
Kansas Geological Survey

Geochemistry of Strontium in Ground Waters at the Chemical Waste Management of Kansas Site Near Furley, Sedgwick County, Kansas

A report for the
U.S. Environmental Protection Agency

Donald O. Whittemore

Open-File Report 92-19

GEOHYDROLOGY



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**GEOCHEMISTRY OF STRONTIUM IN GROUND WATERS AT THE
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SEDGWICK COUNTY, KANSAS**

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by

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GEOCHEMISTRY OF STRONTIUM IN GROUND WATERS AT THE CHEMICAL WASTE MANAGEMENT OF KANSAS SITE NEAR FURLEY, SEDGWICK COUNTY, KANSAS

Executive Summary

Chemical Waste Management of Kansas (CWMK) operates a site formerly used for the land disposal of hazardous wastes. The ground-water quality is monitored at the site for inorganic and organic constituents. One of the monitoring programs involves examining the concentration of selected inorganic and organic constituents relative to Alternative Concentration Levels (ACLs) in a series of monitoring wells. The ACL for strontium was set as 1.0 mg/L (1,000 ug/L) for the site without prior examination of background levels in the area. During the monitoring program, concentrations of strontium were found to be as high as 16.3 mg/L in ground waters from ACL sampling points and as high as 15.2 mg/L in background wells at the CWMK site. The U.S. Environmental Protection Agency asked the Kansas Geological Survey to investigate the source of the high strontium at the site and determine whether the source was natural or related to the past waste disposal. In addition, if the source were determined to be natural, an ACL needed to be suggested for strontium that would be based on scientific evidence for the hydrogeochemical conditions at the site.

The study determined that the high strontium concentrations found in the seep and ground waters of the CWMK site are derived naturally from the solution of minerals observed and expected in the bedrock. The main mineral providing strontium is celestite (strontium sulfate), although dissolution of gypsum (hydrated calcium sulfate) containing strontium contributes to the total-dissolved strontium concentration. Any increases in concentrations of major inorganic constituents introduced by waste leaching are too small to significantly affect the solubility of strontium-containing minerals in the natural ground waters. The conclusions are based on the following summaries of observations and calculations:

- (1) Strontium concentrations in samples from the background wells located in the upgradient direction of ground-water flow are as great as in samples from the ACL compliance wells downgradient of the past waste-disposal area.
- (2) Natural strontium concentrations can be as high as 36 mg/L in some aquifers used as water resources in sedimentary rocks in the United States.
- (3) Appreciable amounts of gypsum occur in the bedrock of the CWMK site at the intervals sampled by most of the ACL wells. Anhydrite (calcium sulfate) exists at greater depths. Appreciable amounts of strontium are released during the hydration of anhydrite to gypsum. The process releases strontium that precipitates as celestite and also provides strontium to the ground water causing the hydration. Small quantities of celestite sufficient to provide the high strontium

concentrations observed in the ground waters are expected at the site based on the geology.

(4) A geochemical equilibria model based on actual sample data for the CWMK site fits the active dissolution of gypsum and celestite to give calcium-sulfate ground waters with relatively high strontium concentrations.

(5) Additional inorganic constituents such as sodium and chloride that could indirectly increase the solubility of celestite are in concentration ranges that could be expected for natural waters in similar geology off the site. Furthermore, if a significant amount of the strontium in the ground water were from waste leachate, the sodium and chloride concentrations would be expected to be much higher than observed. If strontium from waste leachate did reach the B-well level, strontium would be removed to the background levels by precipitation of celestite.

A recommended ACL concentration for strontium for the site is 25 mg/L based on (1) the maximum calculated celestite solubility for the samples as collected; (2) a possible additional range for locations where nearly all gypsum has been dissolved but celestite remains, where flow rates are slow, and/or following a dry period; and (3) possible error in sample analysis.

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INTRODUCTION

Chemical Waste Management of Kansas (CWMK) operates a site formerly used for the land disposal of hazardous wastes by the previous owners. The CWMK facility is located in the N 1/2 of the SW 1/4 of sec. 26, T. 25 S., R. 2 E., in northeastern Sedgwick County and approximately 10 miles northeast of Wichita. The site area for this study includes the area to the south and north of the facility, and approximately comprises the W 1/2 of sec. 26. As a part of the operation of the site, the ground-water quality is monitored for inorganic and organic constituents. One of the monitoring programs involves examining the concentration of selected inorganic and organic constituents relative to Alternative Concentration Limits (ACLs) in a series of monitoring wells. An ACL is a value described in the ground-water portion of the permit regulations in the Resource Conservation and Recovery Act (RCRA). An ACL is an alternate to using a background concentration or a maximum contaminant limit (MCL) for a substance in drinking water. No MCL exists for strontium for drinking water. No background values were available for strontium at the CWMK site at the time the ACL was set as 1.0 mg/L (1,000 µg/L), even though strontium often exceeds 1 mg/L in ground waters in carbonate aquifers of Kansas. Additional sampling points in the CWMK area include springs and seeps along Prairie Creek to the north of the facility. Figure 1 indicates the locations of the B-level monitoring wells and surface water sampling points.

During the ACL monitoring program, concentrations of strontium were found to be as high as 16.3 mg/L in ground and spring waters at the CWMK site. The ACL monitoring network also includes background wells in the upgradient direction of ground-water flow at a distance from the location of buried wastes. Strontium concentrations as high as 15.2 mg/L have been found in samples from the background wells. Thus, the following questions arose. Is the strontium at the site natural and not from the disposed chemicals? If the source is natural, what is the explanation for such high strontium concentrations? What effect could some of the chemicals disposed at the site have on changing the natural concentrations of strontium in the ground waters? Finally, if the source of strontium is natural, what is a suggested ACL appropriate for the CWMK site? This report answers these questions.

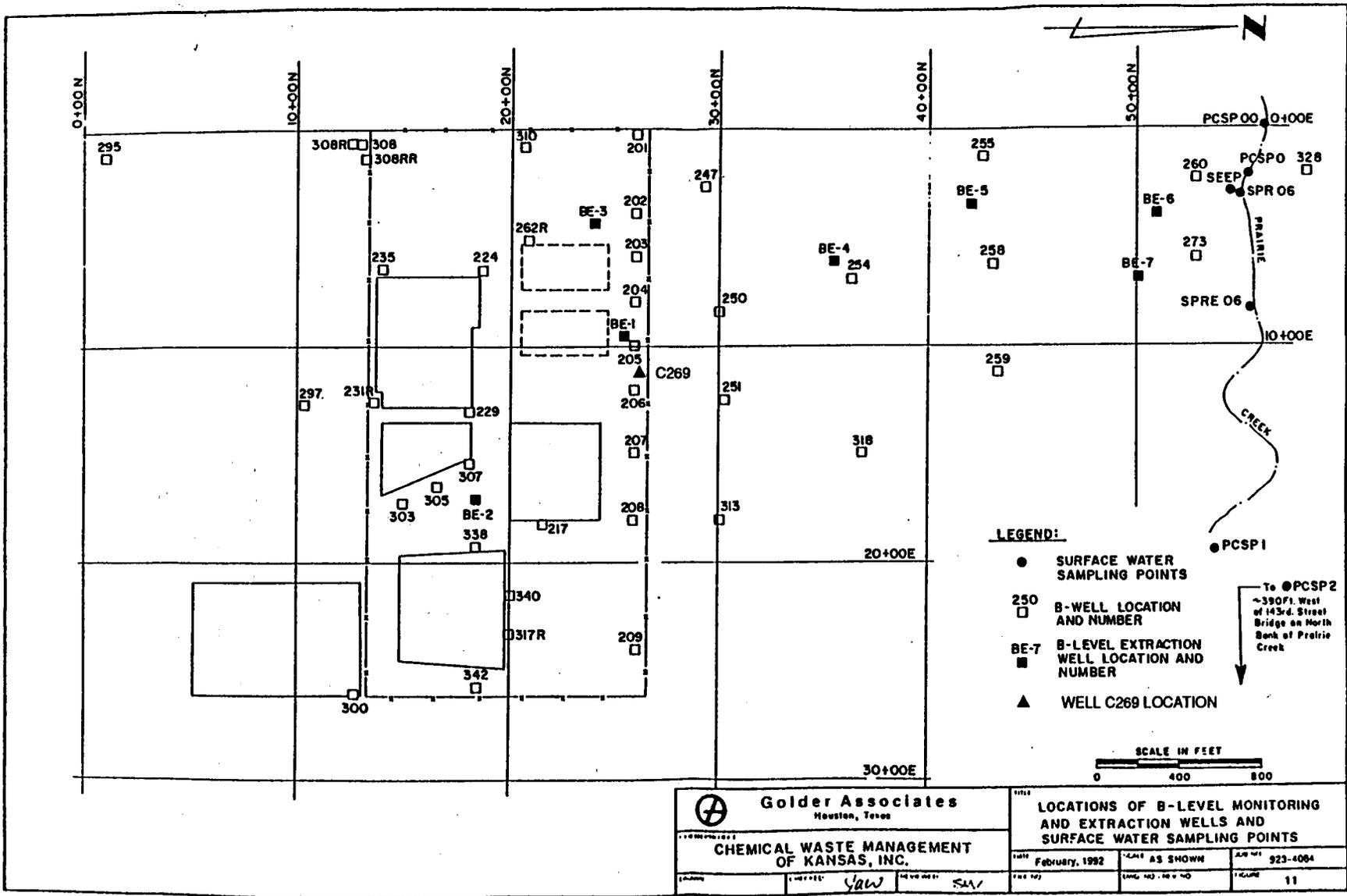


Figure 1. Locations of B-Level Monitoring Wells, Well 269C, Surface Water Sampling Points, and Extraction Wells. The area shown is the W 1/2 of sec. 26, T. 25 S., R. 2 E. in northeastern Sedgwick County. The figure was modified from a map by Golder Associates prepared in 1992 for Chemical Waste Management of Kansas, Inc.

METHODS

Data Sources

The EPA provided ground-water quality data for past measurements at the ACL monitoring points and for other sampling locations both on and outside the CWMK site. After examination of the data, I requested that samples be collected from the ACL compliance wells, seep, and background wells and analyzed for pH and concentrations of all major inorganic constituents and strontium. Staff of CWMK and the EPA collected split samples during January, 1992. The sample collection procedures and field notes are available from the EPA. I visited the site with EPA staff on January 15, 1992, to observe the monitoring network and sampling procedures and examine the characteristics of the site. The EPA and another laboratory used by CWMK analyzed the duplicate samples. Both sets of data were provided. The laboratories of the Kansas Geological Survey (KGS) analyzed the EPA sample from the deep well C269. The charge balance errors are listed in Table 1 along with the chemical data. The errors ranged up to 6.6 percent and averaged 2.5 percent. Charge balance errors less than 5 and 6.6 percent for waters with the dissolved-solids range in this study represent very good and good quality analyses, respectively. The data are of high enough quality to be used in the calculations of this report. I also obtained data including major inorganic constituents for ground waters with high strontium concentrations in different locations in Kansas and other states. Some of the data is from earlier studies of the CWMK site during 1980 and 1981 by the Kansas Department of Health and Environment and the KGS when the site was operated by Kansas Industrial Environmental Services, Inc. (KIES).

Geochemical Equilibrium Calculations

Computer models are available for the calculation of geochemical equilibria in water. The programs allow computation of the state of saturation of a water relative to the solubilities of minerals. In other words, can the water dissolve more of a particular mineral, has it dissolved as much of the mineral as possible, or is there too much dissolved in the water such that the mineral could precipitate to lower the component constituents in solution? Also, if the water is selected to be in equilibrium or saturated with respect to a mineral, certain programs can calculate the dissolved concentrations of the component constituents. Therefore, the computer model can provide data for determining what the natural concentrations of strontium would be in a ground water given the expected minerals present in the rocks.

Table 1. Chemical Data for Ground-Water Samples Collected from the CWMK Site. All temperatures, specific conductance and pH values for the seep and B-well samples are field determinations. All constituent data for the seep and B wells are from the EPA, except for sulfate which is from CWMK. The KGS determined all values for the C269, KGS-1A, and KGS-1 well waters in the laboratory, except for the field value of pH and the laboratory concentration of nitrate for well C269 which are from the EPA. Alkalinity is also represented as bicarbonate. The total-dissolved solids concentration is the sum of the constituents which includes the bicarbonate multiplied by 0.4917 and the nitrate-N multiplied by 4.427. The sample location identities followed by the letter "D" are duplicate samples. The KGS-1A and KGS-1 data are from Welch and Whittemore (1981).

