8	0.017
NA 15	6	<5	-	12	2	<1	13	<2	1.7	0.80	51	19.5	0.027
LS 1	242	34	2	13	<3	8	2	<3	1.8	0.68	64	7.3	0.040
LS 2	26	24	2	28	3	5	2	<3	1.3	0.50	64	0.8	0.042
LS 3	15	34	2	9	8	16	2	<3	1.6	0.68	72	1.0	0.042
LS 4	8	34	<1	6	<3	3	1	<3	1.9	0.82	82	1.0	0.044
LS 5	26	24	1	9	<3	5	1	<3	1.4	0.74	46	1.1	0.029
LS 6	162	14	1	9	<3	8	2	<3	1.9	0.51	69	0.7	0.038
LS 7	12	<4	<1	<3	<3	<3	<1	<3	5.3	0.84	85	1.2	0.060
LS 8	26	40	2	12	3	13	2	<3	3.0	0.82	59	1.2	0.042

Table 7 (Continued)

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
LS 9	12	4	<1	6	<3	5	<1	<3	5.5	0.97	50	1.0	0.038
LS 10	2	<4	<1	3	<3	3	<1	<3	9.6	1.10	51	1.1	0.040
LS 11	11	29	1	6	<3	8	2	<3	2.4	0.82	64	21.6	0.038
LS 12	<1	8	<1	<3	<3	3	<1	<3	2.3	0.70	42	0.8	0.023
LS 13	26	40	2	6	<3	16	2	<3	3.3	0.83	64	2.8	0.048
LS 14	252	4	<1	<3	<3	<3	<1	<3	1.0	0.60	55	6.1	0.040
LS 15	32	45	3	9	<3	16	3	<3	2.0	0.72	69	16.1	0.040
LS 16	18	8	<1	6	<3	<3	<1	<3	1.9	0.72	64	15.0	0.040
LS 17	16	40	2	12	5	11	2	<3	5.5	0.76	92	2.2	0.060
LS 18	27	<4	<1	6	9	<3	<1	<3	5.1	0.46	88	1.6	0.048
LS 19	8	24	1	6	<3	<3	1	<3	1.4	0.66	83	17.5	0.057
JB 50	12	<6	<2	<6	<4	10	<5	5	1.8	0.98	79	1.2	0.053
JB 51	9	<6	<2	<6	<4	5	5	<5	1.3	0.88	46	0.9	0.036
JB 52	12	<6	4	<6	<4	<5	<5	<5	1.7	0.54	105	1.4	0.053
JB 53	12	<6	2	<6	5	5	<5	5	1.8	0.50	89	1.0	0.047
JB 54	12	10	3	6	<4	10	10	<5	3.1	0.62	118	1.1	0.061
JB 55	17	10	2	<6	<4	10	<5	<5	2.2	0.44	100	1.4	0.055
JB 56	4	<6	<2	<6	<4	<5	<5	<5	2.8	0.82	42	0.8	0.032
JB 57	7	<6	2	<6	<4	<5	<5	<5	2.8	0.84	40	0.8	0.032
JB 58	7	<6	<2	<6	<4	<5	<5	<5	3.3	0.82	47	1.6	0.034
JB 59	13	10	2	10	4	<5	<5	11	5.0	0.86	64	1.4	0.041
JB 60	8	6	2	6	<4	5	5	<5	2.3	0.86	56	1.4	0.041
JB 61	13	10	3	<6	<4	5	10	<5	1.8	0.44	101	0.7	0.050
JB 62	8	10	2	<6	<4	5	5	<5	1.4	0.66	83	1.4	0.041
JB 63	9	6	2	<6	<4	5	5	<5	1.9	0.82	44	1.0	0.032
JB 64	14	<6	2	6	4	10	10	<5	2.7	0.80	64	12.4	0.041

Table 7 (Continued)

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
JB 65	12	6	2	6	4	10	5	<5	5.0	0.84	91	1.8	0.055
JB 66	12	6	2	6	4	10	<5	<5	20.0	4.10	97	18.3	0.090
JB 67	7	6	2	<6	<4	5	5	<5	5.7	0.57	109	3.9	0.064

Table 8. Metal analyses for Zinc area.

