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Geochemical and Isotopic Analyses of Waters Associated with the Edwards Limestone Aquifer, Central Texas

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GEOCHEMICAL AND ISOTOPIC ANALYSES OF WATERS ASSOCIATED WITH THE EDWARDS LIMESTONE AQUIFER, CENTRAL TEXAS

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ABSTRACT

The results of analyses of 14 common chemical species dissolved in 92 samples of waters associated with the Edwards Limestone aquifer are tabulated. Additional analyses for stable carbon and radiocarbon and stable sulfur isotopes on 34 of these samples are also tabulated. Field collection and field and laboratory analytical techniques were designed to make these analyses useful for geochemical studies. Edwards waters can be grouped into five chemical types - recharge, main fresh water, varied, and two types of transitional and saline waters. All types are saturated with calcite and all transitional and saline waters are saturated with dolomite as well. Some saline samples are also saturated with gypsum, celestite, strontianite, and fluorite.

INTRODUCTION

Interpretations of solution, cementation, and circulation occurring within the Edwards Limestone aquifer are needed to develop a fuller understanding of the hydrology of the aquifer. These processes greatly affect the capacity of the aquifer to store and transmit water. To make studies of these processes requires accurate data on the chemistry of the water within the aquifer. Because concentrations of some dissolved constituents change significantly with time after sampling, field techniques are required to minimize the effects of these changes. This report presents hydrochemical data that were obtained using special field techniques. A discussion of the techniques of collection, field preparation and analysis, and laboratory analytical techniques are given. The analyses were used to categorize waters into five groups and to show differences in the capacity of the waters to dissolve or precipitate selected carbonate and other minerals. A quantitative interpretation of the hydrochemical processes will be presented elsewhere.

Analytical data on 92 samples from wells, springs, and streams in the Edwards aquifer system are given in two tables. Table 1 includes chemical data on all samples collected and physical data on the collection site. Analyses for carbon and sulfur isotopes, additional chemical species, and redox potential measurements were made on 34 samples. These results are given in table 2, in which some of the chemical data presented in table 1, useful in interpreting the isotopic information, are repeated. Tables 3 and 4 include values for total dissolved carbonate, partial CO_2 pressure, and saturation indices with respect to selected minerals calculated from the chemical data of table 1.

The samples are listed in five groups in table 1. The recharge group of 17 samples are streams recharging the Edwards (numbers A and B) and wells or springs in and near the Edwards outcrop (numbers 1-4 and 58). The main fresh-water group of 37 samples (numbers 15-51) are from the Edwards aquifer proper - that part of the formation widely tapped for water supply. Within these groups, the samples are roughly arranged geographically, from west to east.

The third group of 13 samples (numbers 69A, 52-57, 79, 59-63) are from the western part of the Edwards (principally Uvalde County). In some respects their chemistry is similar to that of samples from the first two groups and in others to that of the last two groups. Thus, they are grouped separately. The fourth and fifth groups, the western and eastern transitional and saline water groups (numbers 64-78 and 80-89, respectively), occur downdip from the main fresh water and include waters transitional from those of the main fresh water to waters of more than 4,000 mg/l dissolved-solids concentration deep in the formation. The samples in these groups are arranged by decreasing dissolved-solids concentration.

ACKNOWLEDGMENTS

We are particularly grateful to the various landowners and municipalities who permitted us to sample their wells. In addition, there are a number of U.S. Geological Survey personnel without whose help this work would not have been possible. They include Martha Bodden, who assisted in the field collection of samples and performed the ^{14}C analyses; J. C. Chemerys, who performed the laboratory chemical analyses of the samples collected in 1970-71; C. T. Rightmire, R. O. Rye, and Joan C. Woodward, who performed the stable-isotope analyses; and T. A. Wyerman, F. J. Brookman, and R. A. Wilkinson, who performed the tritium analyses.

The collection of data used in this report is part of the program of hydrologic investigations by the U.S. Geological Survey in cooperation with the Texas Water Development Board and the city of San Antonio.

SELECTION OF WELLS FOR SAMPLING

To evaluate the geochemical processes occurring in the Edwards aquifer required the collection of samples representing the several chemical types of water contained by the aquifer. The locations of the sampling points chosen are given on figure 1. Details of well construction are given by Rettman (1969).