Sample location	Well depth ft	Sample date	Temp. °C	SpC ^a uS	pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	Alk. ^b mg/L	HCO ₃ ^c mg/L	Cl mg/L	SO ₄ mg/L	NO ₃ -N mg/L	TDS mg/L	CBE ^d %
Seep		1-13-92	12	3700	7.38	548	86.9	69.6	4.07	10.5	266	324.3	109	1400	0.00	2388	0.4
Seep D		1-13-92	12	3700	7.38	557	88.7	70.8	3.91	10.4	262	319.4	109	1400	0.00	2397	1.4
B202	53.5	1-15-92	12	3260	7.14	486	114	63.0	7.54	10.3	203	247.5	62.6	1470	0.00	2335	0.5
B203	53.5	1-13-92	11	3670	7.11	447	137	97.8	8.05	11.5	231	281.6	121	1290	0.00	2251	4.7
B204	62.8	1-13-92	12	3610	6.86	514	99.2	56.3	3.24	10.0	241	293.8	71.4	1410	0.14	2309	0.5
B205	59.0	1-15-92	12	3800	7.15	503	114	62.3	3.54	10.7	238	290.1	77.4	1428	0.26	2343	1.1
B206	57.3	1-13-92	12	1920	7.54	211	87.9	61.5	2.44	13.7	255	310.8	83.9	657	5.65	1295	-1.7
B207	53.0	1-13-92	12	1640	7.19	148	65.3	25.3	1.00	4.11	232	282.8	22.2	405	0.40	812	0.9
B208	48.8	1-15-92	13	1040	7.26	91.3	37.5	22.7	1.00	1.16	275	335.2	61.5	83	1.45	469	-2.1
B250	59.0	1-13-92	10	3320	6.88	518	113	64.9	3.15	10.4	238	290.1	80.8	1400	0.05	2333	2.8
B250 D	59.0	1-13-92	10	3190	6.94	502	109	61.5	2.94	10.2	237	288.9	80.2	1400	0.10	2308	1.2
B254	48.1	1-15-92	13	3270	7.35	513	104	52.8	4.63	11.0	254	309.6	69.9	1640	1.18	2553	-5.7
B260	12.0	1-13-92	12	2440	7.26	502	96.0	51.3	2.43	9.61	257	313.3	71.1	1570	0.06	2457	-5.8
B273	13.5	1-13-92	11	3280	7.26	487	88.3	49.0	2.85	9.51	263	320.6	73.5	1510	0.57	2380	-6.6
B295	68.0	1-15-92	12	3870	7.15	508	139	68.6	4.13	9.04	204	248.7	65.1	1640	0.00	2556	0.0
B297	58.5	1-13-92	12	3670	7.35	520	133	58.5	3.82	9.14	193	235.3	63.3	1500	0.51	2406	3.7
B300	57.0	1-13-92	13	2840	7.14	424	98.6	39.1	3.22	12.8	245	298.7	38.3	1050	0.00	1813	5.9
C269	97.3	1-15-92	12	91100	7.3	771	3440	20800	626	12.4	80.6	98.3	41200	3790	0.15	70688	-0.0
KGS-1A	60	3-18-81		1980	7.8	239	111	64	1.0		288	344	110	710	1.20	1409 ^e	0.5
KGS-1	134	3-18-81		4100	7.8	645	207	195	2.5		397	484	354	1908	1.49	3556 ^e	0.0

^a Specific conductance; units of uS are the same as umho/cm.

^b Alkalinity as mg/L CaCO₃.

^c Calculated from alkalinity x 1.219.

^d Charge balance error; ((cations - anions)/(cations + anions)) x 100, where concentrations are in meq/L.

^e Measured values at 180 °C are 1430 and 3670 mg/L for KGS-1A and KGS-1, respectively. The measured values are higher because they include other constituents not determined such as silica.

I used the geochemical model SOLMINEQ.88 for the calculations because it includes equations for the common strontium minerals and allows calculation of saturation indices for the water as analyzed and for added constituent concentrations to achieve saturation of selected minerals. The program also provides for user change of equilibrium constants for minerals. The equilibrium constant for celestite (SrSO_4) in the SOLMINEQ.88 code is greater than in a recent study of celestite solubility (Reardon and Armstrong, 1987). The calculations for this report are based on Reardon and Armstrong values at the ground water temperatures. The pK's (-log K) used for celestite are, at 10 °C, 6.630; 11 °C, 6.629, 12 °C, 6.628; 13 °C, 6.627; 15 °C, 6.625, and 18 °C, 6.623. The program is compiled in FORTRAN on the Data General computer at the KGS.

RESULTS AND DISCUSSION

Water Chemistry at the CWMK Site

Distribution of dissolved constituents

Table 1 lists the field measurements and dissolved-constituent concentrations for ground-water samples collected in January, 1992, for this study and for two well waters collected and analyzed by the KGS in 1981. Well numbers B295, B297, and B300 in Table 1 are background wells that are located in an upgradient direction of ground-water flow from the other B wells listed in Table 1 that are for ACL compliance monitoring. The KGS-1A well was a windmill well and sampled the upper water-bearing zone in the area. The KGS-1 well was drilled by the KGS and represents a level deeper than the B water-bearing zone. The wells would be equivalent to the CWMK background wells in that they are in an upgradient direction of ground-water flow from the waste disposal locations. Both KGS well locations are shown on the map of the CWMK site by Woodward Clyde Consultants (1988) along with the locations of the seep and B wells. The seep is located in the downgradient direction of ground-water flow from the ACL compliance wells. The C269 well is the deepest of the wells.

The total-dissolved-solids (TDS) concentrations indicate the waters range from fresh (<1,000 mg/L) for samples from wells B207 and B208 to a brine from well C269. Waters from 11 of the 16 different locations of the 1992 samples have TDS contents between 2,200 and 2,600 mg/L. The main components of the high TDS are calcium and sulfate for all the waters in Table 1 except that from C269. Magnesium concentrations are also correlated with calcium and

sulfate. Although sodium and chloride concentrations are lower in the fresher waters, the correlation with TDS is much poorer than for calcium, magnesium, and sulfate. Bicarbonate values fall within a relatively narrow range of 235-335 mg/L for the 1992 samples. The brine from well C269 is a sodium-chloride water with high concentrations of magnesium and sulfate.

No readily apparent difference exists between the chemistry of the group of background well waters collected in 1992 and the group of compliance wells and the seep. The waters collected from the seep and the B-wells have concentrations of major constituents (Table 1) which are similar to the ranges for well waters collected from the CWMK site or surrounding area in 1980 and 1981 and analyzed by the Kansas Department of Health and Environment and the KGS. The latter data are listed in Table E-2 of the water chemistry chapter (Welch and Whittemore, 1981) in the KGS report on the CWMK site, known in 1981 as the KIES waste disposal facility. The data for the KGS-1A and KGS-1 wells in Table 1 are from Table E-2 in Welch and Whittemore (1981).

The calcium and sulfate contents in the KGS-1A and KGS-1 well waters bracket the values in Table 1 for all the seep and B-well samples except the fresher B206, B207, and B208 samples. The magnesium, sodium, bicarbonate, and chloride values for the KGS-1 well sample were appreciably higher than those for all of the seep and B-well samples in Table 1. The magnesium, sodium, bicarbonate, and chloride concentrations for the KGS-1A well water were either about the same as or higher than all the seep and B-well values. Thus, the concentrations of dissolved inorganic substances in the seep and B-well samples collected in 1992 do not appear to reflect inputs that could be identified as mainly from waste sources.

The brine from well C269 has a much higher sodium and chloride content than for the KGS-1 well water. The high ionic strength of the water has increased the solubility of other minerals present, leading to higher concentrations than in the seep and B-well waters.

Strontium concentrations range from 1.16 to 13.7 mg/L and are generally directly correlated with TDS in the seep and B-well waters, i.e., the two freshest waters have lower strontium concentrations, while the high TDS samples have higher strontium (Figure 2). However, the strontium content is inversely related to TDS if only the group of waters with TDS >1,000 mg/L is considered. A similar relationship exists between strontium and sulfate concentrations in the seep and B-well waters (Figure 3).

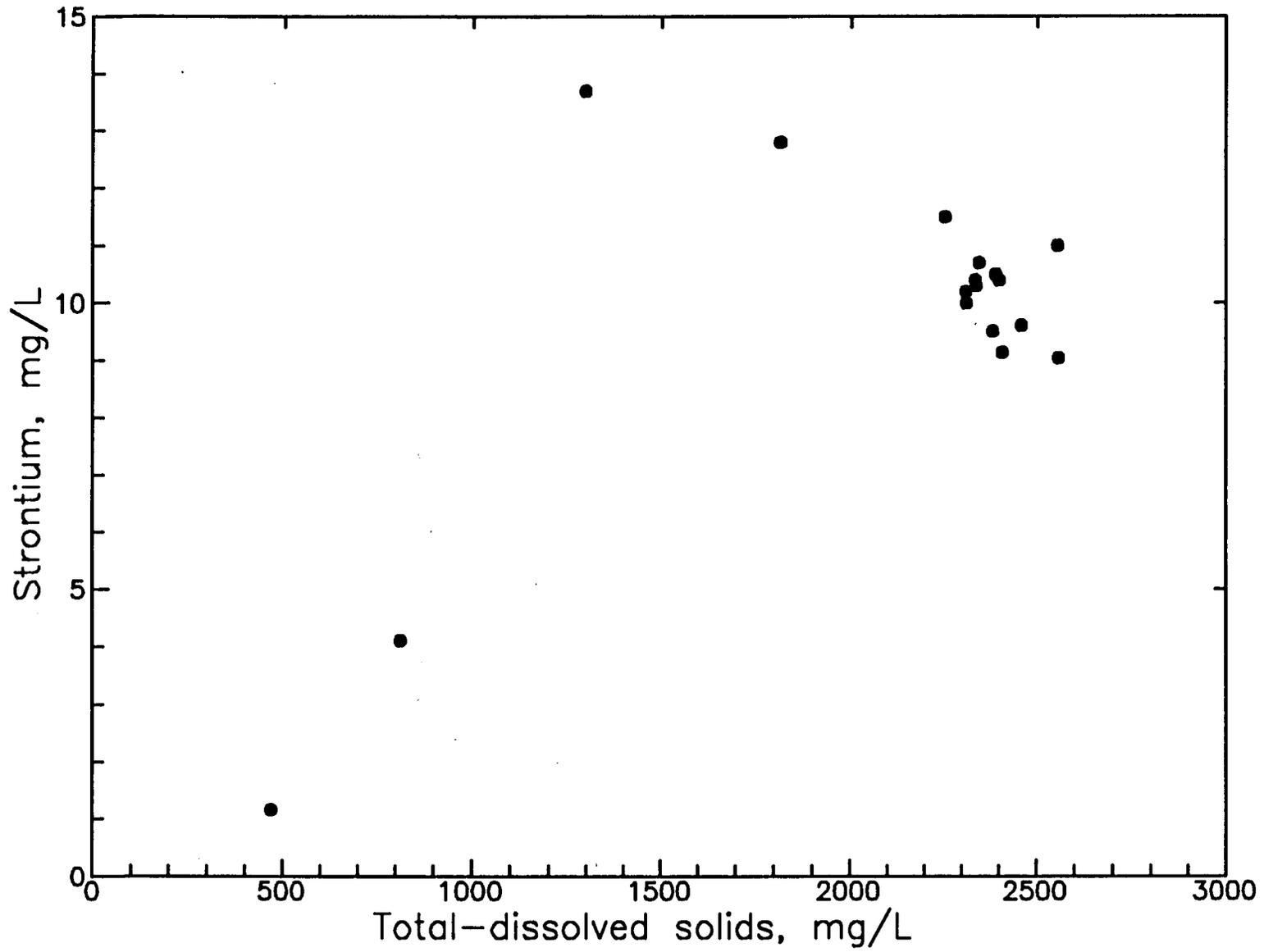


Figure 2. Strontium Versus Total-Dissolved-Solids Concentration in Seep and B-Well Samples Collected January, 1992.

