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SULFUR ISOTOPIC COMPOSITION AND WATER CHEMISTRY IN WATER FROM THE HIGH PLAINS AQUIFER, OKLAHOMA PANHANDLE AND SOUTHWESTERN KANSAS

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Regional ground-water flow in the Ogallala Formation is from west to east across Kansas and Oklahoma; concentration of dissolved solids increases in the direction of flow. This increase may be influenced by residence time, but underlying bedrock appears to control ground-water chemistry. The Ogallala Formation is underlain by Mesozoic rocks in the west and Permian rocks in the east. Mean concentration of dissolved solids in ground water from the Mesozoic rocks is 552 milligrams per liter, and from the Permian rocks is 4,720 milligrams per liter. Mean concentration of dissolved solids for water in the Ogallala Formation is 396 milligrams per liter where it overlies Mesozoic rocks and 569 milligrams per liter where it overlies Permian rocks. $\delta^{34}S$ ($SO_4^{=}$) (sulfate) values range from a high of +6.9 parts per thousand to a low of -25.1 parts per thousand. Sulfate increases from about 20 milligrams per liter to more than 350 milligrams per liter from west to east. Increasing concentration of dissolved solids, lighter $\delta^{34}S$ values and increasing $SO_4^{=}$ (sulfate) in the eastern part of the study area incidate that ground water or H_2S (hydrogen sulfide) from Permian rocks may be moving upward into the Ogallala Formation.

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Multiply inch-pound units	By	To obtain metric unit
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second

SULFUR ISOTOPIC COMPOSITION AND WATER CHEMISTRY IN WATER FROM THE HIGH PLAINS AQUIFER, OKLAHOMA PANHANDLE AND SOUTHWESTERN KANSAS

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ABSTRACT

The Ogallala Formation comprises the High Plains aquifer in Oklahoma and southwestern Kansas. Regional ground-water flow is from west to east in the Ogallala Formation, and the concentration of dissolved solids in ground water increases in the direction of flow. This increase may be influenced by residence time, but underlying bedrock appears to control ground-water chemistry. The Ogallala Formation is underlain by Mesozoic rocks in the west and Permian rocks in the east. Mean concentration of dissolved solids in ground water from the Mesozoic rocks is 552 milligrams per liter and Permian rocks is 4,720 milligrams per liter. Mean concentration of dissolved solids for water in the Ogallala Formation is 396 milligrams per liter where it overlies Mesozoic rocks and 569 milligrams per liter where it overlies Permian rocks. $\delta^{34}S$ ($SO_4^{=}$) (sulfate) values range from a high of +6.9 parts per thousand to a low of -25.1 parts per thousand. Sulfate increases from about 20 milligrams per liter to more than 350 milligrams per liter from west to east. Increasing concentration of dissolved solids, lighter $\delta^{34}S$ values, and increasing $SO_4^{=}$ (sulfate) concentration in the east implies that ground water or H_2S (hydrogen sulfide) from Permian rocks may be moving upward into the Ogallala Formation.

INTRODUCTION

Sulfur-bearing chemical species most commonly found dissolved in low-temperature natural waters are $SO_4^{=}$ (sulfate), HS^- (ionic hydrogen sulfide), and H_2S (molecular hydrogen sulfide); the dominant species depends on the oxidation potential and pH of the system. The common sources of these species in ground-water systems are solution of evaporite minerals, mixing with encroaching ocean waters, decomposition of organic matter, solution and oxidation of sulfide minerals, migration of H_2S, and recharge by sulfate-bearing precipitation (Rightmire and others, 1974).

Sulfur has four stable isotopes, the most common of which are ^{32}S, with a relative abundance of 94.9 percent, and ^{34}S, with a relative abundance of 4.3 percent. The other two isotopes, ^{33}S and ^{35}S, constitute the remaining 0.8 percent. The isotopic composition of sulfur may be characterized by the ratio of $^{34}S/^{32}S$; in this report, sulfur-isotope variations are reported in standard δ notation as:

$$\delta^{34}S = \left[\frac{R\ sample}{R\ standard} - 1\right] \times 10^3 ,$$

where $R = {}^{34}S/{}^{32}S$.

Analyses in this study are reported in parts per thousand (0/00) relative to the Canyon Diablo meteorite standard. A sample that is +10 0/00 contains 10 parts per thousand or 1 percent more than the standard. A sample that is -10 0/00 contains 10 parts per thousand or 1 percent less than the standard. Sulfate analyses in this study were prepared by techniques used by Thode and others (1961), in which the isotopic composition of sulfur in SO_2 is determined by mass spectrometry.

The purpose of this report is to identify the sources of sulfate in ground water using water chemistry and sulfur-isotope data. The possible leakage of water or H_2S upward from Permian age rocks into the Tertiary Ogallala Formation in the Oklahoma Panhandle and southwestern Kansas is discussed. The study area consists of Cimmarron, Texas, and Beaver Counties in Oklahoma; and Morton, Stevens, Seward, and Meade Counties in Kansas (figs. 1 and 2).