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
NA 39	9	41	-	15	12	7	15	<2	1.7	1.15	71	14.9	0.058
NA 40	8	21	-	25	13	4	13	<2	1.5	0.50	84	3.3	0.052
NA 41	6	5	-	12	3	<1	13	<2	1.4	0.76	74	7.2	0.040
NA 42	28	41	-	10	4	12	21	<2	1.5	0.53	75	2.6	0.044
NA 43	6	21	-	10	2	1	10	<2	1.4	0.66	69	2.0	0.042
NA 44	9	14	-	4	1	1	5	<2	1.8	1.10	100	6.0	0.070
NA 45	44	24	-	10	<1	7	13	<2	2.2	1.70	85	3.1	0.058
NA 46	25	11	-	7	1	7	8	<2	1.6	0.74	79	2.4	0.048
NA 47	85	41	-	10	2	18	21	<2	2.0	1.05	55	2.2	0.040
NA 48	18	14	-	4	<1	4	13	<2	1.7	0.92	57	1.2	0.036
NA 65	36	24	-	12	3	10	13	<2	1.4	0.86	60	2.7	0.040
NA 66	24	38	-	17	3	12	13	2	1.7	1.05	57	3.0	0.044
NA 67	9	18	-	15	4	7	18	<2	1.2	0.70	35	1.1	0.022
NA 68	39	21	-	17	4	4	10	<2	2.2	1.20	83	5.7	0.070
NA 69	21	14	-	50	5	1	5	<2	2.2	0.92	82	11.1	0.066
NA 70	13	34	-	25	55	7	13	<2	2.0	1.00	49	2.1	0.038
NA 71	12	28	-	41	3	7	8	<2	1.4	0.80	71	16.5	0.058
NA 72	20	48	-	166	97	12	8	<2	1.7	1.15	47	4.2	0.042
NA 73	8	24	-	10	4	7	13	<2	1.6	1.00	65	2.2	0.050
NA 74	9	21	-	12	6	4	5	<2	1.5	1.10	55	2.3	0.042
LS 20	17	50	3	12	3	11	2	<3	1.8	0.86	44	2.0	0.031
LS 28	31	34	<2	27	11	16	9	<6	1.8	0.78	64	1.8	0.039
LS 29	14	11	2	19	11	8	9	<6	1.9	1.51	73	11.2	0.050
LS 30	20	15	<2	19	20	8	9	<6	2.5	0.95	80	11.1	0.056

Table 8 (Continued)

Sample Number	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppm
LS 31	32	<8	<2	19	7	<4	<5	<6	2.0	1.10	61	5.0	0.046
LS 32	22	<8	<2	<11	4	4	<5	<6	2.2	0.95	64	3.3	0.048
LS 33	36	<8	<2	34	38	4	<5	<6	4.4	2.45	76	7.2	0.070
LS 34	11	<8	<2	<11	4	<4	<5	<6	1.9	1.22	55	2.6	0.041
LS 35	17	11	<2	<11	<3	4	<5	<6	2.0	1.28	56	3.1	0.041
LS 36	9	<8	<2	<11	<3	4	<5	<6	2.4	0.92	68	2.0	0.044
LS 37	31	24	<2	<11	4	16	9	<6	2.1	0.95	62	2.1	0.039
LS 38	-	-	-	-	-	-	-	-	-	-	-	-	-
LS 39	32	28	6	<11	4	16	9	<6	1.8	0.60	60	1.2	0.036
LS 40	64	24	2	<11	17	12	9	<6	2.2	1.38	74	5.9	0.050
LS 41	54	<8	<2	<11	4	4	<5	<6	2.8	1.22	74	4.4	0.050
LS 42	85	15	3	11	24	12	<5	<6	3.0	0.72	76	3.7	0.046
LS 43	25	11	<2	<11	4	8	<5	<6	4.2	2.20	56	4.5	0.070
LS 44	31	24	<2	11	4	16	<5	<6	2.7	1.48	47	2.5	0.046
LS 45	24	41	2	19	3	8	14	<6	1.7	1.00	45	2.0	0.034
LS 46	27	15	<2	11	<3	12	<5	<6	1.9	1.14	52	6.8	0.039
LS 47	214	15	2	<11	<3	8	<5	<6	1.9	1.10	68	30.8	0.046
LS 48	47	31	<2	11	<3	16	9	<6	3.0	1.20	45	2.8	0.043
LS 49	82	18	<2	27	24	12	9	<6	1.6	0.83	76	11.3	0.050

Table 9. Analysis of selected samples for Hg, Ba and F(Zn and Pb values shown for comparison).