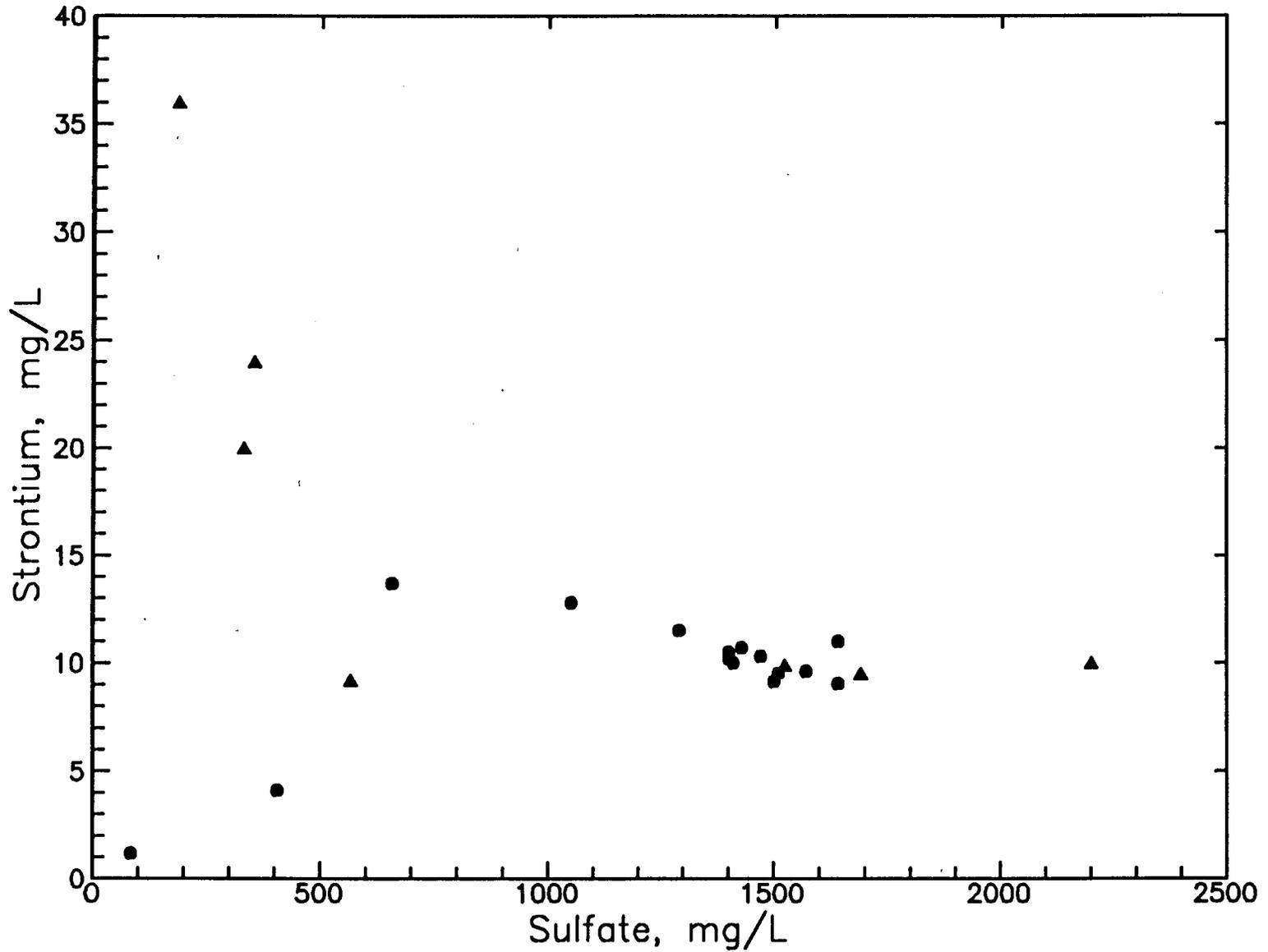


Figure 3. Strontium Versus Sulfate Concentration in Seep and B-Well Samples Collected January, 1992, and in High-Strontium Ground Waters from Kansas, Oklahoma, and Wisconsin. The CWMK samples are represented by circles, the samples from outside the CWMK site by triangles.

Source of dissolved constituents

The bedrock unit underlying the surface of the CWMK site is the Wellington Formation of the Lower Permian Series. The calcium, magnesium, bicarbonate, and sulfate relationships for the seep and B-well waters in Table 1 can be explained by dissolution of varying amounts of the minerals gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), calcite (CaCO_3), and dolomite ($\text{CaMg}(\text{CO}_3)_2$) found in the Wellington Formation. The source of the high calcium and sulfate concentrations in the ground waters is dissolution of gypsum. Several holes were bored and logged by the KGS in early 1981 south of the waste disposal area (Wilson, 1981). The borehole logs indicate that limestone, dolomite, gypsum, and, in the deepest hole (KGS-1), anhydrite (CaSO_4) occur in the predominantly shaley bedrock. The KGS-1 borehole was drilled deeper than the others for the purpose of determining the stratigraphy and mineralogy of the bedrock. Cuttings from the KGS-1 and KGS-2 boreholes were analyzed by x-ray diffraction. The diffraction patterns confirmed that the minerals visually identified in the borehole cuttings were present (Table 2). Gypsum was first encountered at a depth of 64.5 feet below the surface in the KGS-1 borehole, but at a depth as shallow as 18 feet in another borehole (KGS-4A). Boring logs for the A and B wells on the CWMK site indicate that gypsum first occurs at depths ranging from 40 to 58 feet (CWMK, 1989). These depths are generally within the lower part of the depths of the B background and compliance wells.

Gypsum dissolves incongruently (this is, it dissolves to form dissolved species and some new solid phases) in the presence of calcite and/or dolomite in the bedrock because the carbonate mineral dissolution supplies appreciable amounts of bicarbonate. Equilibrium of bicarbonate with carbonate in the water provides carbonate ions to precipitate calcite as the calcium concentration increases during the gypsum dissolution. Thus, the dissolved sulfate increases at a faster rate than the calcium as a result of the limitation of calcite solubility. However, the total calcium does increase even though in equilibrium with calcite because some of the calcium is bound in the ion pair CaSO_4° in solution which increases the total-dissolved calcium content. The formation of calcite during the incongruent gypsum dissolution can form a very porous zone in the subsurface because it cements together the less soluble rock material around the locations of dissolved gypsum.

The concentrations of sodium and chloride in the seep and B-well waters are within the range expected for ground waters in Kansas with high sulfate contents in Permian rocks. Data in Whittemore and Switek (1977) indicate that sodium and chloride contents of waters from different springs in bedrock of the Council Grove Group of Lower Permian age in Pottawatomie

Table 2. Chemical Data for Ground Waters with High Strontium Concentration Collected from Wells in Bedrock Aquifers Outside the Chemical Waste Management of Kansas Site. The original nitrate values have been converted to nitrate-N.

Well ^a location	Water- bearing formation	Temp. °C	Sample date	SpC ^b uS	pH	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr mg/L	HCO3 mg/L	Cl mg/L	SO4 mg/L	NO3 mg/L	TDS mg/L
Marion County, Kansas (O'Connor and Chaffee, 1983)															
19S-04E-9dda	Barneston Limestone	15	6-20-83	3900	6.4	624	93	165	12	9.9	320	361	1524	0.77	2968
Wabaunsee County, Kansas (Skougstad and Horr, 1963)															
14S-12W-5acd	Long Creek Limestone Member		3-19-58	1550	7.3	242	62	36	2.0	9.2	345	42	566	2.5	1190
Morton County, Kansas (Whittemore, unpublished)															
32S-41W-29abbc	Upper Permian sandstone	20	6-12-90	2680	6.9	558	87	52	1.8	9.5	153	9.7	1690	2.2	2530
Oklahoma County, Oklahoma (Parkhurst et al., USGS report in review)															
12N-04W-13bbb	Garber- Wellington formations	18	11-07-88	3540	7.5	500	120	300	2.4	10.0	98	65	2200	11.0	3320
Fond du Lac County, Wisconsin (Skougstad and Horr, 1963)															
F1 13/19/18-125	Late Cambrian sandstone		2-18-58	859	7.4	118	33	21	5.2	36	315	24	184	0.18	610
Outagamie County, Wisconsin (Skougstad and Horr, 1963)															
Ou21/18/25-47	Cambrian sandstone, dolomite		10-27-55	963	7.3	157	21	14	4.6	20	241	8.0	330	0.07	963
			2-18-58	997	7.4	182	19	16	4.6	24	240	7.0	353	0.16	997

^a Locations in Kansas and Oklahoma are township, range, section, and quarter sections designated by letters for the largest to the smallest quarter sections. The letter "a" indicates the NE quarter, "b" the NW, "c" the SW, and "d" the SE quarter.

^b Specific conductance; units of uS are the same as umho/cm.

County are correlated with sulfate values. In addition, the sodium and chloride concentrations change concordantly with changing sulfate in those springs in which TDS varies from different amounts of recharge diluting the mineralized ground waters.

If the source of strontium were mainly from the waste at the site, much higher concentrations of sodium and chloride that would have been in the waste should be found in the ground waters. In addition, the strontium concentrations should be decreasing along with the decreases found for the organic compounds in the B-well waters. However, the strontium contents have remained relatively constant with time for samples from a given B well.

I have identified the source of the brine from well C269 as saltwater associated with oil production. The identification was based on the similarity of the bromide/chloride ratio to the ratio range for oil brines from Sedgwick County, ratios that are much greater than for halite-solution brine from the Wellington Formation. Oil has been produced from the site area; an oil well was formerly located just to the west of the waste-disposal area.

High Strontium Ground Waters at Other Locations in the United States

The chemistry of well waters with high strontium concentrations and chloride contents <400 mg/L from bedrock aquifers in Kansas locations outside of the CWMK site and in other states are shown in Table 3. The data indicate that high dissolved strontium can be found naturally in other areas of Kansas as well as in other states. Concentrations reach as high as 36 mg/L in an aquifer in Wisconsin (Skougstad and Horr, 1963), a value more than twice the highest strontium reported for ground waters from the CWMK site. The waters in Table 3 most similar in major constituent composition to the CWMK site waters, i.e., with both high calcium and sulfate, are from Kansas and Oklahoma. Points for the Marion and Morton counties waters plot in the group of points for the high sulfate waters from the CWMK site on the graph of sulfate versus strontium concentrations (Figure 3). The Wabaunsee County water plots along the trend from low to higher sulfate and strontium values for sulfate <1,000 mg/L. The Wisconsin waters are all fresh (TDS <1,000 mg/L) but also are calcium-sulfate type waters based on equivalent concentrations of the constituents. Points for the Wisconsin waters plot along the inverse relationship between sulfate and strontium shown by all the waters except the two freshest CWMK samples and the Wabaunsee County sample.

Table 3. Mineralogy of Stratigraphic Hole KGS-1 as Determined by X-ray Diffraction Analysis (Wilson, 1981).

Sample depth ft	Mineralogy
0-3.5	Quartz, mixed-layer montmorillonite; minor feldspar
4	As above
5-7	As above, trace 7A clay
7-11	Quartz, mixed-layer montmorillonite and illite; minor calcite and 7A clay; trace feldspar
13-13.5	Quartz, mixed-layer montmorillonite and illite; 7A clay; trace feldspar
14.5-17	Quartz, mixed-layer montmorillonite and illite; 7A clay; trace feldspar
20	Quartz, mixed-layer montmorillonite and illite; minor calcite and 7A clay; trace feldspar
30	Quartz, dolomite, calcite, mixed-layer montmorillonite and illite-mica; minor 7A clay
32.5	As above
35	As above, except calcite greater than dolomite
40	As above
41	As above
45	Dolomite, calcite, quartz; minor clay assemblage as above
50	Quartz, calcite, clay assemblage as above; minor dolomite
55	As above
60	As above
64.5	As above, but more dolomite, and trace gypsum
66	Dolomite, calcite, quartz, clay assemblage as above, and minor gypsum
70-73	Dolomite, quartz, gypsum; minor clay as above; trace calcite and feldspar
74	Gypsum, quartz, clay as above; minor calcite and dolomite
74.5-75	Gypsum, calcite, quartz; minor dolomite and clay
75.5-79.5	Gypsum, quartz, clay assemblage as above; minor calcite, dolomite, and feldspar; possible anhydrite
80-85	Gypsum, calcite, quartz; minor clay and dolomite, trace anhydrite
87	As above
90-95	As above, but more anhydrite
97-101	Anhydrite, gypsum; minor quartz, calcite, and dolomite; trace clay assemblage as above and feldspar
102-108	As above
123-126	As above
129-134	As above

Mode of Occurrence of Strontium in Sedimentary Rocks

Strontium can occur in different modes in sedimentary rocks. The distribution of strontium is related to the calcium content of the minerals present. The amount of strontium that can be incorporated into calcium minerals precipitated from water depends on the strontium/calcium ratio in the water, the structure of the precipitated mineral, the temperature, the salinity and composition of the water, and the effect of organisms that may participate in formation of a mineral (Wehmiller, 1972). Diagenesis of the sediment and resolution and precipitation by ground water can later change the strontium/calcium ratio. Some clay minerals in shales can concentrate strontium due to ion-exchange properties.

Aragonite, a polymorph of calcium carbonate, is a mineral that can incorporate substantial strontium concentrations. Marine aragonite ooids and corals contain 7,740-10,000 mg/kg (ppm) strontium (Kinsman, 1969; Bathurst, 1975). Strontium contents in recent carbonate sediments is generally 3,000-6,000 mg/kg because the sediments commonly include aragonite. However, ancient limestones contain 70-630 mg/kg strontium, with the majority in the range 160-380 mg/kg (Bathurst, 1975), and many dolomites have strontium in the 250 mg/kg range (Weber, 1964). Diagenesis of carbonate sediments to form limestone causes the recrystallization of aragonite to form calcite, or in the case of dolomite rock (dolostone), to form the mineral dolomite. Both of these carbonate minerals cannot incorporate as much strontium in their structures. The strontium excluded from the aragonite would be either removed by flow of subsurface water present during the diagenesis, or if in high enough concentration, would precipitate as strontianite (SrCO_3) or celestite (SrSO_4), depending on the amount of sulfate present. The amount of strontium remaining in limestones or dolomites is only enough to add a few tenths of a mg/L to ground waters dissolving the carbonate rocks. Thus, high strontium concentrations in ground waters in limestones and dolomites would be derived from dissolution of strontianite and/or celestite that had formed earlier. Celestite has been observed in carbonate rocks in Kansas, for example, Fishburn and Davis (1962) have described the geology of deposits of the mineral in Brown County.

Anhydrite can also incorporate substantial amounts of strontium into its structure which is similar to the structures of strontianite and aragonite (Kushnir, 1980). The strontium most probably substitutes for calcium as a solid solution (Kushnir, 1982). Although strontium is also expected to substitute for calcium in gypsum, Kushnir (1980) indicated that additional strontium would occupy interstitial positions among the water molecules. The range in strontium/calcium ratios for the precipitation of anhydrite from a brine is smaller than the range for gypsum because

rates of precipitation can affect the ratio much more in gypsum (Kushnir, 1982). At low precipitation rates the strontium/calcium ratio is higher in anhydrite than gypsum, but at high rates the ratio can be greater in gypsum than in anhydrite.