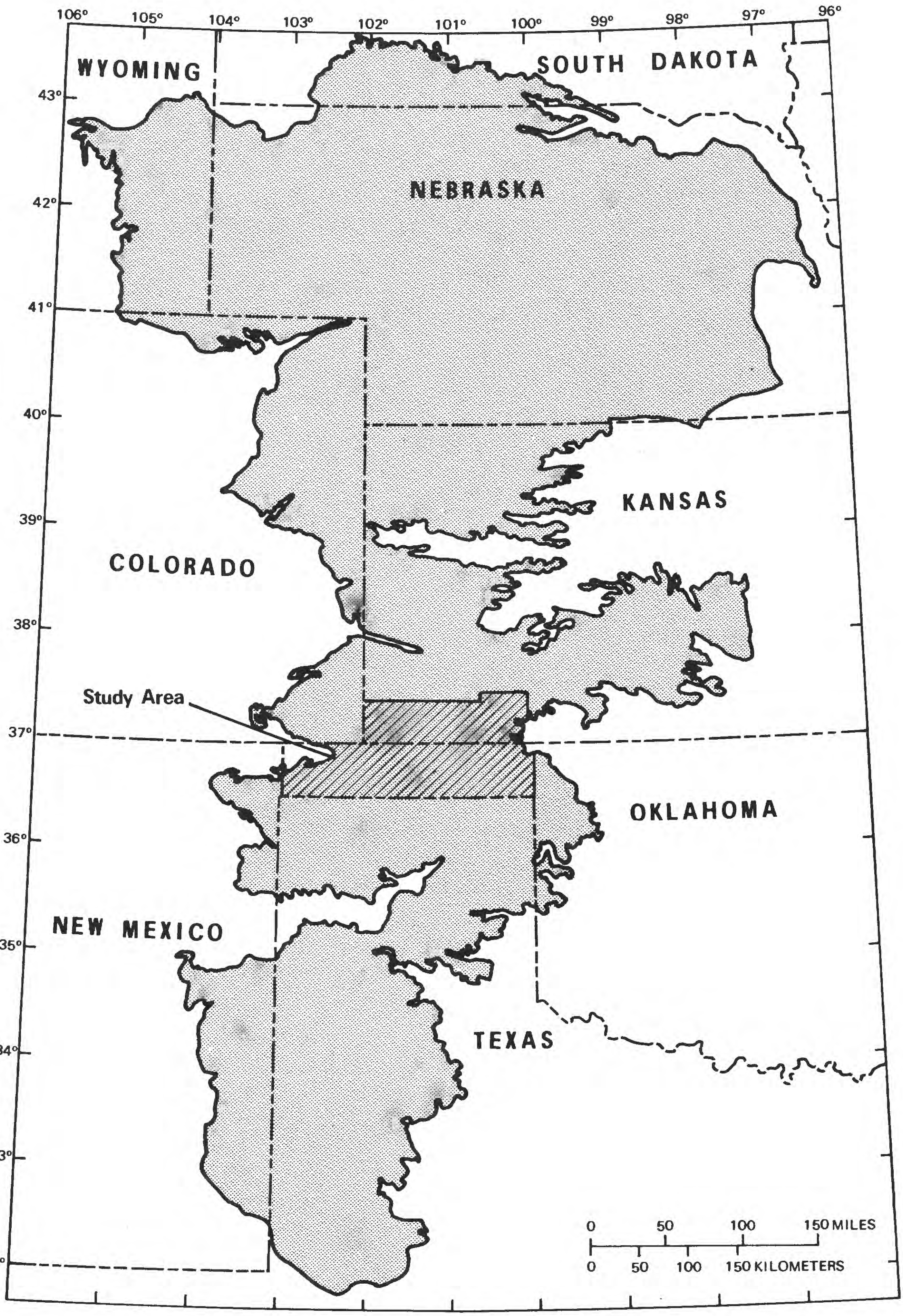

Figure 1.--Location of the High Plains aquifer (shaded) and study area.

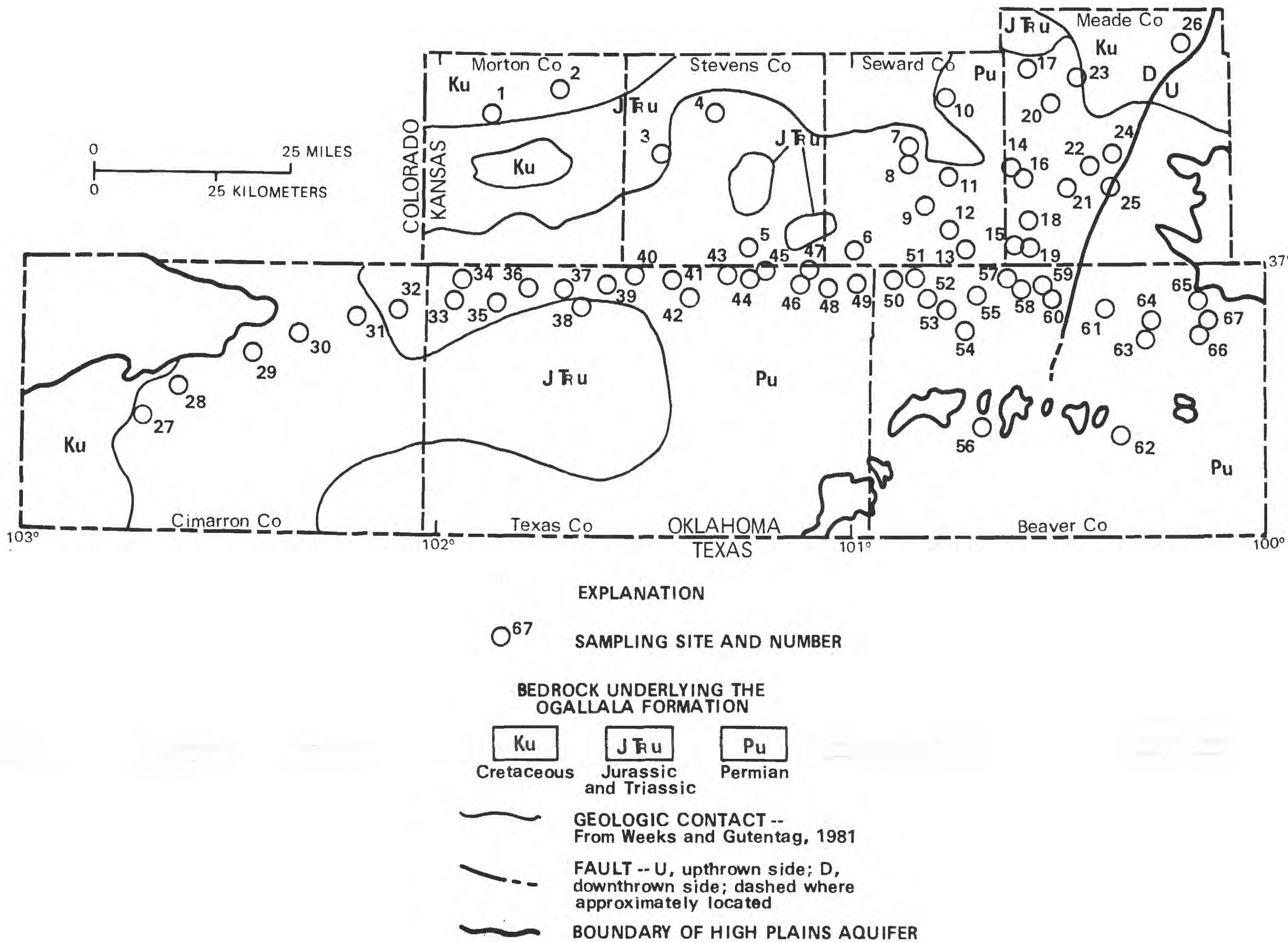

Figure 2.--Sampling-site locations and numbers.

DESCRIPTION OF HIGH PLAINS AQUIFER

The High Plains region is a remnant of a vast plain formed by sediments deposited by streams flowing eastward from the Rocky Mountains. Subsequently, erosion isolated the plains from the mountains and formed escarpments that typically mark the boundary of the High Plains. Wind-blown sand and silt, derived from the beds of rivers that eroded the plains, were deposited over large areas of the High Plains. The fluvial (stream-deposited) and eolian (wind-blown) sediments that form the High Plains comprise the High Plains aquifer, which is a water-table system.