Sample Number	Zn ppb	Pb ppb	Hg ppb	Ba ppb	F ppm
LS 1	242	34	<0.1	10	0.13
LS 8	26	40	<0.1	15	0.13
LS 10	2	<4	0.7	12	0.13
LS 13	26	40	<0.1	8	0.13
LS 14	252	<4	<0.1	4	0.17
LS 15	32	45	<0.1	4	0.17
LS 20	17	50	<0.1	5	0.13
LS 25	6	<4	<0.1	8	0.13
LS 26	2	<4	<0.1	7	0.13
LS 27	32	34	<0.1	8	0.13
NA 18	<1	<5	<0.1	5	0.13
NA 23	4	<5	0.8	12	0.13
NA 25	63	41	<0.1	3	0.13
NA 26	39	48	<0.1	6	0.17
NA 29	19	27	<0.1	6	0.13
NA 36	17	48	0.3	8	0.13
NA 52	20	34	<0.1	9	0.13
NA 55	4	<5	<0.1	14	0.08

Table 10. Variable, precision, recommended limits (for drinking water) for water chemistry parameters.

Variable		Precision	Detection Limits	Limits
Temperature	°C	± 0.5	0.50	-
Specific Conductance	μmhos/cm at 25°C	± 5.	2.00	-
Alkalinity	ppm $CaCO_3$	± 5.	5	-
pH		± 0.1	.01	5 - 9[1]
PO_4^{-3}	as P ppm	± 0.02	.01	-
Cl^-	ppm	± 0.30	.30	250[2]
NH_4^+	as N ppm	± 0.02	.01	0.5[2]
SiO_2	ppm	± 2.00	0.20	-
SO_4^{-2}	ppm	± 5.0	2.0	250[2]
NO_3^-	as N ppm	± 0.5	.02	10[1]
F^-	ppm	± 0.05	.05	-
Zn	ppb	± 10%	2	5000[1]
Pb	ppb	± 10%	5	50[1]

Table 10 (Continued)

Variable		Precision	Detection Limits	Limits
Fe	ppb	± 10%	10	300[1]
Cu	ppb	± 10%	1	1000[1]
Ni	ppb	± 10%	4	-
Co	ppb	± 10%	5	-
Mn	ppb	± 10%	2	50[1]
NA	ppm	± 10%	0.1	-
K	ppm	± 10%	0.1	-
Sr	ppm	± 10%	0.002	-
Ca	ppm	± 10%	1.0	200[3]
Mg	ppm	± 10%	0.05	150[3]
Ba	ppb	± 10%	4	1000[1]
Hg	ppb	± 10%	.1	2[1]

[1]EPA (1976)
[2]Public Health Service (1962)
[3]World Health Organization (1971)

limits used).

Ten springs, (NA 19, NA 20, NA 31, NA 39, NA 44, NA 45, NA 46, NA 47, and NA 48) exceed the ammonium limit of 0.5 ppm. The method of ammonia analysis used early in this project was the Nesslerization method which also detects organics. Thus, these high values of ammonium, may in part reflect a relatively high organic content of this spring. Only one spring, JB 66, exceeded the 10 ppm nitrate limit. This high nitrate content is probably due to local contamination by farm animal waste. Only five springs exceed the limits set for metals and only one of these limits is set for health reasons. Spring NA 19 has a lead concentration of 100 ppb which exceeds the 50 ppb limit. However, there are several springs with lead values in the 40 ppb range which could exceed the drinking water limit ocassionally due to natural variations. Spring NA 20 exceeds the 300 ppb limit for iron and springs NA 70, NA 72 and LS 24 exceed the manganese limit of 50 ppb. The iron and manganese limits are not health limits but rather limits set for staining problems.

COMPARISONS OF WATER CHEMISTRY

As indicated earlier, there has been little work published on the ground water chemistry of northern Arkansas. The U.S. Geological Survey has published a Hydrologic Atlas for the Ozark Plateaus (Lammonds, 1972) based on data in an open file report (Lammonds and

Stephens, 1969); however, iron and manganese were the only two heavy metals analyzed. There is a significant difference between well water and spring water (Steele, et al., 1975 and Hawkes and Webb, 1962) due to plumbing, type of flow, casing etc.; therefore, only spring water data is presented in Table 11. There is an overall similarity of the data in Table 11; however, there are significant differences between the U.S.G.S. data for the Ozark Plateau and the present study. Most of these differences can be attributed to the fact that the U.S.G.S. samples were not filtered, and that the present study has concentrated sampling in mineralized areas. Carbonate Unit 1 data are based on 16 springs issuing from the Boone through Everton Formations. Carbonate Unit 2 data are based on 5 springs issuing from the Black Rock Limestone through Cotter Dolomite units (Lammonds and Stephens, 1969).