Ham (1962) observed an average of 970 mg/kg strontium in gypsum and a range of 895-3165 mg/kg and an average of 1,475 mg/kg strontium in anhydrite in Permian sulfate deposits in Blaine County, Oklahoma. Kushnir (1982) concluded that the lower average for gypsum in comparison with the anhydrite is consistent with a very slow rate of gypsum formation during hydration of the anhydrite. Ham observed no celestite in thin sections of anhydrite, but found celestite in gypsum thin sections. His observations indicate that during hydration of the anhydrite to gypsum, much of the strontium goes into gypsum, but the rest forms celestite that occurs either in the gypsum or along clay seams in the gypsum. He stated "The process of celestite formation by this method apparently is so common as to be virtually universal in western Oklahoma, for no thin section of rock gypsum from that region has been examined which does not contain recognizable celestite." Some of the strontium is also lost to the ground water causing the alteration of the anhydrite.

The formation of celestite during the hydration of anhydrite to gypsum appears to be common wherever this process occurs based on available published literature. For example, Bath et al. (1987) examined the progressive hydration of an anhydrite formation in England. Petrographic examination of the anhydrite and gypsum showed that the bulk of strontium in gypsum zones is bound up in celestite whereas no discrete strontium phase could be identified within the anhydrite zone. They suggested "that strontium leached during the recrystallization of anhydrite to gypsum has been reprecipitated very locally as celestite."

The gypsum at the CWMK site has probably formed from the alteration of anhydrite in the Wellington Formation. Anhydrite is found below the gypsum at the site as indicated in Table 2. Extrapolation of the stratigraphic position of the Hutchinson Salt Member of the Wellington Formation from data to the west indicates that the bedrock penetrated by the KGS-1 borehole would probably be near the base of the Member. Therefore, the bedrock is mainly the lower part of the Wellington Formation which contains the lower anhydrite member. The lower anhydrite member in Reno County consists of 200 ft of gray anhydrite and shale with several beds of dolomite (Leonard, and Kleinschmidt, 1976). Any salt beds that may have once existed at the CWMK site have been dissolved because halite is much more soluble than anhydrite or gypsum.

The average strontium concentration in the Blaine gypsum of Oklahoma is equivalent to a strontium/sulfate mole ratio of about 0.002. If dissolution of this gypsum alone were controlling

strontium in a ground water, the expected concentration of strontium released for every 100 mg/L sulfate dissolved would be approximately 0.18 mg/L. The maximum observed sulfate in ground water at the CWMK site is 1,720 mg/L. If the gypsum were similar to that in Blaine County, Oklahoma, the resultant strontium concentration would be 3.10 mg/L. Thus, there must be an additional source of strontium to provide the substantially higher values in the ground water at the CWMK site. This source is most probably the celestite that is expected to occur in the gypsum just as has been observed in the Blaine gypsum.

The celestite would be associated with the gypsum, either along seams or disseminated within the gypsum. Where the ground water is dissolving gypsum, it will also be dissolving celestite. Additional strontium in the structure of gypsum will be released to solution during the solution of gypsum. Some of the water at greater depths could contain high strontium as a result of the strontium removed during hydration of the anhydrite.

The amount of anhydrite removed to account for about 10 mg/L strontium in solution, assuming the strontium content of the Oklahoma Blaine anhydrite and a rock porosity of 20 percent after dissolution, is only about 0.06 volume percent of the rock. This very small volume would be similar to that for dissolution of the combined gypsum and celestite that results from hydration of anhydrite and concomitant formation of celestite. The total amount of strontium estimated to exist naturally in the readily soluble rock to a depth of 68 feet in the CWMK site area is over 20,000 metric tons (22,000 short tons). This is based on the site study area of about one-half section (one-half square mile), the deepest B-well sampled for this study, the presence of gypsum containing celestite that formed from a total thickness of 3 meters (10 feet) of anhydrite, and a total thickness of 3 meters of calcite and dolomite containing the average strontium for ancient limestones and dolomites.

Geochemical Controls on Dissolved Strontium in Ground Waters

Mineral equilibria calculations

If celestite and/or strontianite is/are the main controls on the high strontium contents in the ground waters of the CWMK site, then calculation of ion activity products for water samples should show whether the dissolved strontium observed is limited by one or both of these minerals. The saturation state of the waters with respect to minerals expected in the Wellington Formation was computed using the equilibria model SOLMINEQ.88 to test this hypothesis. I used the pH, temperature, and dissolved constituent concentrations in Table 1 as input data for the computations. The program calculated ion activities for dissolved species and activity

products for many minerals comprised of the constituents in the data set. After examination of initial results, I selected an additional option in the program to calculate the maximum amount of strontium that could be dissolved in a water if the water were saturated with respect to celestite. I used the same approach for the chemistry data in Table 3 for ground waters outside the CWMK site.

The degree to which a water is in equilibrium with respect to a mineral can be represented by the saturation index. The saturation index is the log of the ratio of the activity product to the equilibrium constant (solubility product) for a particular mineral at the temperature of the water. If a water is saturated with a mineral it cannot dissolve any more of that mineral. The activity product at saturation with respect to a mineral should equal the theoretical solubility product. Thus, at saturation, the activity product/solubility product ratio is 1 and the saturation index is 0. A water that is undersaturated with respect to a mineral has the potential to dissolve more of the mineral and has an activity product/solubility product ratio <1 . The saturation index is then a negative number. A water supersaturated with respect to a mineral has the capacity to precipitate the mineral and has an activity product/solubility product ratio >1 , giving a positive saturation index. The possible errors in the measured constituent concentrations, pH, and temperature for the waters at the CWMK site and in the equilibrium constants in the programs mean that a water is effectively saturated with respect to celestite if the saturation index is between -0.1 and 0.1, and to strontianite if the saturation index is between -0.15 and 0.15. The index for strontianite is much more sensitive to errors in pH than is the index for celestite.

The total-dissolved strontium in the ground waters exists as 5 different species. Appendices A and B list both the total strontium measured and that calculated for saturation with respect to celestite. The appendices also show the computed concentrations of the dissolved species Sr^{2+} , SrSO_4° , SrHCO_3^+ , SrCO_3° , and SrOH^+ . The relative concentrations of these species decrease in the order listed for all of the waters within and outside the CWMK site. Most of the total strontium is in the Sr^{2+} form, whereas concentrations of the ion pair SrSO_4° reach a maximum of 0.58 mg/L in the CWMK waters and 0.62 mg/L in one of the Wisconsin waters.

Mineral equilibria relationships at the CWMK site

The seep samples and all of the B-well waters with dissolved strontium of 9 mg/L or more are either saturated or just slightly undersaturated with respect to celestite (Table 4). The two fresher waters from wells B207 and B208 are appreciably undersaturated with respect to celestite. All of the waters from the CWMK site are undersaturated with respect to strontianite,

Table 4. Saturation Indices for Celestite and Strontianite Computed for Ground-Water and Seep Samples Collected during January, 1992, from the Chemical Waste Management of Kansas Site near Furley. The dates under the heading "Analyzed" refer to the collection date; the 1992 samples are for January, 1992, as listed in Table 1, and the date range refers to the different samples collected for each location during the period. Samples labeled with "D" following the site name are for duplicates.

Sample	Total-dissolved strontium concentration, mg/L			Saturation index for sample as analyzed	
	Analyzed 1992	Analyzed 1989-1991	At saturation with celestite	Celestite	Strontianite
Seep	10.5	11.0-11.3	13.4	-0.10	-0.55
Seep D	10.4		13.5	-0.11	-0.56
B202	10.3	9.81-12.6	11.6	-0.09	-0.92
B203	11.5	11.6-13.5	12.8	-0.09	-0.84
B204	10.0	10.6-12.5	13.1	-0.12	-1.13
B205	10.7	10.7-12.9	12.0	-0.09	-0.82
B206	13.7	13.9-16.3	18.5	-0.13	-0.18
B207	4.11	3.94-4.82	23.9	-0.75	-1.03
B208	1.16	0.80-1.20	95.5	-1.85	-1.34
B250	10.4	10.4-12.2	13.2	-0.10	-1.12
B250D	10.2		13.1	-0.11	-1.06
B254	11.0	11.1-12.5	11.1	-0.03	-0.60
B260	9.61	8.38-10.9	10.9	-0.09	-0.74
B273	9.51	9.03-11.6	10.8	-0.10	-0.73
B295	9.04	8.25-10.3	12.1	-0.13	-0.98
B297	9.14	8.43-9.46	12.9	-0.15	-0.76
B300	12.8	12.0-15.2	14.1	-0.08	-0.69

Table 5. Saturation Indices for Celestite and Strontianite Computed for Ground Waters from Wells in Bedrock Aquifers Outside the Chemical Waste Management of Kansas Site. See Table 2 for location and source information for the samples.

Sample	Total-dissolved strontium concentration		Saturation index for sample as analyzed	
	Analyzed mg/L	At saturation with celestite mg/L	Celestite	Strontianite
Marion Co., KS	9.9	14.1	-0.15	-1.56
Wabaunsee Co., KS	9.2	22.3	-0.34	-0.53
Morton Co., KS	9.5	10.8	-0.08	-1.36
Oklahoma Co., OK	10.0	10.1	-0.02	-1.00
Fond du Lac Co., WI	36	37.3	-0.06	-0.23
Outagamie Co., WI	20	24.6	-0.09	-0.27
Outagamie Co., WI	24	24.1	-0.00	-0.10

although the range is from slightly undersaturated for well B206 to substantially undersaturated for well B208. The results indicate that celestite is the probable mineral controlling the high concentrations of strontium at the site. The saturation indices for the background wells B295, B297, and B300 are similar to those for the high strontium waters from the B-wells used for ACL compliance. Water from well C269 is undersaturated with respect to celestite, even though the strontium concentration is 12.4 mg/L and the sulfate is higher than the B-well waters, because the very high ionic strength of the brine increases the solubility of celestite as well as other minerals.

Data in Appendix A show that the B-well waters are either saturated or supersaturated with respect to calcite and undersaturated to supersaturated with respect to dolomite (indices within -0.15 to 0.15 for saturation). The activity products of calcite, dolomite, and strontianite are much more sensitive to pH than the activity product of celestite. Supersaturation with respect to calcite suggests that either the rate of incongruent dissolution of gypsum in the CWMK ground waters is faster than the calcite precipitation rate, or the measured pH values are higher than actual for some of the ground waters. If the true pH is lower for some of the ground waters, the saturation indices for strontianite would be lower than in Table 4. Dolomite supersaturation could be possible because precipitation of ordered dolomite probably would either not occur or precede at a very slow rate. The seep water is the most supersaturated of any of the waters with respect to calcite and dolomite. This might be expected because dissolved carbon dioxide could be lost to the near surface sediment as the ground water passed from the bedrock through the alluvium and colluvium to the seep location. Loss of dissolved carbon dioxide increases the pH of a water.

All of the seep and B-well waters with sulfate contents >1,000 mg/L are nearly saturated or slightly undersaturated with respect to gypsum and undersaturated with respect to anhydrite. The saturation index range expected for gypsum and anhydrite saturation is -0.05 to 0.05 because the percent errors in calcium and the relevant equilibrium constants should be smaller than for celestite and strontianite, and the indices of gypsum and anhydrite are relatively insensitive to pH. The results fit the active solution of gypsum in the subsurface.

Mineral equilibria relationships for ground waters at other locations

I also computed activity products and saturation indices for the high-strontium waters outside the CWMK site listed in Table 3. The results for celestite and strontianite are in Table 5 as well as in more detailed form in Appendix B. The indices indicate celestite saturation for the

Morton County, Oklahoma, and Wisconsin waters, and slight to moderate undersaturation for the Marion and Wabaunsee counties waters. The greater undersaturation for the Wabaunsee County ground water could be expected due to the substantially lower sulfate concentration than for the other waters with strontium values in the 9-10 mg/L range. All of the Kansas and Oklahoma samples are from Permian sedimentary rocks and have a greater similarity in composition to the CWMK samples than do the Wisconsin waters. Celestite appears to be the main mineral controlling the strontium concentration at these locations, just as indicated for the CWMK site. The Wisconsin ground waters are saturated or slightly undersaturated with respect to strontianite in comparison with the undersaturation for the Kansas and Oklahoma waters. Both minerals may control the strontium concentrations at the Wisconsin locations.

Saturation indices for the waters listed in Table 3 indicate saturation, undersaturation, and slight supersaturation with respect to calcite and dolomite. The Marion and Morton counties and Oklahoma samples are saturated with respect to gypsum, while the Wabaunsee County and Wisconsin waters are undersaturated with respect to gypsum.