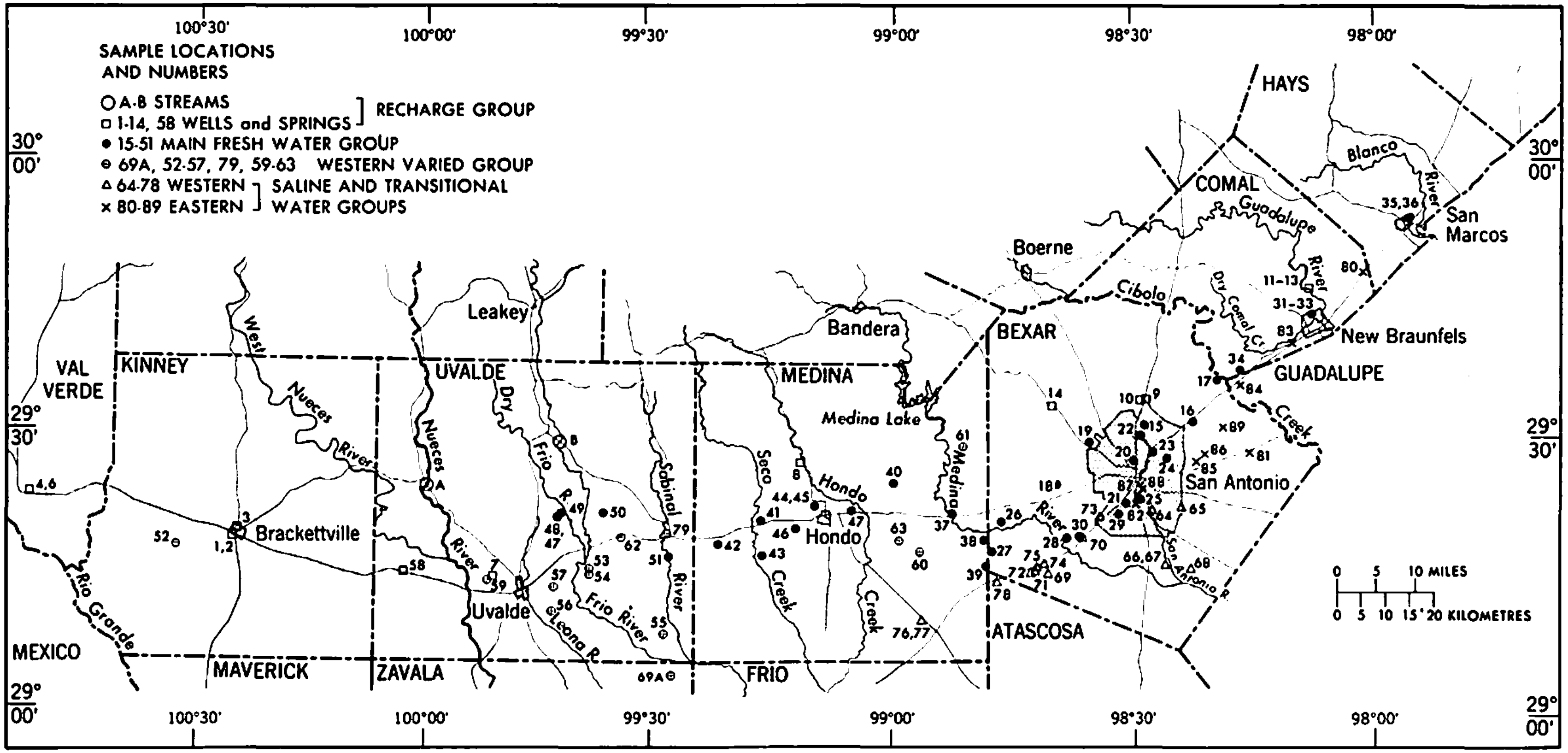

Figure 1: Sampling point location map

In most areas, a number of wells were available for sampling. To prevent any uncertainty as to the source of the samples, only wells of known depth and with casing records available were sampled. Further, where possible, only those wells with a vigorous natural flow or a large-capacity pump were selected to insure only a minimal change in the temperature or chemical composition of the water during residence in the well bore. Finally, where possible, wells with a fitting near the well head were selected so that a portion of the total flow of the well could be sampled and field analyses made with no aeration or exposure to the atmosphere.

In a few areas of relatively saline water, the only wells available had small pumps or only sluggish flow. Low flow rates through the well bores could have lowered the temperatures and affected the CO_2 content of the samples from these wells because both the temperature and partial pressure of CO_2 of these samples were above atmospheric levels. Neither saturation indices nor CO_2 pressures calculated, as discussed below, for samples from these wells differed from those calculated from samples from high discharge wells of similar overall chemistry. Thus no detectable changes in chemistry occurred in low flow rate wells.