A study in the Joplin, Missouri area only included three springs (Proctor et al., 1977). The maximum metal values obtained for these springs are given in Table 11. The major mineralization in the Joplin area includes sphalerite, galena and marcasite (FeS_2). It is interesting to note the higher lead values for this study compared to those in the Joplin area.

Ten springs were included in a detailed study of a part of Washington County, Arkansas (Wagner et al., 1976 and Coughlin, 1975). These springs all issue from the Boone Limestone and are relatively free of heavy metals, especially in comparison with springs from

Table 11. Comparison of spring water data. The top values are the range and the bottom value is the median value. See footnote for Joplin data.

Area	Specific Cond. 25°C	Alkalinity as mg/l $CaCO_3$	pH	PO_4^{-3} as P ppm	Cl^- ppm	NH_4^+ as N ppm	SiO_2 ppm	$SO_4^=$ ppm	NO_3^- as N ppm	F^- ppm
Ponca[1]	12-447 302	15-358 183	5.2-8.0 7.4	<.01-.47 .01	.6- 4.3 2.0	<.01-1.56 .07	3.1-7.8 5.7	<5.0-23.5 5.9	<.02-1.30 .14	
Rush[1]	136-546 348	70-410 195	6.8-8.3 7.6	<.01-.17 <.01	.9-45.1 4.2	<.01- .50 .02	4.2-7.9 5.9	<5.0-55.0 8.5	<.03-20.23 .33	.08-.17 .13 (Ponca, Rush and Zinc combined)
Zinc[1]	168-552 348	90-315 205	6.5-7.8 7.3	<.01-.07 .01	1.3- 6.5 2.2	<.01-2.34 .04	4.6-8.5 7.0	<4.2-11.9 5.0	<.02- 2.20 .3	
Northern Arkansas[2]										
Carbonate unit 1	192-451 270	85-207 140	7.0-8.4 7.5	-	1.5-16.0 3.4	-	6.0-11.0 7.4	<.4- 9.0 2.5	.02-13.0 3.4	<.1-.1 <.1
Carbonate unit 2	320-600 329	140-282 169	7.6-8.4 7.9	-	1.5- 4.2 3.5	-	8.2-14.0 11.1	<.4- 8.0 2.2	1.4 - 3.9 2.6	<.1-.2 <.1
Joplin[3]	-	136	7.2	-	-	-	-	-	-	-
Washington[4] Co., AR	-	-	-	<.01-.09 .01	-	-	-	-	11.0 - 4.6 5.6	-

[1] Data from this study.
[2] Data from Lammonds and Stephens (1969)
[3] Data from Proctor et al., (1977). Average values for alkalinity and pH. Maximum values for metals.
[4] Data from Coughlin (1975).

Table 11 (continued)

Area	Zn ppb	Pb ppb	Cd ppb	Fe ppb	Mn ppb	Ni ppb	Co ppb	Cu ppb	Na ppm	K ppm	Ca ppm	Mg ppm	Sr ppb	Ba ppb	Hg ppb
Ponca	<1- 63	<4-100	<1-2	<3-373	<1- 57	<3-33	<1-27	<2-13	.1-6.7	.4-1.4	2-98	.5-11.9	22-272		
	10	13	2	18	4	11	4	3	1.4	.7	65	2.4	42		
Rush	4-252	<4-40	<1-3	<3-36	<3-22	<1-16	<1-18	<2-11	.8-20.0	.4-4.1	22-118	.7-34.5	17- 90	4-15 (Ponca, Rush, Zinc)	<.1- .8 (Ponca, Rush, Zinc)
	12	6	2	6	<4	5	8	<3	1.9	.7	64	1.6	41	8	<.1
Zinc	6-214	<8-48	<2-6	<11-50	<1-97	<4-18	<5-21	<2-2	1.2- 4.2	.5-2.5	35-100	1.1-30.8	22-70		
	25	24	<2	12	4	7	9	<6	1.8	1.0	68	3.1	46		
Northern Arkansas Carbonate Unit 1	-	-	-	<10-200	<10-10	-	-	-	1.6-12.0	.6-1.5	41-105	.9-10.0	-	-	-
				30	<10				2.0	.8	52	1.2			
Carbonate Unit 2	-	-	-	<10-100	-	-	-	-	1.8-2.0	.8-1.5	26-65	5.2-37.0	-	-	-
				80	<10				2.0	1.2	53	25.0			
Joplin	200	6	-	11	-	-	-	1.5	-	-	-	-	-	-	<.1
Washington Co., AR	<2-381	<1-2	<.2-1.0	<1-46	<.4-36	<2-5	2-6	<1-9	3-18	.9-3.5	30-75	1-2	25-41	-	-
	20	<1	<1	<2	1	<2	4	<1	5	1.8	54	2	38		