Comparison of observed dissolved strontium with equilibrium concentrations

Tables 4 and 5 also show the calculated strontium concentrations that could be present in the ground waters if the waters were saturated with respect to celestite. Figure 4 displays the strontium data for this calculation relative to the measured contents versus the measured dissolved sulfate. The strontium values at celestite saturation are larger by 0.1 to 3.8 mg/L for the January, 1992, seep and all B-well samples with sulfate >1,000 mg/L (Table 4). The maximum strontium concentrations measured for several samples collected at each of the same locations during 1989-1991 are all within about 3.5 mg/L, and many are within 1 mg/L, of the computed strontium values for celestite saturation at each location. If the analytical error in the measured values is on the order of one mg/L, then the maximum observed values fit excellently with celestite saturation. Table 5 indicates that the ground waters with dissolved sulfate >1,000 mg/L from other locations in Kansas and Oklahoma have computed strontium values at celestite saturation that are from 0.1 to about 4 mg/L above the observed, a range similar to that for the CWMK site.

Samples from well B206 have consistently had the highest measured strontium of all the B-wells used for ACL compliance. The computed strontium at celestite saturation for the water collected from well B206 in January, 1992, is 18.5 mg/L, while the maximum strontium from sample analyses is 16.3 mg/L. Thus, the geochemical model results predict accurately that this

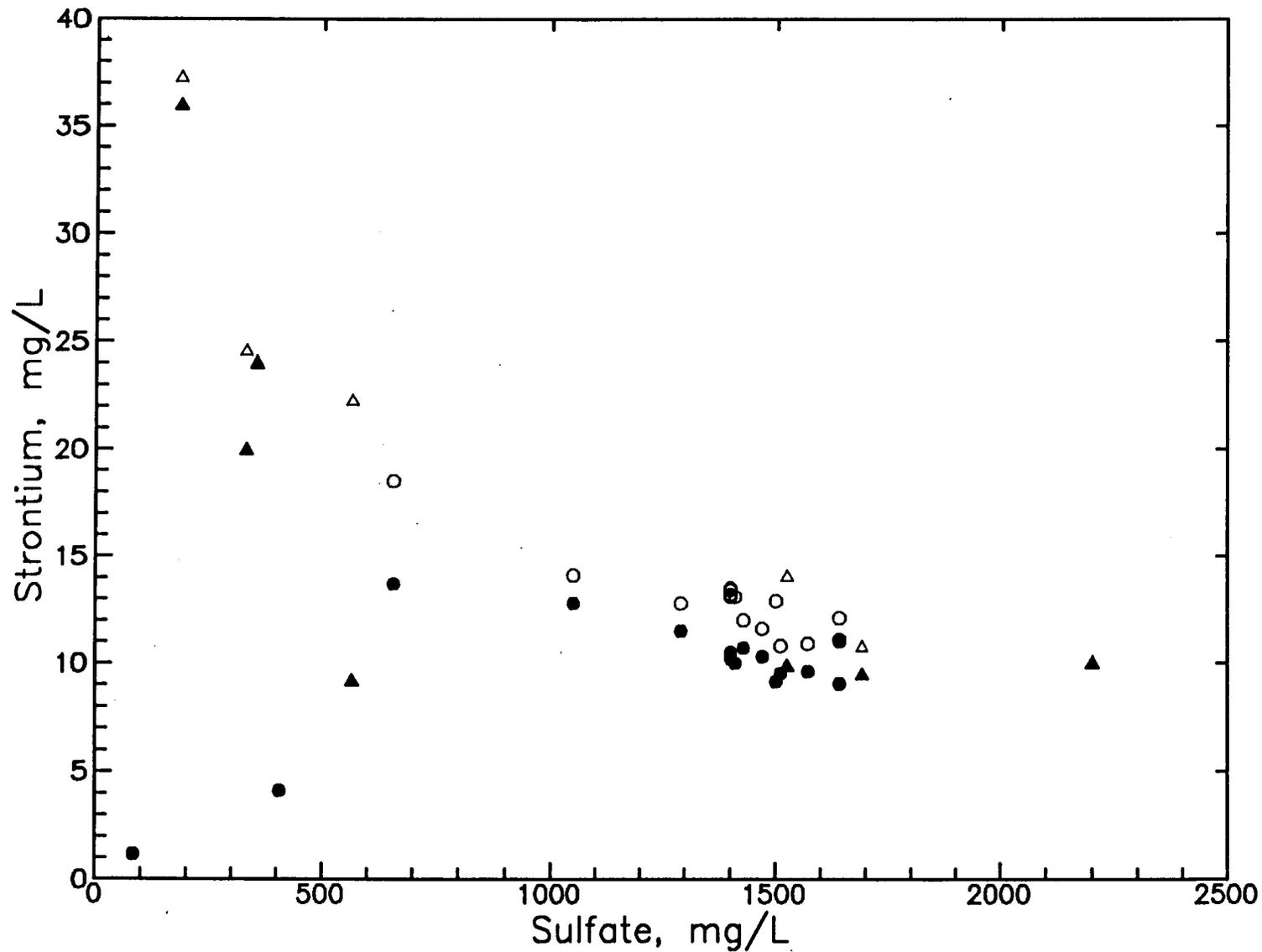


Figure 4. Observed and Calculated Strontium Versus Sulfate Concentration for Seep and B-Well Samples Collected January, 1992, and in High-Strontium Ground Waters from Kansas, Oklahoma, and Wisconsin. All the sulfate concentrations are measured values. The solid symbols represent measured strontium and the open symbols strontium calculated for celestite saturation. The CWMK samples are represented by circles, the samples from outside the CWMK site by triangles.

well would yield higher strontium values than the seep and other B wells with sulfate >600 mg/L.

The even greater concentrations of strontium computed at celestite saturation in Tables 4 and 5 are for ground waters with dissolved sulfate <600 mg/L. For example, the strontium concentrations at celestite saturation are 23.9 and 22.3 mg/L for the B207 sample at the CWMK site and the Wabaunsee County water, respectively, where measured sulfate concentrations were 405 and 566 mg/L, respectively. These locations probably represent ground waters where (1) there are substantially smaller amounts of gypsum and celestite remaining than at the sites with higher dissolved strontium and sulfate, and/or (2) fresher recharge flows at too fast a rate to allow the waters to approach mineral saturation. There could be a possibility of strontium concentrations reaching into the low 20's of mg/L in ground water at the CWMK site if the following conditions were met: (1) a location where nearly all of the gypsum had been removed by dissolution but appreciable amounts of celestite remained, (2) a location where flow rates were slow allowing the ground water to reach saturation with respect to celestite, and (3) a period of no recharge during which no freshwaters could infiltrate and dilute the ground water dissolving the celestite.

Although the Wisconsin waters contain measured strontium of up to 36 mg/L, the types of water and bedrock are different from the CWMK site. The probable solution of celestite and, possibly also strontianite, occurs in the Wisconsin bedrock in the presence of much lower sulfate concentrations. I would not expect such a high strontium in ground waters at most of the CWMK sites sampled for this study because the high sulfate concentration from gypsum dissolution would limit celestite solubility.

Variations in the strontium concentrations of near surface ground waters could be expected to occur with variations in the amount of fresh recharge. Whittemore and Switek (1977) found that strontium contents of waters from different springs in Permian bedrock containing gypsum in Pottawatomie County increase during dry periods and decrease during wet spells as do sulfate values. Appreciable changes in the amounts of recharge at the CWMK site could be expected to cause small variations in strontium concentrations of the B-wells and larger variations in the seep-water contents. Variations in recharge at the site are reflected in the changes in the recorded water levels.

CONCLUSIONS

The high strontium concentrations found in the seep and ground waters of the CWMK site are derived naturally from the solution of minerals observed and expected in the bedrock which is the Wellington Formation of Lower Permian age. The main mineral providing strontium is celestite (strontium sulfate), although dissolution of gypsum (hydrated calcium sulfate) contributes to the total-dissolved strontium. Any increases in concentrations of major inorganic constituents introduced by waste leaching are too small to significantly affect the solubility of strontium-containing minerals in the natural ground waters. The conclusions are based on the following summarized observations and calculations:

- (1) Strontium concentrations in samples from the background wells located in the upgradient direction of ground-water flow are as great as in samples from the ACL compliance wells downgradient of the past waste-disposal area.
- (2) Natural strontium concentrations can be as high as 36 mg/L in aquifers used as water resources in sedimentary rocks in the United States. High strontium concentrations on the order of the CWMK site values occur in ground waters in Permian bedrock in Kansas and Oklahoma.
- (3) Appreciable amounts of strontium are released during the hydration of anhydrite to gypsum. The strontium is released to ground water and also precipitates as the mineral celestite during this process. The gypsum observed in the subsurface at the CWMK site is probably derived from the hydration of anhydrite. Anhydrite is observed at greater depths at the site. Small quantities of celestite sufficient to provide high strontium concentrations in ground waters are expected at the site based on the geology.
- (4) Saturation indices computed for different minerals indicate that the ground waters at the CWMK site closely approach or are at saturation with respect to celestite for the seep and all the B wells yielding waters with sulfate contents >600 mg/L. The computed results fit the active dissolution of gypsum and celestite. All the waters are undersaturated with respect to strontianite (strontium carbonate). The calculated results are similar for ground waters with high strontium concentrations outside the site, especially for waters with dissolved sulfate >600 mg/L in Permian bedrock in Kansas and Oklahoma.
- (5) The sodium and chloride concentrations in the seep and B-well waters are in the range that could be expected for natural ground waters with high sulfate contents in the Permian strata of the area. If a significant amount of the strontium in the ground water were from waste leachate, the sodium and chloride concentrations would be expected to be much higher than observed

because these constituents would be major inorganic components of waste mixtures containing strontium. If strontium from waste leachate did reach the B-well level, strontium would be removed to the background levels by precipitation of celestite due to the near saturation of the ground waters with respect to celestite. In addition, there is no observable ionic-strength effect that would increase celestite and gypsum solubility at the ACL compliance wells if high contents of sodium and chloride were derived from waste leachates.

The maximum strontium concentration that could be naturally expected at the CWMK site locations sampled for this study is approximately 20 mg/L, given calculations of strontium values for saturation with respect to celestite and possible error in sample analysis. A recommended ACL concentration for strontium for the site is 25 mg/L based on the maximum calculated for celestite saturation for the samples as collected and a possible additional range for locations where nearly all gypsum has been dissolved but celestite remains, and where flow rates are slow. The highest strontium concentrations would probably also require an extended dry period where no fresh recharge could enter the subsurface to dilute the ground water.

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APPENDIX A.

**Solution-Mineral-Equilibria Computations from SOLMINEQ.88 (VERSION: USGS-ARC-88-8)
for Ground-Water and Seep Samples Collected during January, 1992, from the Chemical Waste
Management of Kansas Site near Furley, Kansas**

SAMPLE: SEEP

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.5000	.1199E-03	.7991E+01	.9127E-04	.4349E-04	.4764	4.3616
SrOH +			.1942E-05	.1857E-10	.1548E-10	.8336	10.8102
SrCO3			.9553E-02	.6476E-07	.6536E-07	1.0093	7.1847
SrHCO3 +			.3193E+00	.2150E-05	.1774E-05	.8249	5.7511
SrSO4			.4853E+01	.2644E-04	.2669E-04	1.0093	4.5737

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.694	-4.197	-.497	CELESTITE	-6.731	-6.626	-.105
CALCITE	-7.797	-8.417	.620	STRONTIANITE	-9.834	-9.280	-.554
DOLOMITE	-16.182	-16.879	.697				
GYP SUM	-4.694	-4.600	-.095				

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SAMPLE: SEEP

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.3816	.1528E-03	.1019E+02	.1164E-03	.5542E-04	.4763	4.2563
SrOH +			.2474E-05	.2366E-10	.1972E-10	.8335	10.7051
SrCO3			.1217E-01	.8247E-07	.8324E-07	1.0093	7.0797
SrHCO3 +			.4069E+00	.2740E-05	.2260E-05	.8249	5.6459
SrSO4			.6180E+01	.3367E-04	.3399E-04	1.0093	4.4687

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.694	-4.197	-.497	CELESTITE	-6.626	-6.626	.000
CALCITE	-7.797	-8.417	.620	STRONTIANITE	-9.729	-9.280	-.449
DOLOMITE	-16.183	-16.879	.697				
GYP SUM	-4.695	-4.600	-.095				

SAMPLE: SEEP D

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.4000	.1188E-03	.7935E+01	.9064E-04	.4310E-04	.4755	4.3656
SrOH +			.1925E-05	.1842E-10	.1534E-10	.8332	10.8141
SrCO3			.9307E-02	.6310E-07	.6369E-07	1.0093	7.1960
SrHCO3 +			.3113E+00	.2096E-05	.1728E-05	.8245	5.7624
SrSO4			.4770E+01	.2599E-04	.2623E-04	1.0093	4.5811
PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.690	-4.197	-.492	CELESTITE	-6.739	-6.626	-.112
CALCITE	-7.796	-8.417	.620	STRONTIANITE	-9.845	-9.280	-.565
DOLOMITE	-16.179	-16.879	.700				
GYPSUM	-4.690	-4.600	-.091				