The geology of the High Plains aquifer was described by Gutentag and Weeks (1980) and Weeks and Gutentag (1981). The aquifer consists mainly of Tertiary and Quaternary material and covers about 174,000 square miles in eight States--Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (fig. 1).

The Ogallala Formation is the major water-bearing unit of the High Plains aquifer. The Ogallala underlies 156,000 square miles and consists of semi-consolidated clay, sand, silt, and gravel. Recharge of ground water to the Ogallala is primarily from precipitation, but small amounts may be due to return flow from irrigation, infiltration from lakes, streams, and rivers, and subsurface inflow from underlying rocks. Wells in this aquifer commonly yield 500 to 1,000 gallons per minute and may yield as much as 2,500 gallons per minute.

The consolidated rocks underlying the study area range in age from Cretaceous in the western part of the study area to Permian in the eastern part (fig. 2). The Cretaceous, Jurassic, and Triassic rocks in the western part of the study area consist predominantly of thin to thick bedded sandstone with interbedded shale, conglomerate, siltstone, and lesser amounts of limestone and dolomite. The Permian rocks in the eastern part of the study area consist of thick sequences of interbedded red shale, siltstone, sandstone, gypsum, anhydrite, dolomite, bedded salt, and local limestone beds.

Previous reports show that regional ground-water flow is from west to east across the Oklahoma Panhandle (Hart and others, 1976) and southwestern Kansas (Hathaway and others, 1978). These reports also show that specific conductance and the concentration of dissolved solids in ground water generally increase in the direction of flow.

GROUND-WATER CHEMISTRY VARIATIONS

Initially, 93 chemical analyses of ground water from the study area were reviewed to confirm the trends shown by previous investigators. The data were obtained from WATSTORE (Water Data Storage and Retrieval System) files of the U.S. Geological Survey. The data for selected chemical parameters are summarized in table 1. The data confirm that higher concentrations of dissolved constituents in water samples from the Ogallala Formation generally occur in the eastern part of the study area where the underlying rocks are of Permian age. The mean concentration of dissolved solids in 11 water samples from Mesozoic rocks is 552 mg/L (milligrams per liter), and the mean concentration of dissolved solids in 25 water samples from the overlying Ogallala Formation is 396 mg/L. The mean concentration of dissolved solids in 6 water samples from Permian rocks is 4,720 mg/L, and the mean concentration in 51 water samples from the overlying Ogallala Formation is 569 mg/L. The data in table 1 indicate similar variations in the concentrations of sodium-plus-potassium, chloride, and sulfate; however, the range and standard deviation of the concentration of sulfate in water samples from the Ogallala Formation is larger where the Ogallala overlies Mesozoic rocks than where it overlies Permian rocks (table 1).

Because of the correlation between water-chemistry variations and bedrock changes, 67 additional water samples from the High Plains aquifer were collected to determine whether sulfur isotopes could be used to identify the cause of the variation in chemistry. Ground-water samples were collected from 40 irrigation wells, 6 stock wells, 20 domestic well, and 1 industrial well during 1979 and 1980. The locations of these sampling sites are shown

Table 1.--*Statistical summary of selected chemical parameters from 93 water samples from the Oklahoma Panhandle and southwestern Kansas*

[units in milligrams per liter except as noted; °C = degrees Celsius]

Parameter	Statistic	Geologic source of water samples			
		Permian rocks	Mesozoic rocks	Ogallala Formation overlying Permian rocks	Ogallala Formation overlying Mesozoic rocks
Sodium plus potassium ($Na^+ + K^+$)	Mean	1,185	122	90	46
	Standard deviation	444	112	163	85
	Range	600-1,660	25-349	10-1,090	8-79
	Number of samples	6	11	51	25
Sulfate ($SO_4^=$)	Mean	1,436	175	109	88
	Standard deviation	827	242	80	165
	Range	150-2,230	38-867	13-352	17-842
	Number of samples	6	11	51	25
Chloride (Cl^-)	Mean	1,296	20	98	20
	Standard deviation	829	19	238	13
	Range	23-2,200	9-72	7-1,590	6-75
	Number of samples	6	11	51	25
Specific conductance (micromhos per centimeter at 25°C)	Mean	6,773	650	883	482
	Standard deviation	2,397	283	809	58
	Range	3,500-8,940	450-2,320	318-5,950	386-2,480
	Number of samples	6	11	51	25
Dissolved solids (sum)	Mean	4,720	552	569	396
	Standard deviation	2,013	448	490	313
	Range	2,040-6,920	280-1,750	140-3,450	225-1,790
	Number of samples	6	11	51	25

in figure 2. All wells had been in operation prior to sampling. Samples were collected at the wellhead whenever possible to minimize the possibility of contamination. Temperature, specific conductance, dissolved oxygen, bicarbonate, and pH were measured in the field. Samples prepared by standard techniques were analyzed for trace elements, major ions, oxygen isotopes, and sulfur isotopes at the U.S. Geological Survey's national water quality laboratory.

Results of the chemical analysis of the 67 water samples are presented in tables 2 and 3 (at the back of this report), and the dissolved-solids concentrations are shown in figure 3. The data (fig. 3) indicate that the concentration of dissolved solids increases from west to east in the direction of ground-water flow. West of 102° W longitude, the mean dissolved-solids concentration is 304 mg/L, based on 6 water samples. Between 101° W and 102° W longitude, the mean dissolved-solids concentration is 397 mg/L, based on 22 water samples. East of 101° W longitude, the mean dissolved-solids concentration is 472 mg/L, based on 39 water samples (fig. 3 and tables 2 and 3).

This increase in the concentration of dissolved solids primarily is due to increasing concentrations of sodium, chloride, and sulfate (tables 2 and 3). Based on the data in tables 2 and 3, the mean sodium concentration increases from 21 mg/L west of 102° W longitude to 64 mg/L east of 101° W longitude. Similarly, the mean chloride concentration increases from 23 mg/L to 75 mg/L and the mean sulfate concentration increases from 42 mg/L to 85 mg/L.