the mineralized areas (Table 11).

GEOCHEMICAL EXPLORATION

Although there are not many published ground water geochemical studies, the method appears to be very promising, especially for certain types of deposits. Often an ion or element can be used as a pathfinder for ore, e.g. sulfate or mercury for sulfide deposits. It is interesting to note that the mineralized areas generally contain more sulfate than other springs from northern Arkansas (Table 11). However, the mercury content does not appear to be indicative of mineralization compared with mercury values of <.2 to .8 ppb reported by Barber and Steele (1980) for ground water in the northwest Arkansas region.

Figure 3 indicates that the phases controlling lead and zinc solubility in the vast majority of the spring waters will be $PbCO_3$ (angelsite) and $ZnCO_3$ (smithsonite) based on the pH, and a reasonable estimate of Eh of these waters. Dilday (1982) has shown that the solubility of $PbCO_3$ under typical ground water conditions in the study area would yield about 1760 ppb lead. The maximum content measured is 100 ppb. Similar calculations made for $ZnCO_3$ yield a zinc concentration of 340 ppm compared to a maximum concentration of 252 ppb. Although many factors contribute to the lowering of the observed lead and zinc concentrations compared to theoretical values,

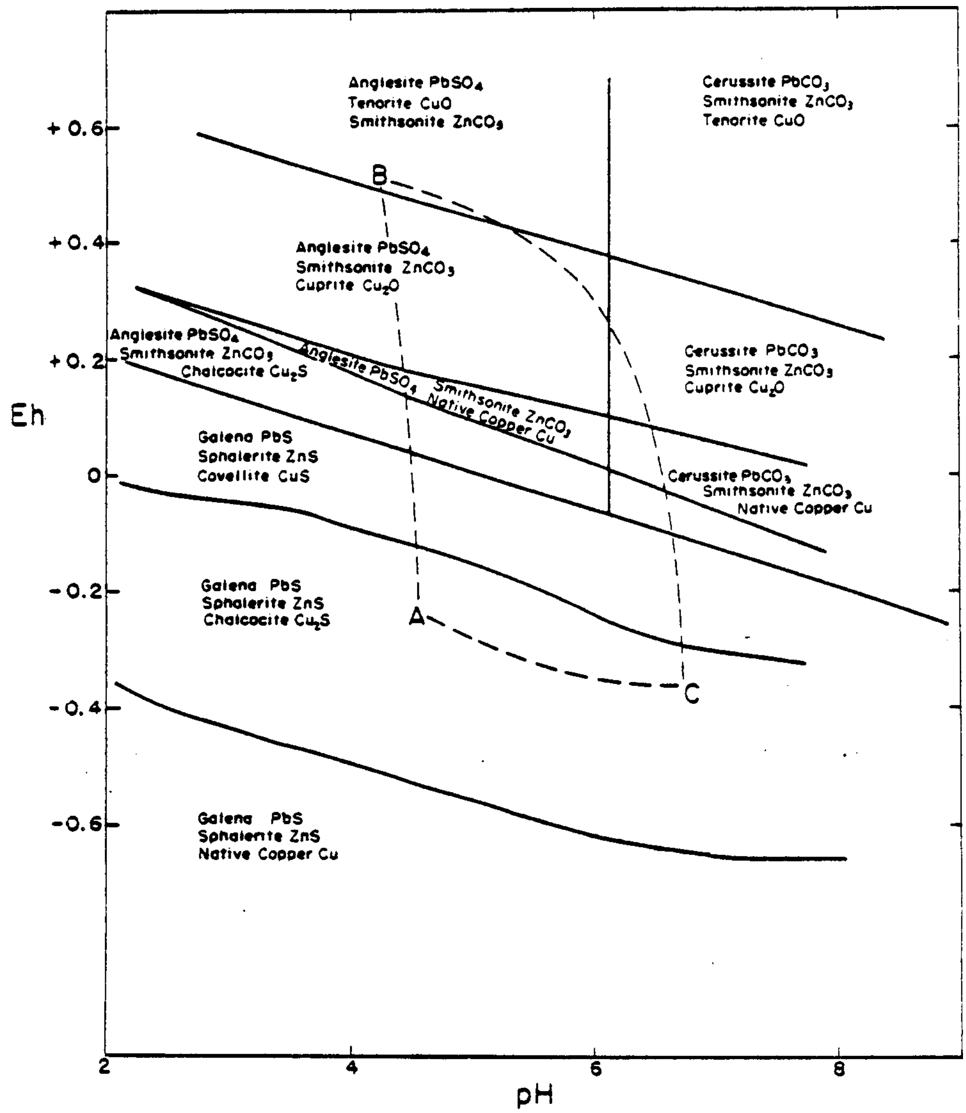

Figure 3. Composite diagram of stability of metal sulfides and oxidation products at 25°C and 1 atmospheric total pressure in the presence of total dissolved carbonate = $10^{-1.5}$, total dissolved sulfur = 10^{-1}. From Garrels and Christ, 1965, p. 395.

dilution by mixing of ground water, kinetics and sorption are probably the most important. Nonetheless it is surprising to note how low the zinc concentrations are. Although the lead and zinc values are not exceedingly high, they do reflect the mineralization in the Ponca, Rush and Zinc areas (Table 11).