SAMPLE: SEEP D

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.4846	.1540E-03	.1029E+02	.1176E-03	.5588E-04	.4753	4.2528
SrOH +			.2495E-05	.2387E-10	.1988E-10	.8331	10.7015
SrCO3			.1206E-01	.8175E-07	.8252E-07	1.0094	7.0835
SrHCO3 +			.4036E+00	.2717E-05	.2240E-05	.8244	5.6497
SrSO4			.6180E+01	.3367E-04	.3399E-04	1.0094	4.4687
PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.690	-4.197	-.493	CELESTITE	-6.626	-6.626	.000
CALCITE	-7.796	-8.417	.620	STRONTIANITE	-9.733	-9.280	-.453
DOLOMITE	-16.180	-16.879	.699				
GYPSUM	-4.691	-4.600	-.091				

SAMPLE: B202

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.3000	.1176E-03	.7745E+01	.8847E-04	.4249E-04	.4803	4.3717
SrOH +			.1090E-05	.1042E-10	.8706E-11	.8352	11.0602
SrCO3			.4138E-02	.2805E-07	.2831E-07	1.0090	7.5481
SrHCO3 +			.2398E+00	.1615E-05	.1335E-05	.8267	5.8746
SrSO4			.5054E+01	.2754E-04	.2778E-04	1.0090	4.5562

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.722	-4.197	-.525	CELESTITE	-6.714	-6.626	-.087
CALCITE	-8.206	-8.417	.211	STRONTIANITE	-10.197	-9.280	-.917
DOLOMITE	-16.833	-16.879	.047				
GYPSUM	-4.723	-4.600	-.123				

SAMPLE: B202

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	11.6132	.1326E-03	.8734E+01	.9976E-04	.4791E-04	.4803	4.3196
SrOH +			.1229E-05	.1175E-10	.9816E-11	.8351	11.0081
SrCO3			.4665E-02	.3163E-07	.3191E-07	1.0091	7.4960
SrHCO3 +			.2704E+00	.1820E-05	.1505E-05	.8267	5.8225
SrSO4			.5696E+01	.3103E-04	.3132E-04	1.0091	4.5042

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.722	-4.197	-.525	CELESTITE	-6.662	-6.626	-.035
CALCITE	-8.206	-8.417	.211	STRONTIANITE	-10.145	-9.280	-.865
DOLOMITE	-16.833	-16.879	.04				
GYPSUM	-4.723	-4.600	-.12				

SAMPLE: B203

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	11.5000	.1313E-03	.8944E+01	.1022E-03	.4914E-04	.4810	4.3086
SrOH +			.1065E-05	.1018E-10	.8508E-11	.8354	11.0702
SrCO3			.4782E-02	.3241E-07	.3271E-07	1.0090	7.4854
SrHCO3 +			.3044E+00	.2050E-05	.1695E-05	.8270	5.7708
SrSO4			.4976E+01	.2711E-04	.2735E-04	1.0090	4.5630

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.807	-4.191	-.616	CELESTITE	-6.717	-6.627	-.090
CALCITE	-8.210	-8.413	.202	STRONTIANITE	-10.121	-9.283	-.838
DOLOMITE	-16.721	-16.867	.146				
GYPSUM	-4.807	-4.602	-.206				

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SAMPLE: B203

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.8131	.1463E-03	.9967E+01	.1138E-03	.5475E-04	.4809	4.2616
SrOH +			.1186E-05	.1135E-10	.9479E-11	.8354	11.0232
SrCO3			.5327E-02	.3611E-07	.3644E-07	1.0091	7.4384
SrHCO3 +			.3392E+00	.2284E-05	.1889E-05	.8270	5.7239
SrSO4			.5541E+01	.3019E-04	.3047E-04	1.0091	4.5162

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.807	-4.191	-.616	CELESTITE	-6.670	-6.627	-.043
CALCITE	-8.210	-8.413	.202	STRONTIANITE	-10.074	-9.283	-.791
DOLOMITE	-16.722	-16.867	.146				
GYPSUM	-4.807	-4.602	-.206				

SAMPLE: B204

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.0000	.1142E-03	.7575E+01	.8652E-04	.4158E-04	.4806	4.3811
SrOH +			.5596E-06	.5353E-11	.4471E-11	.8353	11.3496
SrCO3			.2530E-02	.1715E-07	.1730E-07	1.0089	7.7619
SrHCO3 +			.2793E+00	.1881E-05	.1555E-05	.8269	5.8083
SrSO4			.4735E+01	.2580E-04	.2603E-04	1.0089	4.5845

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.712	-4.197	-.515	CELESTITE	-6.742	-6.626	-.116
CALCITE	-8.381	-8.417	.036	STRONTIANITE	-10.411	-9.280	-1.131
DOLOMITE	-17.267	-16.879	-.388				
GYP SUM	-4.713	-4.600	-.113				

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SAMPLE: B204

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.0737	.1493E-03	.9906E+01	.1131E-03	.5437E-04	.4805	4.2647
SrOH +			.7317E-06	.6999E-11	.5846E-11	.8352	11.2331
SrCO3			.3307E-02	.2242E-07	.2262E-07	1.0091	7.6455
SrHCO3 +			.3651E+00	.2459E-05	.2033E-05	.8268	5.6919
SrSO4			.6185E+01	.3370E-04	.3401E-04	1.0091	4.4684

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.712	-4.197	-.515	CELESTITE	-6.626	-6.626	.000
CALCITE	-8.381	-8.417	.036	STRONTIANITE	-10.295	-9.280	-1.015
DOLOMITE	-17.267	-16.879	-.388				
GYP SUM	-4.713	-4.600	-.113				

SAMPLE: B205

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.7000	.1222E-03	.8113E+01	.9267E-04	.4435E-04	.4787	4.3531
SrOH +			.1165E-05	.1114E-10	.9299E-11	.8345	11.0316
SrCO3			.5165E-02	.3501E-07	.3533E-07	1.0091	7.4518
SrHCO3 +			.2928E+00	.1971E-05	.1628E-05	.8259	5.7883
SrSO4			.5055E+01	.2754E-04	.2779E-04	1.0091	4.5561

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.722	-4.197	-.525	CELESTITE	-6.714	-6.626	-.087
CALCITE	-8.110	-8.417	.307	STRONTIANITE	-10.101	-9.280	-.821
DOLOMITE	-16.654	-16.879	.225				
GYP SUM	-4.723	-4.600	-.123				

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SAMPLE: B205

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.0131	.1372E-03	.9110E+01	.1041E-03	.4980E-04	.4786	4.3028
SrOH +			.1308E-05	.1251E-10	.1044E-10	.8344	10.9813
SrCO3			.5798E-02	.3930E-07	.3966E-07	1.0092	7.4016
SrHCO3 +			.3287E+00	.2213E-05	.1828E-05	.8259	5.7380
SrSO4			.5673E+01	.3091E-04	.3119E-04	1.0092	4.5059

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.722	-4.197	-.525	CELESTITE	-6.663	-6.626	-.037
CALCITE	-8.110	-8.417	.307	STRONTIANITE	-10.051	-9.280	-.771
DOLOMITE	-16.654	-16.879	.225				
GYP SUM	-4.723	-4.600	-.123				

SAMPLE: B206

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.7000	.1564E-03	.1120E+02	.1278E-03	.6970E-04	.5453	4.1568
SrOH +			.4358E-05	.4167E-10	.3588E-10	.8610	10.4452
SrCO3			.2245E-01	.1522E-06	.1529E-06	1.0052	6.8155
SrHCO3 +			.4989E+00	.3358E-05	.2871E-05	.8551	5.5419
SrSO4			.4606E+01	.2509E-04	.2522E-04	1.0052	4.5983

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.244	-4.197	-1.046	CELESTITE	-6.756	-6.626	-.129
CALCITE	-7.952	-8.417	.464	STRONTIANITE	-9.465	-9.280	-.185
DOLOMITE	-16.072	-16.879	.807				
GYPSUM	-5.244	-4.600	-.644				

SAMPLE: B206

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	18.5079	.2113E-03	.1513E+02	.1728E-03	.9413E-04	.5448	4.0263
SrOH +			.5886E-05	.5628E-10	.4845E-10	.8608	10.3147
SrCO3			.3031E-01	.2054E-06	.2065E-06	1.0052	6.6852
SrHCO3 +			.6736E+00	.4534E-05	.3876E-05	.8549	5.4116
SrSO4			.6209E+01	.3382E-04	.3399E-04	1.0052	4.4686

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.244	-4.197	-1.047	CELESTITE	-6.626	-6.626	.000
CALCITE	-7.953	-8.417	.464	STRONTIANITE	-9.334	-9.280	-.054
DOLOMITE	-16.073	-16.879	.807				
GYPSUM	-5.245	-4.600	-.645				

SAMPLE: B207

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	4.1100	.4692E-04	.3492E+01	.3987E-04	.2364E-04	.5930	4.6264
SrOH +			.6471E-06	.6187E-11	.5436E-11	.8787	11.2647
SrCO3			.3215E-02	.2179E-07	.2186E-07	1.0034	7.6604
SrHCO3 +			.1562E+00	.1051E-05	.9188E-06	.8743	6.0368
SrSO4			.1098E+01	.5982E-05	.6002E-05	1.0034	5.2217

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.495	-4.197	-1.297	CELESTITE	-7.379	-6.626	-.753
CALCITE	-8.425	-8.417	-.009	STRONTIANITE	-10.309	-9.280	-1.030
DOLOMITE	-16.992	-16.879	-.113				
GYP SUM	-5.495	-4.600	-.895				

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SAMPLE: B207

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	23.9097	.2730E-03	.2035E+02	.2324E-03	.1372E-03	.5905	3.8626
SrOH +			.3751E-05	.3586E-10	.3148E-10	.8778	10.5020
SrCO3			.1858E-01	.1259E-06	.1263E-06	1.0035	6.8985
SrHCO3 +			.9055E+00	.6094E-05	.5322E-05	.8733	5.2739
SrSO4			.6314E+01	.3438E-04	.3451E-04	1.0035	4.4621

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.500	-4.197	-1.302	CELESTITE	-6.620	-6.626	.007
CALCITE	-8.428	-8.417	-.011	STRONTIANITE	-9.548	-9.280	-.268
DOLOMITE	-16.997	-16.879	-.118				
GYP SUM	-5.500	-4.600	-.900				

SAMPLE: B208

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	1.1600	.1324E-04	.1078E+01	.1231E-04	.7970E-05	.6474	5.0986
SrOH +			.2768E-06	.2646E-11	.2376E-11	.8978	11.6242
SrCO3			.1652E-02	.1119E-07	.1121E-07	1.0022	7.9503
SrHCO3 +			.6502E-01	.4375E-06	.3914E-06	.8947	6.4074
SrSO4			.8863E-01	.4826E-06	.4837E-06	1.0022	6.3154

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-6.241	-4.204	-2.036	CELESTITE	-8.476	-6.625	-1.851
CALCITE	-8.377	-8.421	.043	STRONTIANITE	-10.613	-9.277	-1.336
DOLOMITE	-16.920	-16.892	-.028				
GYPSUM	-6.241	-4.598	-1.643				

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SAMPLE: B208

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	95.4958	.1090E-02	.8916E+02	.1018E-02	.6407E-03	.6295	3.1933
SrOH +			.2209E-04	.2112E-09	.1883E-09	.8916	9.7251
SrCO3			.1291E+00	.8750E-06	.8772E-06	1.0025	6.0569
SrHCO3 +			.5196E+01	.3497E-04	.3105E-04	.8881	4.5079
SrSO4			.6701E+01	.3649E-04	.3658E-04	1.0025	4.4367

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-6.276	-4.204	-2.072	CELESTITE	-6.597	-6.625	.028
CALCITE	-8.398	-8.421	.022	STRONTIANITE	-8.720	-9.277	.558
DOLOMITE	-16.960	-16.892	-.069				
GYPSUM	-6.276	-4.598	-1.679				

SAMPLE: B250

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.4000	.1188E-03	.7970E+01	.9103E-04	.4360E-04	.4789	4.3605
SrOH +			.5038E-06	.4819E-11	.4022E-11	.8346	11.3956
SrCO3			.2429E-02	.1647E-07	.1662E-07	1.0092	7.7794
SrHCO3 +			.2700E+00	.1818E-05	.1501E-05	.8261	5.8235
SrSO4			.4758E+01	.2592E-04	.2616E-04	1.0092	4.5823

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.718	-4.184	-.534	CELESTITE	-6.733	-6.628	-.105
CALCITE	-8.386	-8.409	.023	STRONTIANITE	-10.401	-9.286	-1.115
DOLOMITE	-17.221	-16.856	-.365				
GYPSUM	-4.719	-4.604	-.114				

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SAMPLE: B250

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.2687	.1516E-03	.1017E+02	.1162E-03	.5562E-04	.4788	4.2548
SrOH +			.6428E-06	.6149E-11	.5132E-11	.8345	11.2897
SrCO3			.3099E-02	.2101E-07	.2120E-07	1.0094	7.6736
SrHCO3 +			.3444E+00	.2319E-05	.1915E-05	.8260	5.7177
SrSO4			.6065E+01	.3305E-04	.3335E-04	1.0094	4.4768

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.718	-4.184	-.534	CELESTITE	-6.628	-6.628	.000
CALCITE	-8.386	-8.409	.023	STRONTIANITE	-10.295	-9.286	-1.009
DOLOMITE	-17.221	-16.856	-.365				
GYPSUM	-4.719	-4.604	-.114				