Although the highest concentrations of dissolved solids occur in the eastern part of the study area where the bedrock underlying the aquifer is of Permian age, not all water samples contain high concentrations. As shown by figure 3 and tables 2 and 3, the concentrations of dissolved constituents in about one-half of the samples east of 101° W longitude do not contain significantly higher concentrations than those samples west of 102° W longitude. If the water chemistry is affected by water moving upward from the Permian bedrock into the Ogallala Formation, then ground-water flow along

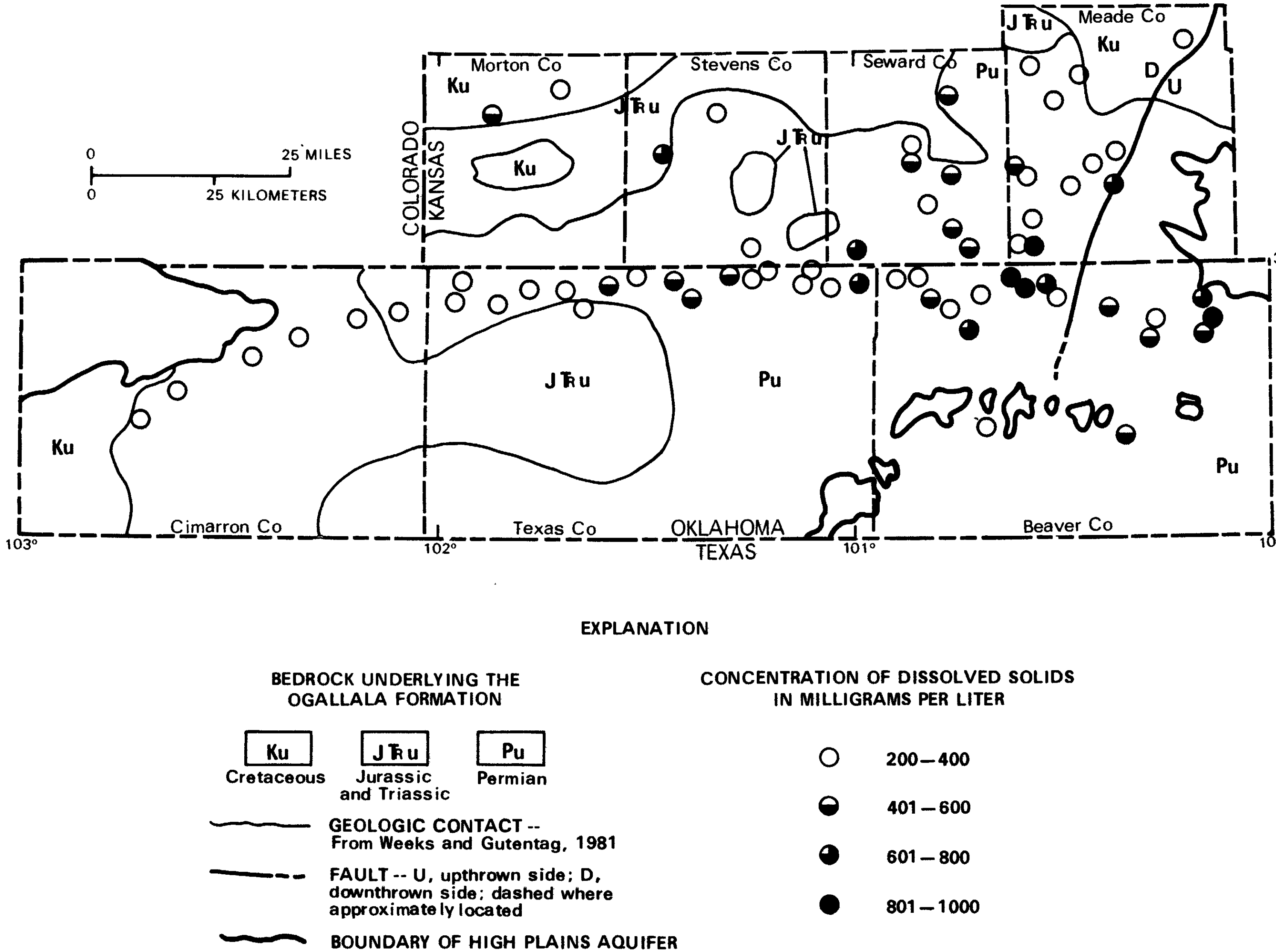

Figure 3.--Bedrock underlying the Ogallala Formation and dissolved-solids concentration in 67 water samples collected from the Ogallala Formation, 1979-80.

joints or fractures associated with faulting (fig. 3) in the Permian rock, leakage from improperly plugged bedrock wells, and (or) vertical chemical gradients in the Ogallala Formation could account for locally high concentrations of dissolved solids.

SULFUR ISOTOPES IN GROUND WATER

The sulfur-isotope composition of ground water in the study area (tables 2 and 3) was analyzed for possible anomalies that would substantiate upward movement of water into the Ogallala Formation from the Permian bedrock; results of this analysis are summarized in figure 4. Ground water in the western part of the study area contains mostly positive $\delta^{34}S$ ($SO_4^{=}$) with a maximum value of +3.6 0/00. There are a few negative values in this area, but none is less than -2.4 0/00. In the eastern part of the study area, most of the $\delta^{34}S$ ($SO_4^{=}$) values are negative and range from +6.9 to -25.1 0/00 (fig. 3). The isotopic composition of the water in the eastern part of the study area is atypical for ground-water sulfates.

The occurrence of $\delta^{34}S$ ($SO_4^{=}$) values as low as those observed in the shaded area of figure 4 can be explained by the oxidation of sulfide minerals or oxidation of HS^- or H_2S. The depositional history of the Ogallala Formation and the present oxidizing condition of the ground water generally preclude the presence of sedimentary sulfides or generation of HS^- or H_2S within the formation. Therefore, transport of isotopically light sulfur species into the Ogallala Formation is suspected.

The area of negative $\delta^{34}S$ ($SO_4^{=}$) values in the Ogallala shown in figure 4 could be explained by the release of isotopically light sedimentary sulfides into solution as dissolved sulfates in ground water in the Permian rocks. If water in Permian rocks is migrating upward, the isotopically light sulfates would be found in water samples from the Ogallala Formation. This assumes that water in Permian rocks has negative delta values for sulfur. Water samples from Permian rocks were collected from four piezometers in Morton and Stevens Counties, Kansas. The $\delta^{34}S$ ($SO_4^{=}$) values from these samples were