The lead and zinc anomalous values (Tables 12 and 13) were determined using the methods of Lepeltier (1969) and Sinclair (1976). It is interesting to note that anomalous sites are indicated as well as and perhaps better by lead compared to zinc, even for predominantly zinc mineralized areas. One might expect more anomalous values near known mineralization; however, this is indicated to be the case only in the Rush area. The general lack of a relationship between distance to mineralization and number of anomalies may be attributed to (1) the quality of the mineralization mapping, and (2) hydrological factors.

The quality of mapped mineralization in the three northern Arkansas areas investigated appears to be varied, and thus, has affected the results in Tables 12 and 13. The location of mineralization was obtained from McKnight (1935), Stroud et al., (1969) and Rand McNally (1917). Ponca has had only the main mines and prospects mapped, whereas, the Rush area has a number of minor prospects and "shows" mapped. The quality of mapping for the Zinc area is probably intermediate of the other two areas. For example, unmapped

Table 12. Number of anomalies with respect to distance to known mineralization.

	Distance to Nearest Mineralization (meters)				
Area	0-402	402-804	804-1615	1615-3230	3230
Ratio of Pb Anomalies and Number of Springs					
Ponca	0/3 = 0%	7/19 = 37%	3/8 = 38%	9/15 = 60%	1/3 = 33%
Rush	4/12 = 33%	6/14 = 43%	3/11 = 27%	1/14 = 7%	0/1 = 0%
Zinc	6/10 = 60%	5/8 = 63%	9/12 = 75%	10/12 = 83%	1/1 = 100%
Ratio of Zn Anomalies and Number of Springs					
Ponca	0/3 = 0%	3/19 = 16%	1/8 = 13%	3/15 = 33%	0/3 = 0%
Rush	4/12 = 33%	4/14 = 29%	2/11 = 18%	1/14 = 7%	0/1 = 0%
Zinc	8/10 = 80%	5/8 = 63%	9/12 = 75%	2/12 = 17%	0/1 = 0%
Ratio of Anomalous Sites and Number of Springs					
Ponca	0/3 = 0%	7/19 = 37%	3/8 = 38%	10/15 = 67%	1/3 = 33%
Rush	5/12 = 42%	8/14 = 57%	4/11 = 36%	1/4 = 7%	0/1 = 0%
Zinc	8/10 = 80%	7/8 = 88%	11/12 = 92%	10/12 = 83%	1/1 = 100%

Table 13. Comparison of number of anomalous sites based on all sites and number of anomalous sites based on only hydrologically significant sites.