ANALYTICAL TECHNIQUES

Field Procedures

None of the samples were filtered either in the field or the laboratory. Thus values given in this report should be considered "total" rather than "dissolved" concentrations (Brown, Skougstad, and Fishman, 1970, p. 37). Because all samples were perfectly clear, and because of uncertainties about the effectiveness of filters in removing very fine-grained suspended material (Kennedy, Zellweger, and Jones, 1974), it is considered that the "total" values reported here are virtually equivalent to "dissolved" values as defined by Brown, Skougstad and Fishman.

pH

All pH measurements were made in the field when the sample was collected. Commercial pH meters, electrodes, and liquid buffers were used. Before measuring the pH, the buffers and the electrodes were brought to the temperature of the sample. The meter was standardized with pH 4 and pH 7 buffers and the pH of several freshly collected samples was measured in an open beaker until the results were reproducible. The meter was then restandardized. Duplicate measurements, including temperature adjustment and meter standardization, made during a single visit to a sampling point agreed within 0.05 pH units.

Alkalinity

Field alkalinities were measured using a modification of the laboratory electrometric titration method described by Brown, Skougstad, and Fishman (1970, p. 41). Instead of titrating to a pH 4.5 endpoint as in the laboratory procedure, a graph of pH versus millilitres of titrant acid was prepared and the endpoint picked at the point where the slope of the titration curve was steepest in the vicinity of pH 4.5. Duplicate determinations made during a single visit to a well agreed within 6 mg/l.

Redox Potential

The theory and measurement of redox potentials are discussed by Stumm and Morgan (1970) and Back and Barnes (1965). Redox potential measuring equipment and techniques are discussed by Back and Barnes (1961). The techniques and cell described by Back and Barnes were used with a platinum thimble electrode and a saturated calomel reference electrode. The measured potential was read on the milivolt scale of a pH meter, readable to 0.002 volts. Sample water was allowed to flow through the cell until the measured potential had stabilized. At that time the flow to the cell was shut off and the final potential read after the voltage had stabilized again. The measurement time for all wells was less than two hours. Successive measurements during the same visit to wells which sampled oxidizing water, those with measured redox potentials more positive than +0.1 volts, agreed within 0.002 volts. Successive measurements in more reducing waters, however, agreed only within about 0.04 volts.

Sulfide

Analyses for total sulfide (H_2S + HS^- + S^+) were made in the field using an electrometric titration procedure. The pH of a given volume of sample was raised to above 11 by the addition of KOH pellets. Then the potential of a commercial sulfide electrode against a saturated calomel reference electrode was measured as the solution was titrated with a standard silver solution. Results of titrations of duplicate samples agreed within 2 mg/l and the detection limit was about 1 mg/l. Although the procedure worked reasonably well for samples with sulfide contents of greater than 5 mg/l, the electrode response was extremely slow, requiring 5 minutes or more per point. Thus, although the results agreed reasonably well with the lab results (within 10 percent) and were internally consistent, this technique is not recommended to others.

Samples for laboratory analyses were collected in 1-pint brown glass bottles to which 1 or 2 pellets of reagent grade KOH had been added. The high pH produced by the KOH tended to prevent the loss of volatile H_2S from the sample by driving the sulfide equilibrium toward the soluble bisulfide (HS^-) and sulfide ($S^=$) species. A solution of zinc acetate was added to this alkaline solution to precipitate the sulfide as ZnS and further preserve it. In the laboratory the preserved sample was analyzed by the iodometric titration method described by Brown, Skougstad, and Fishman (1970, p. 154).

The laboratory and field determinations agreed within 10 percent and neither was consistently high or low. Thus, it appears that the field fixing procedure is adequate to preserve sulfide and that the tedious field titration method is probably not necessary.

Laboratory Analytical Techniques - Chemical Constituents

Alkaline Earths

One-pint samples for the alkaline earths calcium, magnesium, and strontium were collected in plastic bottles. They were fixed to prevent precipitation by the addition of 25 drops of concentrated, reagent grade HCl. The analyses were made in the laboratory using atomic absorption spectrophotometry as described by Brown, Skougstad, and Fishman (1970).

Iron, Aluminum, and Ammonium

Analyses for these species were performed on the same acidified sample as were the alkaline earth analyses. The methods used were also those described by Brown, Skougstad, and Fishman (1970).

Remaining Constituents

One-quart untreated samples were collected in plastic bottles and used for the remainder of the analyses reported in table 1. Again, the methods used were those given by Brown, Skougstad, and Fishman (1970).