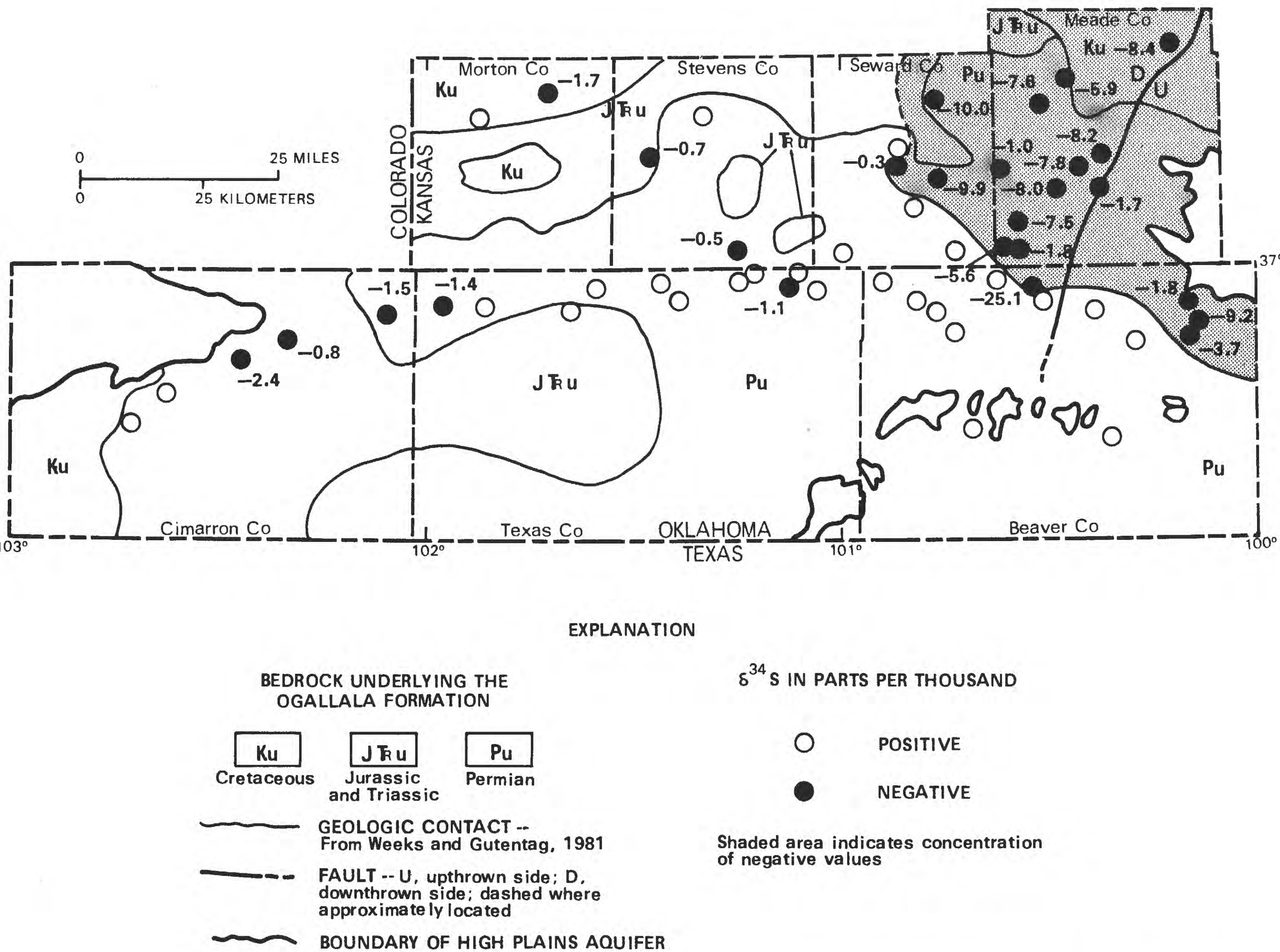

Figure 4.--Bedrock underlying the Ogallala Formation and the distribution of $\delta^{34}S$ ($SO_4^{=}$) in water samples from the Ogallala Formation.

positive and ranged from +0.6 to +8.5 0/00, indicating that the negative values in the Ogallala Formation cannot be explained by simple mixing of water from the Ogallala and Permian rocks.

Isotopically light $\delta^{34}S$ ($SO_4^=$) values in water in the Ogallala might be caused by migration of isotopically light H_2S, produced by the bacterial reduction of sulfate in underlying formations (Reynolds and Goldhaber, 1978). H_2S may be migrating into the Ogallala and oxidized into sulfate resulting in negative $\delta^{34}S$ ($SO_4^=$) values. Dissolved oxygen decreases eastward in the Ogallala Formation (tables 2 and 3) and could be caused by oxidation of H_2S. The occurrence of ground water with low $\delta^{34}S$ ($SO_4^=$) values and high dissolved-solids concentrations in the eastern part of the study area could be explained by fracturing associated with faulting which would provide avenues for migration of H_2S and upward convection or diffusion of solutes. This mechanism also could explain why some samples have low $\delta^{34}S$ ($SO_4^=$) values and low concentrations of dissolved solids and others have low $\delta^{34}S$ ($SO_4^=$) values and high dissolved-solids concentrations. The first case is influenced only by H_2S migration, which lowers the $\delta^{34}S$ ($SO_4^=$) but does not appreciably affect the dissolved-solids concentration. In the second case, appropriate amounts of H_2S and solutes are moving upward making the water in the Ogallala Formation isotopically light in sulfur and increasing its dissolved-solids concentration.

CONCLUSIONS

Results of this study indicate that the concentration of dissolved solids in Ogallala Formation water increases from west to east; this increase primarily is due to increases in the sodium, chloride, and sulfate content. An area of negative $\delta^{34}S$ ($SO_4^=$) values was found in the eastern part of the study area. The mechanism causing the variations in $\delta^{34}S$ ($SO_4^=$) values and solute concentrations has not been identified to the exclusion of other possibilities. However, it appears that the variations could be explained by migration of H_2S or upward convection or diffusion of solutes from the underlying Permian rocks. Additional data describing the occurrence of H_2S, sulfur minerals, and sulfur isotopes, as well as hydraulic heads, in both the Ogallala Formation and Permian bedrock are needed to explain fully the changes in water chemistry.

Table 2.--*Chemical data from water samples collected from the High Plains aquifer in southwestern Kansas, 1979-80*

[Analyses are in milligrams per liter except as indicated; °C = degrees Celsius; µg/L = micrograms per liter; NO_2 = nitrite; NO_3 = nitrate; $CaCO_3$ = calcium-carbonate; $\delta^{18}O_{SMOW}$ = Del oxygen-18 referenced to Vienna standard mean ocean water; $\delta^{34}S_{CD}$ = Del sulfur-34 referenced to Canyon Diablo meteorite standard; 0/00 = parts per thousand; irr. = irrigation; ind. = industrial; sto. = stock; dom.= domestic]

Table 2.--*Chemical data from water samples collected from the High Plains aquifer in southwestern Kansas, 1979-80*--Continued