SAMPLE: B250 D

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.2000	.1165E-03	.7780E+01	.8886E-04	.4276E-04	.4811	4.3690
SrOH +			.5667E-06	.5420E-11	.4529E-11	.8355	11.3440
SrCO3			.2732E-02	.1852E-07	.1869E-07	1.0090	7.7285
SrHCO3 +			.2640E+00	.1778E-05	.1470E-05	.8271	5.8326
SrSO4			.4743E+01	.2584E-04	.2607E-04	1.0090	4.5838

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.725	-4.184	-.541	CELESTITE	-6.735	-6.628	-.107
CALCITE	-8.341	-8.409	.068	STRONTIANITE	-10.350	-9.286	-1.064
DOLOMITE	-17.133	-16.856	-.278				
GYPSUM	-4.726	-4.604	-.122				

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SAMPLE: B250 D

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	13.0565	.1491E-03	.9962E+01	.1138E-03	.5473E-04	.4810	4.2618
SrOH +			.7255E-06	.6939E-11	.5797E-11	.8355	11.2368
SrCO3			.3496E-02	.2370E-07	.2392E-07	1.0092	7.6213
SrHCO3 +			.3380E+00	.2275E-05	.1882E-05	.8270	5.7254
SrSO4			.6066E+01	.3305E-04	.3335E-04	1.0092	4.4769

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.726	-4.184	-.541	CELESTITE	-6.628	-6.628	.000
CALCITE	-8.341	-8.409	.068	STRONTIANITE	-10.243	-9.286	-.957
DOLOMITE	-17.133	-16.856	-.277				
GYPSUM	-4.726	-4.604	-.122				

SAMPLE: B254

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	11.0000	.1256E-03	.8037E+01	.9180E-04	.4338E-04	.4725	4.3627
SrOH +			.1998E-05	.1912E-10	.1590E-10	.8319	10.7985
SrCO3			.9015E-02	.6112E-07	.6171E-07	1.0096	7.2097
SrHCO3 +			.3159E+00	.2127E-05	.1751E-05	.8231	5.7568
SrSO4			.5810E+01	.3166E-04	.3196E-04	1.0096	4.4953

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.671	-4.204	-.467	CELESTITE	-6.656	-6.625	-.031
CALCITE	-7.887	-8.421	.533	STRONTIANITE	-9.872	-9.277	-.595
DOLOMITE	-16.262	-16.892	.630				
GYP SUM	-4.672	-4.598	-.074				

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SAMPLE: B254

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	11.1312	.1271E-03	.8133E+01	.9290E-04	.4390E-04	.4725	4.3576
SrOH +			.2022E-05	.1934E-10	.1609E-10	.8319	10.7934
SrCO3			.9123E-02	.6185E-07	.6244E-07	1.0096	7.2045
SrHCO3 +			.3196E+00	.2152E-05	.1772E-05	.8231	5.7516
SrSO4			.5879E+01	.3204E-04	.3234E-04	1.0096	4.4902

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.671	-4.204	-.467	CELESTITE	-6.651	-6.625	-.026
CALCITE	-7.887	-8.421	.533	STRONTIANITE	-9.867	-9.277	-.590
DOLOMITE	-16.262	-16.892	.630				
GYP SUM	-4.672	-4.598	-.074				

SAMPLE: B260

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.6100	.1098E-03	.7068E+01	.8073E-04	.3852E-04	.4771	4.4144
SrOH +			.1304E-05	.1248E-10	.1040E-10	.8338	10.9829
SrCO3			.6255E-02	.4241E-07	.4280E-07	1.0092	7.3686
SrHCO3 +			.2756E+00	.1855E-05	.1531E-05	.8252	5.8150
SrSO4			.4981E+01	.2714E-04	.2739E-04	1.0092	4.5624

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.686	-4.197	-.489	CELESTITE	-6.720	-6.626	-.094
CALCITE	-7.984	-8.417	.433	STRONTIANITE	-10.018	-9.280	-.738
DOLOMITE	-16.479	-16.879	.400				
GYPSUM	-4.687	-4.600	-.087				

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SAMPLE: B260

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.9231	.1248E-03	.8035E+01	.9177E-04	.4378E-04	.4770	4.3587
SrOH +			.1482E-05	.1418E-10	.1182E-10	.8338	10.9272
SrCO3			.7109E-02	.4820E-07	.4865E-07	1.0093	7.3130
SrHCO3 +			.3132E+00	.2109E-05	.1740E-05	.8252	5.7594
SrSO4			.5660E+01	.3084E-04	.3112E-04	1.0093	4.5069

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.686	-4.197	-.489	CELESTITE	-6.664	-6.626	-.038
CALCITE	-7.984	-8.417	.433	STRONTIANITE	-9.962	-9.280	-.682
DOLOMITE	-16.479	-16.879	.400				
GYPSUM	-4.687	-4.600	-.087				

SAMPLE: B273

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.5100	.1086E-03	.7027E+01	.8027E-04	.3864E-04	.4814	4.4130
SrOH +			.1182E-05	.1131E-10	.9450E-11	.8356	11.0246
SrCO3			.6085E-02	.4125E-07	.4162E-07	1.0090	7.3807
SrHCO3 +			.2742E+00	.1846E-05	.1527E-05	.8272	5.8161
SrSO4			.4858E+01	.2647E-04	.2671E-04	1.0090	4.5734

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.703	-4.191	-.513	CELESTITE	-6.728	-6.627	-.100
CALCITE	-7.992	-8.413	.421	STRONTIANITE	-10.016	-9.283	-.733
DOLOMITE	-16.518	-16.867	.350				
GYPSUM	-4.704	-4.602	-.102				

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SAMPLE: B273

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.8231	.1236E-03	.7999E+01	.9136E-04	.4397E-04	.4813	4.3568
SrOH +			.1346E-05	.1287E-10	.1075E-10	.8356	10.9684
SrCO3			.6924E-02	.4694E-07	.4736E-07	1.0090	7.3245
SrHCO3 +			.3120E+00	.2101E-05	.1738E-05	.8272	5.7600
SrSO4			.5527E+01	.3011E-04	.3039E-04	1.0090	4.5173

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.704	-4.191	-.513	CELESTITE	-6.672	-6.627	-.044
CALCITE	-7.992	-8.413	.421	STRONTIANITE	-9.960	-9.283	-.677
DOLOMITE	-16.518	-16.867	.350				
GYPSUM	-4.704	-4.602	-.102				

SAMPLE: B295

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.0400	.1033E-03	.6716E+01	.7671E-04	.3609E-04	.4705	4.4426
SrOH +			.9517E-06	.9104E-11	.7566E-11	.8311	11.1211
SrCO3			.3579E-02	.2427E-07	.2451E-07	1.0098	7.6107
SrHCO3 +			.2040E+00	.1374E-05	.1129E-05	.8222	5.9472
SrSO4			.4616E+01	.2515E-04	.2540E-04	1.0098	4.5951

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.686	-4.197	-.489	CELESTITE	-6.753	-6.626	-.126
CALCITE	-8.193	-8.417	.223	STRONTIANITE	-10.260	-9.280	-.980
DOLOMITE	-16.741	-16.879	.138				
GYPSUM	-4.687	-4.600	-.087				

SAMPLE: B295

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.1066	.1383E-03	.8996E+01	.1028E-03	.4833E-04	.4704	4.3158
SrOH +			.1274E-05	.1219E-10	.1013E-10	.8310	10.9945
SrCO3			.4790E-02	.3247E-07	.3279E-07	1.0099	7.4842
SrHCO3 +			.2732E+00	.1839E-05	.1512E-05	.8221	5.8204
SrSO4			.6177E+01	.3366E-04	.3399E-04	1.0099	4.4686

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.686	-4.197	-.489	CELESTITE	-6.626	-6.626	.000
CALCITE	-8.194	-8.417	.223	STRONTIANITE	-10.133	-9.280	-.853
DOLOMITE	-16.742	-16.879	.137				
GYPSUM	-4.687	-4.600	-.087				

SAMPLE: B297

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.1400	.1044E-03	.6925E+01	.7909E-04	.3753E-04	.4745	4.4256
SrOH +			.1566E-05	.1498E-10	.1247E-10	.8328	10.9041
SrCO3			.5986E-02	.4058E-07	.4096E-07	1.0095	7.3876
SrHCO3 +			.2147E+00	.1445E-05	.1191E-05	.8240	5.9241
SrSO4			.4371E+01	.2382E-04	.2404E-04	1.0095	4.6190

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.703	-4.197	-.505	CELESTITE	-6.777	-6.626	-.150
CALCITE	-7.963	-8.417	.454	STRONTIANITE	-10.037	-9.280	-.757
DOLOMITE	-16.308	-16.879	.571				
GYP SUM	-4.703	-4.600	-.104				

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SAMPLE: B297

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.9381	.1478E-03	.9805E+01	.1120E-03	.5313E-04	.4744	4.2747
SrOH +			.2215E-05	.2119E-10	.1765E-10	.8327	10.7534
SrCO3			.8466E-02	.5739E-07	.5794E-07	1.0095	7.2370
SrHCO3 +			.3038E+00	.2046E-05	.1686E-05	.8240	5.7733
SrSO4			.6181E+01	.3368E-04	.3400E-04	1.0095	4.4685

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.703	-4.197	-.506	CELESTITE	-6.626	-6.626	.000
CALCITE	-7.963	-8.417	.453	STRONTIANITE	-9.886	-9.280	-.606
DOLOMITE	-16.308	-16.879	.571				
GYP SUM	-4.704	-4.600	-.104				

SAMPLE: B300

THE ACTIVITY PRODUCTS AND SATURATION INDEX

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.8000	.1462E-03	.1008E+02	.1151E-03	.5789E-04	.5031	4.2374
SrOH +			.1621E-05	.1550E-10	.1309E-10	.8445	10.8831
SrCO3			.7318E-02	.4960E-07	.4996E-07	1.0073	7.3014
SrHCO3 +			.4080E+00	.2746E-05	.2299E-05	.8370	5.6385
SrSO4			.5198E+01	.2832E-04	.2852E-04	1.0073	4.5448

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.862	-4.204	-.658	CELESTITE	-6.706	-6.625	-.080
CALCITE	-8.121	-8.421	.300	STRONTIANITE	-9.964	-9.277	-.687
DOLOMITE	-16.663	-16.892	.228				
GYPSUM	-4.863	-4.598	-.265				

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SAMPLE: B300

THE ACTIVITY PRODUCTS AND SATURATION INDEX - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	14.1133	.1612E-03	.1111E+02	.1269E-03	.6383E-04	.5030	4.1950
SrOH +			.1787E-05	.1709E-10	.1443E-10	.8444	10.8407
SrCO3			.8067E-02	.5468E-07	.5508E-07	1.0073	7.2590
SrHCO3 +			.4498E+00	.3028E-05	.2534E-05	.8370	5.5961
SrSO4			.5728E+01	.3121E-04	.3144E-04	1.0073	4.5026

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.862	-4.204	-.658	CELESTITE	-6.663	-6.625	-.038
CALCITE	-8.121	-8.421	.300	STRONTIANITE	-9.922	-9.277	-.644
DOLOMITE	-16.663	-16.892	.228				
GYPSUM	-4.863	-4.598	-.265				

SAMPLE: DEEP WELL C269 ACTIVITY PRODUCTS AND SATURATION INDICES CALCULATED USING PITZER EQUATIONS

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	12.4000	.1447E-03	.1193E+02	.1392E-03	.2190E-04	.1573	4.6596
SrOH +			.9914E-06	.9689E-11	.6240E-11	.6440	11.2048
SrCO3			.4661E-03	.3228E-08	.4365E-08	1.3519	8.3601
SrHCO3 +			.3458E-01	.2379E-06	.1430E-06	.6010	6.8447
SrSO4			.9481E+00	.5278E-05	.7136E-05	1.3519	5.1466

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.937	-4.199	-.738	CELESTITE	-7.181	-6.628	-.553
CALCITE	-8.766	-8.419	-.347	STRONTIANITE	-11.010	-9.282	-1.728
DOLOMITE	-16.598	-16.883	.285				
GYPSUM	-4.971	-4.601	-.370				

SAMPLE: DEEP WELL C269 CALCULATED USING PITZER EQUATIONS - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	44.3346	.5174E-03	.4265E+02	.4977E-03	.7822E-04	.1572	4.1067
SrOH +			.3542E-05	.3462E-10	.2229E-10	.6439	10.6519
SrCO3			.1664E-02	.1153E-07	.1559E-07	1.3520	7.8073
SrHCO3 +			.1235E+00	.8498E-06	.5107E-06	.6009	6.2919
SrSO4			.3387E+01	.1885E-04	.2549E-04	1.3520	4.5936

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.938	-4.199	-.739	CELESTITE	-6.629	-6.628	-.001
CALCITE	-8.766	-8.419	-.347	STRONTIANITE	-10.457	-9.282	-1.175
DOLOMITE	-16.600	-16.883	.284				
GYPSUM	-4.972	-4.601	-.371				

APPENDIX B.