ISOTOPE SAMPLING AND ANALYSIS

Samples collected during 1970 and 1971 were analyzed for the ratios of the stable carbon isotopes ($^{13}C/^{12}C$) and for the radiocarbon (^{14}C) content of the carbonate species (CO_2, HCO_3^-, $CO_3^=$) dissolved in them. The carbon isotope results have been published by Pearson and Bodden (1975). Samples were also taken for analyses of the stable sulfur isotope ratio ($^{34}S/^{32}S$) in the dissolved sulfate and the dissolved sulfide. The sulfate-sulfur isotope data have been previously reported by Rightmire and others (1974). A number of tritium (^3H) analyses have been made on samples from the Edwards (Pearson, Rettman, and Wyerman, 1975). Those available for points sampled for this study are given in table 2.

Field Procedures

Stable Carbon Isotopes

In order to prevent any loss of carbonate as gaseous CO_2, the samples in the field were fixed so that all the carbonate dissolved in them precipitated as $SrCO_3$, which could then be separated from the remainder of the sample in the laboratory (Gleason, Friedman, and Hanshaw, 1969). Samples were collected in 1-quart glass bottles with minimum aeration. To this was added by pipet 50 ml of a strontium-hydroxide solution, prepared by dissolving 1 pound of reagent grade $SrCl_2$ $6H_2O$ in a 5-pint bottle of reagent grade, concentrated (30 percent) NH_4OH. This solution raised the pH of the sample so that all the dissolved carbonate was present as the carbonate ($CO_3^=$) ion, which then combined with the strontium in the solution to precipitate $SrCO_3$.

Carbon-14

A carbon-14 analysis requires approximately 3 grams of carbon, equivalent to all the carbonate from several tens of litres of water. Rather than ship this volume to the laboratory, the carbonate was extracted in the field. A stainless steel, 100-litre capacity funnel-shaped device with a wide-mouthed screwnecked 2-litre bottle connected to the bottom was used for extraction. The funnel was filled with minimum aeration, and to it added, in order, 10-15 grams solid $FeSO_4$, 1 litre 50 percent NaOH solution, and 1 litre 0.8 molal $SrCl_2$ solution. The $FeSO_4$ acted as a flocculating agent; the NaOH raised the pH so that all the dissolved carbonate was present as the $CO_3^=$ ion; and the strontium combined with the $CO_3^=$ ion to form $SrCO_3$ which settled into the bottle at the bottom of the funnel. After several hours of settling, the bottle was disconnected from the funnel, capped, and returned to the laboratory.

Sulfur Isotope Samples

To preserve the stable sulfur isotope ratios in the sulfate and sulfice species during shipping and storage before analysis, the sulfate was separated from the sulfide in the field. A commercial stainless steel 1-gallon pressure filtering system was used. The filter system reservoir was filled with sample and pellets of reagent grade KOH added to raise the pH to above 11. A sufficient amount of zinc acetate solution was added to precipitate all the sulfide present as ZnS. The ZnS and solution were separated by filtering through a 4-inch diameter 0.45-micrometre pore-size membrane filter under nitrogen pressure. The filtrate was returned to the laboratory where it was processed for sulfate-sulfur isotope analysis. The ZnS and filter were carefully folded, stored in a small vial under nitrogen, and returned to the lab for sulfide-sulfur isotopic analysis.

Laboratory Analytical Techniques - Isotopes

Stable isotope ratios are measured using a mass spectrometer. Because it is difficult to measure absolute values of isotope ratios with any precision, such ratios are measured and reported relative to arbitrary, but widely used standards. The measurements are reported in the δ notation where:

$$\delta \text{ (o/oo)} = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000$$

R_{sample} and R_{standard} are the isotope ratios ($^{13}C/^{12}C$, $^{34}S/^{32}S$) in the sample and standard, respectively. The standard to which the carbon isotope ratios reported here are referred is the PDB standard (Craig, 1957), while the sulfur isotope ratios are referred to the Canon Diablo troilite (CD) standard.

Stable Carbon Isotopes

The 1-quart samples treated in the field to precipitate all the carbonate as $SrCO_3$ were filtered under nitrogen and the $SrCO_3$ precipitated thoroughly rinsed and dried. This carbonate was then reacted with 100 percent H_3PO_4 to produce the CO_2 gas required by the mass spectrometer (McCrea, 1950).

Stable Sulfur Isotopes

The gas required for the measurement of sulfur isotopes is sulfur dioxide (SO_2). This gas was prepared from the sulfide samples by combustion (Rafter, 1957a). The sulfate samples were treated by precipitating all the sulfate they contained as barium sulfate, which was then converted to sulfide (Rafter, 1957b) for combustion to SO_2 for the mass spectrometer.