Map number	Latitude-longitude	Well depth (feet)	Use of water	Temperature (°C)	Silica (SiO_2)	Iron (Fe) (µg/L)	Manganese (Mn) (µg/L)	Calcium (Ca)
1	3715311015145	187	Irr.	16.2	29	<10	<1	39
2	3719451014127	215	Irr.	16.0	22	<10	<3	44
3	3712461012907	360	Irr.	16.3	26	20	<3	100
4	3716211011940	480	Irr.	17.3	33	<10	<1	45
5	3702181011033	400	Irr.	16.6	31	<10	<3	66
6	3701281010040	353	Irr.	16.1	30	10	<3	110
7	3712371005223	335	Irr.	17.3	25	<10	<3	63
8	3711211005241	360	Irr.	17.7	27	20	<1	63
9	3706421004906	360	Irr.	17.5	31	10	<1	61
10	3716151004637	420	Irr.	17.5	23	<10	<1	61
11	3709571004538	232	Ind.	17.7	25	<10	<1	61
12	3703001004536	285	Irr.	17.4	31	<10	<1	52
13	3702051004203	300	Irr.	17.3	27	<10	<3	63
14	3710371003716	425	Irr.	17.9	29	<10	10	79
15	3701361003532	100	Sto.	18.0	25	40	2	53
16	3709201003518	425	Irr.	17.4	23	<10	<3	49
17	3721171003547	200	Irr.	16.3	21	<10	<3	48
18	3704211003444	280	Irr.	17.1	23	<10	<3	55
19	3700591003420	260	Irr.	18.0	23	10	<3	63
20	3717071003131	300	Irr.	16.5	22	<10	<3	46
21	3708131002924	445	Irr.	18.0	23	<10	<3	51
22	3710221002710	300	Dom.	16.7	26	<10	<1	50
23	3719441002500	250	Irr.	16.6	25	10	<1	56
24	3711541002314	340	Irr.	17.3	24	<10	<3	51
25	3708451002352	120	Dom.	16.6	25	20	<3	30
26	3724321001205	238	Irr.	15.8	23	<10	<3	54

Table 2.--*Chemical data from water samples collected from the High Plains aquifer in southwestern Kansas, 1979-80*--Continued

Map number	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen (NO_2 + NO_3 as N)
1	37	45	4.2	240	130	15	---	2.6
2	26	31	3.7	210	80	18	2.2	3.7
3	45	68	5.5	240	230	100	.7	11
4	21	22	4.3	220	51	18	.9	2.4
5	19	18	3.7	190	80	27	.6	3.8
6	40	59	4.4	250	110	180	.9	7.1
7	24	32	4.2	220	110	19	.9	3.5
8	25	41	4.5	240	140	13	.8	3.8
9	18	26	3.6	230	59	19	.4	4.7
10	21	44	4.6	220	130	14	.9	2.9
11	21	49	4.6	230	130	12	.9	2.8
12	19	120	3.7	240	69	140	.7	4.2
13	16	95	4.2	240	51	140	.8	4.3
14	26	50	4.6	200	220	13	1.1	1.0
15	18	49	4.3	210	91	44	.9	1.9
16	18	35	4.1	210	84	9.3	1.0	1.9
17	12	22	3.7	190	39	9.4	.9	2.1
18	15	28	4.2	220	68	13	1.0	2.0
19	19	240	4.6	210	94	350	1.0	1.7
20	12	23	3.8	190	49	8.1	.9	1.2
21	14	21	3.6	200	47	8.4	.9	2.0
22	15	27	3.6	210	61	10	.8	1.5
23	12	18	3.8	230	33	17	.6	2.8
24	14	22	3.6	200	50	16	1.0	1.3
25	9	250	3.1	240	77	270	1.2	1.2
26	13	20	3.8	200	38	19	.8	1.6

Table 2.--*Chemical data from water samples collected from the High Plains aquifer in southwestern Kansas, 1979-80*--Continued

Map number	Iodide (I)	Bromide (Br)	Sele- nium (Se) (μg/L)	Boron (B)	Dis- solved solids (sum)	Hardness as $CaCO_3$	
						Total	Non- carbon- ate
1	0.02	0.1	6	0.26	420	250	72
2	.01	.2	6	.20	334	220	57
3	.02	1.0	18	.16	705	440	260
4	.01	.1	3	.10	304	200	30
5	.01	.2	8	.10	343	240	93
6	.02	.7	22	.10	665	440	250
7	.02	.2	5	.17	390	260	86
8	.04	.2	5	.23	414	260	63
9	.02	.2	3	.12	336	230	38
10	.01	.2	9	.17	410	240	70
11	.04	.2	4	.18	420	240	50
12	.03	.3	4	.12	558	210	11
13	.03	.1	3	.08	520	220	33
14	.03	.2	2	.19	522	300	140
15	.03	.2	6	.12	391	210	34
16	.01	.1	6	.14	329	200	36
17	.00	.1	3	.09	252	170	19
18	.01	.1	6	.12	318	200	29
19	.03	.1	5	.13	900	240	76
20	.00	.1	5	.28	260	160	14
21	.00	.1	4	.12	270	190	0
22	.03	.1	4	.09	298	190	14
23	.02	.2	3	.07	282	190	1
24	.01	.1	7	.08	282	190	35
25	.03	.1	5	.09	785	110	0
26	.01	.1	4	.05	272	190	28

Table 2.--*Chemical data from water samples collected from the High Plains aquifer in southwestern Kansas, 1979-80*--Continued

Map number	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH (standard units)	Dissolved oxygen (DO)	Isotopes	
					$\delta^{18}O_{SMOW}$ 0/00	$\delta^{34}S_{CD}$ 0/00
1	1.4	680	7.70	10.8	-9.0	0.0
2	.9	580	7.72	10.6	-9.5	-1.7
3	1.4	1,180	7.63	11.6	-7.9	-.7
4	.7	515	7.80	9.5	-8.2	.6
5	.5	590	7.75	7.8	---	-.5
6	1.2	1,195	7.64	10.8	-7.6	1.0
7	.9	670	7.68	7.9	-8.4	1.0
8	1.1	675	7.48	7.3	-8.2	-.3
9	.8	545	7.42	8.2	-7.7	2.9
10	1.3	690	7.70	7.6	-8.5	-10.0
11	1.4	662	7.55	7.7	-9.0	-9.9
12	3.6	990	7.40	7.4	-7.8	----
13	2.8	935	7.73	8.6	-7.6	.9
14	1.2	795	7.75	7.0	-8.6	-1.0
15	1.5	625	7.42	6.0	-8.1	-5.6
16	1.1	545	7.81	6.8	-8.5	----
17	.7	440	7.60	8.0	---	----
18	.9	535	7.72	8.2	---	-7.5
19	6.8	1,650	7.68	7.2	-8.6	-1.8
20	.8	450	7.60	7.1	-8.4	-7.6
21	.7	470	7.70	7.4	-8.2	-8.0
22	.9	472	7.41	5.8	-8.4	-7.8
23	.6	480	7.30	7.6	-7.5	-5.9
24	.7	480	7.83	----	-8.3	-8.2
25	10	1,440	7.80	7.3	---	-1.7
26	.6	480	7.75	5.0	-8.8	-8.4