	Distance to Nearest Mineralization (meters)				
Area	0-402	402-804	804-1615	1615-3230	>3230
Ratio of Pb Anomalies and Number of Springs[1]					
Ponca	0/3 = 0%	7/19 = 37%	3/8 = 38%	10/15 = 67%	1/3 = 33%
Rush	5/12 = 42%	8/14 = 57%	4/11 = 36%	1/14 = 7%	0/1 = 0%
Zinc	8/10 = 80%	7/8 = 88%	11/12 = 92%	10/12 = 83%	1/1 =100%
Modified Anomalous Ratio[2]					
Ponca	0/0	5/10 = 50%	2/6 = 33%	1/3 = 33%	0/0
Rush	3/3 =100%	5/9 = 56%	3/6 = 50%	0/2 = 0%	0/0
Zinc	6/6 =100%	3/3 =100%	6/7 = 86%	1/1 =100%	0/1 = 0%

[1] From Table 12.

[2] Ratio based only on springs that might be hydrologically connected with mineralization based on topography.

mineralization (perhaps occurring as small or weakly mineralized deposits) are probably affecting springs that are 800 or more meters from known mineralization. The fact that Rush shows a general decline of anomalies with distance from known mineralization suggests that there is not as much unmapped mineralization present.

Hydrological factors including ground water flow direction, as well as recharge aspects (e.g. wet versus dry seasons) also affect anomalous values. A crude attempt was made to take into account the flow of the ground water with respect to the location of the mineralization (Table 13). All springs that were up slope from mineralization or on the other side of drainage divides from mineralization were eliminated and a modified anomalous ratio calculated from the remaining data. Although the modified ratio did not greatly affect the percent of anomalous springs near mineralization, the Rush area did show an improved distance to mineralization versus number of anomalous sites relationship (Table 13).

The study in the Joplin area (Proctor et al., 1977) found that generally the highest lead and zinc values for spring and well samples were obtained during the Fall, a dry period. It may be that samples collected for this study during wet periods (seasonal or soon after rains) do not exhibit anomalous concentrations due to dilution.

These factors plus others make it difficult to locate a specific deposit in these areas using ground water chemistry. However, ground water geochemical exploration does appear to be quite useful in locating mineralized areas (compare lead values from Washington County with data from Ponca, Rush and Zinc.

GEOTHERMOMETRY

The presence of a well with high heat flow in the northeastern part of Arkansas suggested that it might be valuable to determine the subsurface temperatures of the springs in northern Arkansas. There were no anomously high surface temperatures measured except for spring NA 31 with a temperature of 26.0°C. Only one other spring (NA 35) and the one well sampled (NA 24) had surface temperatures over 20.0°C. All three of these samples were collected during August with air temperatures in excess of 30°C and thus may represent warming of the waters at the surface. The fact that none of these samples had high silica contents also argues against geothermal heating.

The subsurface temperatures based on silica geothermometry using both chalcedony and quartz (Fournier and Rowe, 1966 and Fournier, 1973), do not yield values considered to be significant. The maximum subsurface temperature (34°C) is obtained using the maximum silica concentration of 8.5 ppm and using quartz solubility:

$$T_{SiO_2} = [1315/(5.205 - \log_{10} SiO_2)] - 273.15.$$

The median subsurface temperatures for each area are— 28°C for Zinc and 22°C for both Rush and Ponca using quartz solubility.

CONCLUSIONS

Basically the ground water in the three mineralized areas is a calcium bicarbonate that is of good quality. However, a few springs do exceed drinking water limits for ammonia, nitrate, lead, iron and manganese. Although individual anomalous sites do not indicate nearby mineralization effectively, the mineralized areas do appear to have higher lead, and perhaps zinc and sulfate than surrounding non-mineralized areas with similar geology. Thus, although specific deposits may not be located by ground water geochemistry, mineralized areas should be detected fairly easily with sufficient sampling. Neither surface temperatures nor subsurface temperatures based on silica geothermometry indicate significant geothermal heating of these spring waters.

REFERENCES

APHA, 1971, Standard Methods for the Examination of Water and Wastewater, 13 ed.: American Public Health Association, Washington, D.C., 874 p.

Barber, L. II, and Steele, K.F., 1980, Mercury content of waters in the midcontinent region: Proceedings of the Ark. Acad. Sciences, Vol. 34, p. 19-21.