**Solution-Mineral-Equilibria Computations Extracted from SOLMINEQ.88
(VERSION: USGS-ARC-88-8) Output for Ground Waters from Wells in Bedrock Aquifers
Outside the Chemical Waste Management of Kansas Site**

MARION COUNTY, KANSAS 19S-04E-09DDA 6-20-83 FLOWING WELL, BARNESTON LIMESTON

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.9000	.1131E-03	.7594E+01	.8675E-04	.3905E-04	.4501	4.4084
SrOH +			.2478E-06	.2371E-11	.1950E-11	.8224	11.7100
SrCO3			.1037E-02	.7030E-08	.7111E-08	1.0115	8.1481
SrHCO3 +			.3148E+00	.2120E-05	.1722E-05	.8125	5.7638
SrSO4			.4444E+01	.2422E-04	.2450E-04	1.0115	4.6109

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.653	-4.221	-.432	CELESTITE	-6.778	-6.625	-.153
CALCITE	-8.713	-8.431	-.282	STRONTIANITE	-10.838	-9.275	-1.563
DOLOMITE	-18.040	-16.923	-1.117				
GYPSUM	-4.654	-4.596	-.058				

MARION COUNTY, KANSAS 19S-04E-09DDA 6-20-83 FLOWING WELL, BARNESTON LIMESTON - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	14.1501	.1617E-03	.1086E+02	.1241E-03	.5582E-04	.4499	4.2532
SrOH +			.3540E-06	.3387E-11	.2785E-11	.8223	11.5552
SrCO3			.1480E-02	.1003E-07	.1015E-07	1.0120	7.9934
SrHCO3 +			.4499E+00	.3030E-05	.2461E-05	.8124	5.6088
SrSO4			.6344E+01	.3457E-04	.3499E-04	1.0120	4.4561

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.653	-4.221	-.433	CELESTITE	-6.623	-6.625	.002
CALCITE	-8.713	-8.431	-.282	STRONTIANITE	-10.683	-9.275	-1.408
DOLOMITE	-18.041	-16.923	-1.118				
GYPSUM	-4.654	-4.596	-.058				

WABAUNSEE COUNTY, KANSAS 14S-12W-05ACD 3-19-58 LONG CREEK LIMESTONE MEMBER

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.2000	.1050E-03	.7615E+01	.8695E-04	.4842E-04	.5568	4.3150
SrOH +			.1733E-05	.1657E-10	.1434E-10	.8654	10.8434
SrCO3			.1008E-01	.6830E-07	.6862E-07	1.0046	7.1636
SrHCO3 +			.3868E+00	.2604E-05	.2239E-05	.8599	5.6500
SrSO4			.2832E+01	.1542E-04	.1549E-04	1.0046	4.8099

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.221	-4.197	-1.023	CELESTITE	-6.967	-6.626	-.341
CALCITE	-8.066	-8.417	.350	STRONTIANITE	-9.813	-9.280	-.533
DOLOMITE	-16.510	-16.879	.369				
GYP SUM	-5.221	-4.600	-.622				

WABAUNSEE COUNTY, KANSAS 14S-12W-05ACD 3-19-58 LONG CREEK LIMESTONE MEMBER - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	22.3373	.2550E-03	.1851E+02	.2114E-03	.1174E-03	.5556	3.9302
SrOH +			.4200E-05	.4016E-10	.3473E-10	.8649	10.4592
SrCO3			.2438E-01	.1652E-06	.1660E-06	1.0047	6.7799
SrHCO3 +			.9377E+00	.6311E-05	.5424E-05	.8594	5.2657
SrSO4			.6831E+01	.3721E-04	.3738E-04	1.0047	4.4273

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.223	-4.197	-1.026	CELESTITE	-6.585	-6.626	.042
CALCITE	-8.068	-8.417	.349	STRONTIANITE	-9.429	-9.280	-.149
DOLOMITE	-16.513	-16.879	.366				
GYP SUM	-5.224	-4.600	-.624				

MORTON COUNTY, KANSAS 32S-41W-29ABBC 6-12-90 UPPER PERMIAN SERIES SANDSTONE

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	9.5000	.1085E-03	.6783E+01	.7748E-04	.3681E-04	.4751	4.4340
SrOH +			.1170E-05	.1119E-10	.9320E-11	.8330	11.0306
SrCO3			.1993E-02	.1351E-07	.1363E-07	1.0089	7.8655
SrHCO3 +			.1683E+00	.1133E-05	.9340E-06	.8244	6.0297
SrSO4			.5485E+01	.2989E-04	.3015E-04	1.0089	4.5207

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.616	-4.260	-.356	CELESTITE	-6.704	-6.621	-.083
CALCITE	-8.533	-8.451	-.082	STRONTIANITE	-10.621	-9.266	-1.355
DOLOMITE	-17.857	-16.994	-.863				
GYPSUM	-4.617	-4.593	-.024				

MORTON COUNTY, KANSAS 32S-41W-29ABBC 6-12-90 UPPER PERMIAN SERIES SANDSTONE - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.8131	.1235E-03	.7722E+01	.8820E-04	.4190E-04	.4751	4.3778
SrOH +			.1331E-05	.1274E-10	.1061E-10	.8330	10.9743
SrCO3			.2268E-02	.1538E-07	.1552E-07	1.0090	7.8092
SrHCO3 +			.1915E+00	.1290E-05	.1063E-05	.8244	5.9734
SrSO4			.6241E+01	.3401E-04	.3431E-04	1.0090	4.4646

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.616	-4.260	-.357	CELESTITE	-6.648	-6.621	-.027
CALCITE	-8.533	-8.451	-.082	STRONTIANITE	-10.564	-9.266	-1.299
DOLOMITE	-17.857	-16.994	-.863				
GYPSUM	-4.617	-4.593	-.024				

OKLAHOMA COUNTY, OKLAHOMA 12N-04W-13BBB 11-07-88 GARBER-WELLINGTON AQUIFER

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.0000	.1143E-03	.6984E+01	.7979E-04	.3549E-04	.4448	4.4499
SrOH +			.3783E-05	.3620E-10	.2968E-10	.8201	10.5275
SrCO3			.4221E-02	.2862E-07	.2896E-07	1.0120	7.5382
SrHCO3 +			.9531E-01	.6419E-06	.5199E-06	.8100	6.2840
SrSO4			.6200E+01	.3379E-04	.3419E-04	1.0120	4.4661

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.628	-4.243	-.384	CELESTITE	-6.643	-6.621	-.021
CALCITE	-8.252	-8.442	.190	STRONTIANITE	-10.267	-9.268	-.999
DOLOMITE	-16.924	-16.963	.040				
GYPSUM	-4.628	-4.593	-.035				

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OKLAHOMA COUNTY, OKLAHOMA 12N-04W-13BBB 11-07-88 GARBER-WELLINGTON AQUIFER - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	10.1313	.1158E-03	.7076E+01	.8084E-04	.3596E-04	.4448	4.4442
SrOH +			.3833E-05	.3667E-10	.3007E-10	.8201	10.5218
SrCO3			.4276E-02	.2900E-07	.2934E-07	1.0120	7.5325
SrHCO3 +			.9656E-01	.6504E-06	.5268E-06	.8100	6.2784
SrSO4			.6281E+01	.3423E-04	.3464E-04	1.0120	4.4604

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-4.628	-4.243	-.384	CELESTITE	-6.637	-6.621	-.016
CALCITE	-8.252	-8.442	.190	STRONTIANITE	-10.262	-9.268	-.993
DOLOMITE	-16.924	-16.963	.040				
GYPSUM	-4.628	-4.593	-.035				

FOND DU LAC COUNTY, WISCONSIN F1 13/19/18-125 2-18-58 LATE CAMBRIAN SANDSTONE

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	36.0000	.4110E-03	.3235E+02	.3693E-03	.2325E-03	.6296	3.6335
SrOH +			.1017E-04	.9726E-10	.8672E-10	.8916	10.0619
SrCO3			.5825E-01	.3946E-06	.3956E-06	1.0025	6.4027
SrHCO3 +			.1715E+01	.1154E-04	.1025E-04	.8881	4.9892
SrSO4			.5452E+01	.2969E-04	.2976E-04	1.0025	4.5263

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.834	-4.197	-1.637	CELESTITE	-6.684	-6.626	-.057
CALCITE	-8.202	-8.417	.215	STRONTIANITE	-9.052	-9.280	.228
DOLOMITE	-16.739	-16.879	.140				
GYPSUM	-5.834	-4.600	-1.234				

FOND DU LAC COUNTY, WISCONSIN F1 13/19/18-125 2-18-58 LATE CAMBRIAN SANDSTONE - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	37.3136	.4260E-03	.3354E+02	.3829E-03	.2410E-03	.6294	3.6181
SrOH +			.1054E-04	.1008E-09	.8987E-10	.8916	10.0464
SrCO3			.6034E-01	.4088E-06	.4099E-06	1.0025	6.3873
SrHCO3 +			.1778E+01	.1196E-04	.1062E-04	.8881	4.9738
SrSO4			.5645E+01	.3074E-04	.3082E-04	1.0025	4.5112

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.834	-4.197	-1.637	CELESTITE	-6.669	-6.626	-.042
CALCITE	-8.202	-8.417	.215	STRONTIANITE	-9.036	-9.280	.243
DOLOMITE	-16.740	-16.879	.140				
GYPSUM	-5.835	-4.600	-1.235				

OUTAGAMIE COUNTY, WISCONSIN OU21/18/25-47 10-27-55 CAMBRIAN SANDSTONE, DOLOMITE

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	20.0000	.2283E-03	.1716E+02	.1959E-03	.1212E-03	.6187	3.9164
SrOH +			.4231E-05	.4045E-10	.3592E-10	.8879	10.4447
SrCO3			.1841E-01	.1247E-06	.1251E-06	1.0027	6.9028
SrHCO3 +			.6859E+00	.4616E-05	.4081E-05	.8841	5.3893
SrSO4			.5075E+01	.2764E-04	.2771E-04	1.0027	4.5574

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.492	-4.197	-1.295	CELESTITE	-6.715	-6.626	-.088
CALCITE	-8.329	-8.417	.087	STRONTIANITE	-9.552	-9.280	-.272
DOLOMITE	-17.320	-16.879	-.440				
GYPSUM	-5.492	-4.600	-.893				

OUTAGAMIE COUNTY, WISCONSIN OU21/18/25-47 10-27-55 CAMBRIAN SANDSTONE, DOLOMITE - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	24.6133	.2810E-03	.2113E+02	.2413E-03	.1491E-03	.6181	3.8265
SrOH +			.5202E-05	.4974E-10	.4415E-10	.8876	10.3551
SrCO3			.2262E-01	.1532E-06	.1537E-06	1.0027	6.8135
SrHCO3 +			.8434E+00	.5676E-05	.5016E-05	.8838	5.2996
SrSO4			.6225E+01	.3390E-04	.3399E-04	1.0027	4.4686

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.494	-4.197	-1.296	CELESTITE	-6.626	-6.626	.000
CALCITE	-8.330	-8.417	.087	STRONTIANITE	-9.463	-9.280	-.183
DOLOMITE	-17.321	-16.879	-.442				
GYPSUM	-5.494	-4.600	-.894				

OUTAGAMIE COUNTY, WISCONSIN OU21/18/25-47 2-28-58 CAMBRIAN SANDSTONE, DOLOMITE

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	24.0000	.2740E-03	.2056E+02	.2347E-03	.1430E-03	.6094	3.8446
SrOH +			.6307E-05	.6030E-10	.5334E-10	.8846	10.2730
SrCO3			.2711E-01	.1837E-06	.1842E-06	1.0029	6.7346
SrHCO3 +			.8057E+00	.5422E-05	.4775E-05	.8806	5.3211
SrSO4			.6191E+01	.3371E-04	.3381E-04	1.0029	4.4710

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.421	-4.197	-1.224	CELESTITE	-6.628	-6.626	-.002
CALCITE	-8.176	-8.417	.240	STRONTIANITE	-9.384	-9.280	-.104
DOLOMITE	-17.121	-16.879	-.241				
GYPSUM	-5.421	-4.600	-.821				

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OUTAGAMIE COUNTY, WISCONSIN OU21/18/25-47 2-28-58 CAMBRIAN SANDSTONE, DOLOMITE - ADDED Sr++

SPECIES	-----ANALYZED-----		-----CALCULATED-----		ACTIVITY	ACTIVITY COEFF.	-LOG10 ACTIVITY
	MG/L	MOLALITY	MG/L	MOLALITY			
Sr ++	24.1312	.2755E-03	.2067E+02	.2360E-03	.1438E-03	.6094	3.8423
SrOH +			.6342E-05	.6063E-10	.5363E-10	.8846	10.2706
SrCO3			.2726E-01	.1847E-06	.1852E-06	1.0029	6.7323
SrHCO3 +			.8101E+00	.5452E-05	.4801E-05	.8806	5.3187
SrSO4			.6224E+01	.3389E-04	.3399E-04	1.0029	4.4686

PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)	PHASE	LOG (AP)	LOG (KT)	LOG (AP/KT)
ANHYDRITE	-5.421	-4.197	-1.224	CELESTITE	-6.626	-6.626	.000
CALCITE	-8.176	-8.417	.240	STRONTIANITE	-9.381	-9.280	-.101
DOLOMITE	-17.121	-16.879	-.241				
GYPSUM	-5.421	-4.600	-.822				