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*

[Analyses are in milligrams per liter except as indicated; °C = degrees Celsius; µg/L = micrograms per liter; NO_2 = nitrite; NO_3 = nitrate; $CaCO_3$ = calcium-carbonate; $\delta^{18}O_{SMOW}$ = Del oxygen-18 referenced to Vienna standard mean ocean water; $\delta^{34}S_{CD}$ = Del sulfur-34 referenced to Canyon Diablo meteorite standard; 0/00 = parts per thousand; irr. = irrigation; ind. = industrial; sto. = stock; dom.= domestic]

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Latitude-longitude	Well depth (feet)	Use of water	Temperature (°C)	Silica (SiO_2)	Iron (Fe) (μg/L)	Manganese (Mn) (μg/L)	Calcium (Ca)
27	3645431023621	230	Irr.	17.1	33	<10	<1	49
28	3645461023057	275	Irr.	18.3	27	<10	<1	34
29	3648521021908	220	Irr.	16.8	34	<10	<1	35
30	3650321021451	270	Irr.	17.0	38	<10	<1	34
31	3653321020835	230	Dom.	16.8	30	20	3	40
32	3654141020348	237	Dom.	17.7	30	<10	<1	25
33	3655171015649	350	Irr.	17.6	30	<10	<1	30
34	3657251015616	200	Sto.	17.8	24	<10	2	30
35	3655161015119	360	Dom.	17.1	27	<10	<1	31
36	3657571014805	300	Dom.	16.9	29	10	<1	58
37	3657441014420	285	Dom.	17.1	29	<10	<1	57
38	3655031014155	345	Irr.	17.3	25	<10	<1	38
39	3657541013755	250	Dom.	17.1	27	<10	<1	79
40	3658431013140	400	Dom.	17.8	33	10	<1	70
41	3657541012401	300	Dom.	17.0	34	40	<1	85
42	3655411012136	427	Irr.	18.0	34	<10	<1	82
43	3659141011503	140	Dom.	16.9	33	20	<1	91
44	3658471011108	165	Dom.	16.6	23	20	2	72
45	3659111011046	428	Irr.	17.1	34	<10	<1	63
46	3659101010631	635	Irr.	17.8	36	10	<1	60
47	3659361010626	354	Irr.	17.4	34	10	<1	60
48	3658441010343	522	Irr.	17.6	33	30	2	55
49	3657521005908	125	Dom.	16.2	28	<10	<1	100
50	3658441005353	100	Dom.	16.9	38	30	5	36
51	3658571005017	280	Dom.	17.5	33	20	<1	49
52	3656251004928	465	Irr.	17.7	38	<10	<1	55
53	3655341004703	280	Dom.	17.9	38	10	<1	52
54	3653221004227	400	Irr.	18.4	31	<10	<3	64
55	3656391004020	100	Dom.	16.2	33	30	<1	76
56	3642381003904	500	Irr.	17.3	37	<10	<3	45

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Latitude-longitude	Well depth (feet)	Use of water	Temperature (°C)	Silica (SiO_2)	Iron (Fe) (μg/L)	Manganese (Mn) (μg/L)	Calcium (Ca)
57	3658231003537	480	Dom.	18.5	33	50	10	90
58	3657031003338	125	Sto.	17.3	29	50	3	83
59	3658001003000	200	Irr.	17.3	30	20	5	53
60	3656101002917	124	Dom.	18.9	34	20	2	69
61	3655231002200	80	Sto.	17.8	30	110	20	110
62	3641191001604	180	Irr.	16.9	35	<10	<1	46
63	3652281001146	200	Dom.	18.1	--	<10	<1	96
64	3654261001014	80	Sto.	17.8	31	80	3	120
65	3656061000434	80	Irr.	17.5	31	<10	<3	110
66	3652371000233	200	Irr.	16.8	34	30	6	75
67	3653271000223	84	Sto.	17.3	51	400	130	110

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen ($NO_2 + NO_3$ as N)
27	29	20	4.4	230	49	33	1.4	3.7
28	26	24	5.1	220	36	12	1.4	3.1
29	35	21	5.6	220	63	37	2.2	2.3
30	34	19	5.1	210	53	15	2.3	1.2
31	27	22	5.9	210	33	35	2.4	4.9
32	26	20	6.6	240	20	4.1	2.9	1.7
33	29	26	6.3	230	42	19	2.3	2.0
34	29	31	6.1	250	65	10	1.9	1.9
35	27	32	6.3	240	54	14	2.1	2.0
36	29	36	5.1	300	61	23	1.0	5.5
37	14	17	5.3	240	30	7.2	.6	4.8
38	29	33	5.8	240	67	10	2.0	2.3
39	47	40	8.4	190	79	140	1.2	6.6
40	16	20	3.4	180	89	35	.4	4.2
41	20	28	3.5	190	170	17	.4	2.7
42	23	23	3.8	200	150	12	.5	2.8
43	21	21	3.7	200	83	69	.5	7.8
44	21	23	4.0	220	54	44	.6	9.3
45	21	26	4.0	220	95	23	.5	3.4
46	23	29	4.0	210	81	13	.6	3.5
47	26	28	4.4	230	86	33	.6	4.8
48	21	27	4.1	220	70	21	.5	4.2
49	64	43	.9	350	110	110	1.1	14
50	28	27	3.9	250	47	20	1.7	3.5
51	22	37	3.9	250	66	20	1.3	2.8
52	27	76	4.4	250	70	98	1.5	3.0
53	24	37	3.7	240	61	29	1.1	3.0
54	31	130	5.8	250	74	230	.9	2.9
55	18	36	5.0	260	25	56	2.5	12
56	22	28	5.0	240	28	24	1.5	2.5

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrogen ($NO_2 + NO_3$ as N)
57	41	210	5.8	240	110	370	0.8	2.1
58	79	99	9.9	420	310	44	2.1	9.2
59	25	140	4.0	250	200	110	.7	1.0
60	17	40	4.1	250	50	53	.6	4.8
61	26	27	4.3	220	24	170	.7	2.1
62	14	100	3.6	250	49	100	1.2	3.5
63	22	25	4.1	220	59	74	.6	12
64	11	4	2.1	400	14	2.0	.3	5.0
65	29	72	5.0	320	200	57	1.0	1.8
66	25	37	3.3	310	63	38	.7	3.5
67	32	120	5.9	340	130	190	1.4	.3