Bedinger, M.S., Pearson, F.J., Jr., Reed, J.E., Sniegocki, R.T. and Stone, C.G., 1979, The waters of Hot Springs National Park, Arkansas - their nature and origin: U.S. Geol. Surv. Prof. Paper 1044-C, 33 p.

Caplan, William M., 1957, Subsurface geology Northwestern Arkansas: Arkansas Geological Commission, Information Circ. 19, 14 p.

Coughlin, T.L., 1975, Geologic and environmental factors affecting ground water in the Boone Limestone of northcentral Washington County, Arkansas: unpub. M.S. Thesis, Univ. of Arkansas, Fayetteville, 98 p.

Dilday, T.F. III, 1982, Hydrogeochemical exploration for Mississippi Valley - type mineral deposits, Arkansas: unpub. M.S. Thesis, Univ. of Arkansas, Fayetteville, 82 p.

EPA, 1974, Methods for Chemical Analysis of Water and Wastes: U.S. Environmental Protection Agency, Washington, D.C., 298 p.

EPA, 1976, Quality Criteria for Water: U.S. Environmental Protection Agency, Washington, D.C., 256 p.

Fournier, R.O. and Rowe, J.J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and steam wells: Am. Jour. Sci., vol. 264, p. 685-697.

Garrels, R.M., and Christ, C.L., 1965, Solutions, Minerals, and Equilibria: Harper and Row Publishers, New York, 450 p.

Hach Chemical Company, 1975, Water Analysis Handbook: Hach Chemical Company, Ames, Iowa, 186 p.

Hawkes, H.E. and Webb, J.S., 1962, Geochemistry in Mineral Exploration, Harper and Row, New York, 415 p.

Lammonds, A.G., 1972, Water-resources reconnaissance of the Ozark Plateaus Province, northern Arkansas: Hydrologic Investigations Atlas HA-383, U.S. Geol. Survey.

Lammonds, A.G. and Stephens, J.W., 1969, Water-resources data for the Ozark Plateaus Province, Arkansas, unpublished report, available through the U.S. Geological Survey, Water Resources Division, Little Rock, Arkansas.

Lepeltier, C., 1969, A simplified statistical treatment of geochemical data by graphical representation: Econ. Geol., Vol. 64, p. 538-550.

McKnight, E.T., 1935, Zinc and Lead Deposits of Northern Arkansas: U.S. Geol. Surv. Bull. 853, 311 p.

Nix, J. and Goodwin, 1970, The simultaneous extraction of Fe, Mn, Cu, Co, Ni, Cr, Pb and Zn from natural water for determination by atomic absorption: At. Absorpt. Newsl., Vol. 9, p. 119-122.

Proctor, P.D., Kisvarsanyi, G., Garrison, E. and Dilamarter, R.R., 1976, Heavy metal additions to waters of the Joplin area, Tri-State mining district, Missouri: in Hydrologic Problems in Karst Regions, R.R. Dilamarter ed., Western Kentucky Univ. Press, Bowling Green, KY, 481 p.

Public Health Service, 1962, Public Health Service Drinking Water Standards: U.S. Public Health Service, Dept. of Health, Education and Welfare, 61 p.

Rand McNally, 1917, Mineral map of the Arkansas zinc and lead district: Rand McNally and Co., Chicago, Ill., 1 p.

Sinclair, A.J., 1976, Applications of probability graphs in mineral exploration: Assoc. of Explor. Geochemists, Special Vol. 4, 93 p.

Smith, D.A., 1978, Lead-zinc mineralization in the Ponca-Boxley area, Arkansas: unpub. M.S. Thesis, Univ. of Arkansas, Fayetteville, 188 p.

Steele, K.F., MacDonald, H.C. and Grubbs, R., 1975, Composition of groundwater in Northwest Arkansas: Arkansas Farm Research.

Stroud, R.B., Arndt, R.H., Fulkerson, F.B. and Diamond, W.G., 1969, Mineral resources and industries of Arkansas: U.S. Bureau of Mines, Bull. 645, 418 p.

Wagner, G.H., Steele, K.F., MacDonald, H.C. and Coughlin, T.L., 1976, Water quality as related to linears, rock chemistry and rain water chemistry in rural carbonate terrain: Jour. Envir. Qual., Vol. 5, p. 444-451.

World Health Organization, 1971, International Standards for Drinking Water: 3rd ed., WHO, Geneva, 70 p.