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Iodide (I)	Bromide (Br)	Sele-nium (Se) (μg/L)	Boron (B)	Dis-solved solids (sum)	Hardness as $CaCO_3$	
						Total	Non-carbon-ate
27	0.05	0.3	5	0.17	336	240	53
28	.03	.2	3	.13	277	190	11
29	.07	.6	6	.12	344	230	51
30	.05	.2	6	.13	305	220	53
31	.08	.4	3	.16	304	210	39
32	.02	.1	1	.17	255	170	0
33	.01	.2	3	.20	300	190	6
34	.06	.1	2	.19	322	190	0
35	.08	.2	2	.13	314	190	0
36	.05	.3	1	.32	396	260	18
37	.01	.1	1	.23	283	200	3
38	.05	.2	3	.25	331	210	17
39	.07	1.1	10	.19	523	390	240
40	.03	.5	7	.10	360	240	93
41	.02	.2	4	.11	454	290	140
42	.03	.2	4	.10	430	300	140
43	.02	.6	14	.04	429	310	150
44	.01	.4	6	.16	360	270	86
45	.02	.2	6	.12	378	240	63
46	.03	.2	5	.09	354	240	72
47	.03	.4	11	.11	390	260	68
48	.03	.2	7	.12	344	220	43
49	.05	1.0	17	.10	644	510	230
50	.03	.2	5	.09	328	210	0
51	.05	.2	4	.12	358	210	8
52	.04	.3	5	.09	496	250	43
53	.03	.2	5	.12	367	230	32
54	.04	.1	6	.14	693	290	87
55	.04	.3	3	.11	392	260	51
56	.01	.1	1	.08	311	200	13

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Iodide (I)	Bromide (Br)	Selenium (Se) (μg/L)	Boron (B)	Dissolved solids (sum)	Hardness as $CaCO_3$	
						Total	Noncarbonate
57	0.05	0.6	7	0.09	986	390	200
58	.32	.2	39	.32	872	530	190
59	.03	.2	2	.12	693	250	45
60	.03	.3	4	.07	396	240	37
61	.01	.3	0	.06	503	380	200
62	.02	.1	1	.08	476	170	0
63	.01	.3	8	.06	401	330	170
64	.04	.1	1	.06	387	350	17
65	.01	.1	12	.14	665	390	150
66	.03	.2	4	.14	432	290	36
67	.09	.6	16	.14	809	410	130

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH (standard units)	Dissolved oxygen (DO)	Isotopes	
					$\delta^{18}O_{SMOW}$ 0/00	$\delta^{34}S_{CD}$ 0/00
27	0.6	555	7.40	8.9	-7.7	2.4
28	.8	465	7.55	----	-7.7	1.3
29	.6	570	7.45	8.2	-7.5	-2.4
30	.6	482	7.55	7.9	-7.3	-.8
31	.7	525	7.43	13.4	-7.7	----
32	.7	408	7.54	8.4	-8.1	-1.5
33	.8	472	7.49	9.5	-7.7	-1.4
34	1.0	530	7.51	8.1	---	----
35	1.0	502	7.51	9.1	-7.8	.2
36	1.0	680	7.25	8.2	-6.8	----
37	.5	470	7.20	10.6	---	----
38	1.0	530	7.40	7.9	-8.0	1.6
39	.9	905	7.30	8.9	-8.0	.4
40	.6	585	7.38	9.1	---	----
41	.7	662	7.20	7.8	-7.8	3.1
42	.6	620	7.35	7.6	-7.8	1.0
43	.5	770	7.20	9.9	-7.3	----
44	.6	620	7.29	10.9	-7.0	2.8
45	.7	588	7.40	7.9	-7.9	3.6
46	.8	540	7.42	8.3	-8.7	-1.1
47	.8	632	7.35	10.5	-8.0	2.6
48	.8	552	7.40	8.9	-8.1	1.2
49	.8	1,140	7.00	8.5	-7.0	----
50	.8	515	7.40	6.1	-8.1	.5
51	1.1	582	7.30	7.4	-8.3	----
52	2.1	840	7.38	7.7	-8.1	2.4
53	1.1	590	7.35	6.4	-8.1	.0
54	3.3	1,280	7.78	6.2	-7.7	1.5
55	1.0	750	7.10	9.4	-7.3	----
56	.9	520	7.55	7.8	---	6.2

Table 3.--*Chemical data from water samples collected from the High Plains aquifer in the Oklahoma Panhandle, 1979-80*--Continued

Map number	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH (standard units)	Dissolved oxygen (DO)	Isotopes	
					$\delta^{18}O_{SMOW}$ 0/00	$\delta^{34}S_{CD}$ 0/00
57	4.6	1,780	7.28	4.5	-7.9	1.6
58	1.9	1,310	7.42	6.2	-6.1	----
59	3.9	1,155	7.50	7.7	-7.2	-25.1
60	1.1	685	7.20	9.6	-7.4	2.6
61	.6	945	7.43	8.6	-7.1	3.6
62	3.6	855	7.71	7.8	-7.8	6.9
63	.6	785	7.50	7.8	---	1.5
64	.1	608	6.85	4.2	-2.6	----
65	1.6	1,050	7.45	5.9	---	-1.8
66	.9	692	7.35	6.4	-7.1	-3.7
67	2.6	1,305	7.35	3.9	-6.7	-9.2

REFERENCES CITED

Gutentag, E. D., and Weeks, J. B., 1980, Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-642.

Hart, D. L., Hoffman, G. L., and Goematt, R. L., 1976, Geohydrology of the Oklahoma Panhandle; Beaver, Texas, and Cimarron Counties: U.S. Geological Survey Water-Resources Investigations 25-75, 62 p.

Hathaway, L. R., Carr, B. L., Flanagan, M. A., Galle, O. K., Waugh, T. C., Dickey, H. P., and Magnuson, L. M., 1978, Chemical quality of irrigation waters in southwestern Kansas: Kansas Geological Survey Chemical Quality Series 6, 35 p.

Reynolds, R. L., and Goldhaber, M. B., 1978, Origin of a south Texas roll-type uranium deposit: alteration of iron-titanium oxide minerals: Economic Geology, v. 73, p. 1677-1689.

Rightmire, C. T., Pearson, F. J., Back. W., Rye, R. O., and Hanshaw, B. B., 1974, Distribution of sulphur isotopes of sulphate in ground waters from the principal artesian aquifer of Florida and the Edwards aquifer of Texas: International Atomic Energy Agency Proceedings, Symposium on Isotope techniques in ground-water hydrology, p. 191-207.

Thode, H. S., Monster, J., and Dunford, H. B., 1961, Sulphur isotope geochemistry: Geochimica et Cosmochimica Acta 25, p. 159-174.

Weeks, J. B., and Gutentag, E. D., 1981, Bedrock geology, altitude of base, and 1980 saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-648.

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