Radiocarbon and Tritium

The ^{14}C contents of the waters were measured by liquid scintillation counting of benzene synthesized from the large $SrCO_3$ samples precipitated in the field. They are reported as percentages of an idealized modern ^{14}C standard. The measurement technique and reporting conventions are described by Pearson and Bodden (1975).

The tritium samples were analyzed by gas or liquid scintillation counting following electrolytic enrichment (Pearson, Rettman, and Wyerman, 1975). Tritium concentrations are given in tritium units (T.U.). One tritium unit corresponds to a concentration of 1 tritium atom per 10^{18} hydrogen atoms and equals 3.2 picocuries per litre.

CALCULATED PARAMETERS

All the analyses in table 1 have been processed with the computer program WATEQ (Truesdell and Jones, 1974). This program computes the equilibrium distribution of various chemical species in a solution and compares the activity products of various combinations of these dissolved species with the theoretical equilibrium constants which would exist were the waters in equilibrium with a number of solid minerals phases. Tables 3 and 4 show certain of the values calculated by WATEQ which are significant in the Edwards aquifer system. Their various meanings are described here.

Total Dissolved Carbonate

Total dissolved carbonate is calculated from the measured alkalinity and the pH. The measured alkalinities include only those carbonate species which react with acid above a pH of approximately 4.5, that is, the bicarbonate (HCO_3^-) and carbonate ($CO_3^=$) species. Most ground-water systems include as well the species H_2CO_3 and dissolved CO_2 gas. The concentration of these species is calculated from the alkalinity and pH. The total dissolved carbonate reported in table 2 and in table 3 is merely the sum of the analyzed HCO_3^- and $CO_3^=$ plus the calculated dissolved H_2CO_3 and CO_2.

PCO_2

The partial pressure, in atmospheres, of CO_2 gas in equilibrium with the water, is also calculated from the alkalinity and pH, by WATEQ.

Saturation Indices (SI)

Saturation indices are measures of whether a given sample is undersaturated (SI = negative), saturated (SI = 0), or supersaturated (SI = positive) with respect to various minerals. The details of the method by which saturation indices are calculated are given by Truesdell and Jones (1974).

The significance of the saturation indices (SI's) in tables 3 and 4 can be shown by an example using the mineral calcite ($CaCO_3$). Calcite solution can be written:

$$CaCO_{3(crystalline)} \rightarrow Ca^{+2}_{(aqueous)} + CO^{=}_{3(aqueous)}$$

In a solution saturated with respect to calcite, the product of the activities (=thermodynamic concentrations) of the free aqueous Ca^{+2} and $CO_3^{=}$ ions will equal a constant K, sometimes called the solubility product.

To determine whether water is saturated with respect to calcite, the product of the activities (AP) of the Ca^{+2} and $CO_3^{=}$ ions dissolved in the water, is compared with the equilibrium solubility product of Ca^{+2} and $CO_3^{=}$ at the water's temperature (KT). If AP is smaller than KT, more calcite can dissolve, and the water is undersaturated with respect to calcite. At saturation, AP equals KT, and if AP is greater than KT, the water is supersaturated with respect to calcite. The saturation index (SI) is the common logarithm of AP/KT. Thus, negative SI's indicate undersaturation and positive SI's supersaturation.

The solubility product is a function of temperature and for calcite at 25°C is $10^{-8.41}$ (Plummer and Mackenzie, 1974). The solubility products of most minerals are small numbers, so it is convenient to refer to their common logarithms - that is, $\log K_{\text{calcite, } 25°\text{C}} = -8.41$. Values of log K used in WATEQ to calculate the SI's in tables 3 and 4 are given in table 5, along with the enthalpies of the reactions ($\Delta H_{\text{reactions}}$). The enthalpies are used to calculate values of log K at temperatures other than 25°C (Truesdell and Jones, 1974, p. 244).

Errors in chemical analyses will produce errors in saturation index values calculated from them. Brown, Skougstad, and Fishman (1970, p. 36) discuss analytical precision. Using errors for dissolved species in the range of those reported by Brown, Skougstad, and Fishman, and a pH error of ±0.05 units (p. 6 above), it can be shown that the standard deviation of SI_{calcite} should be about ±0.1 and that of SI_{dolomite} about ±0.2 (see, for example, Harmon and others, 1975).

The distribution of values of SI_{calcite} and SI_{dolomite} for samples of the recharge and fresh water groups and in the transitional and saline water groups is shown in figures 2 and 3.

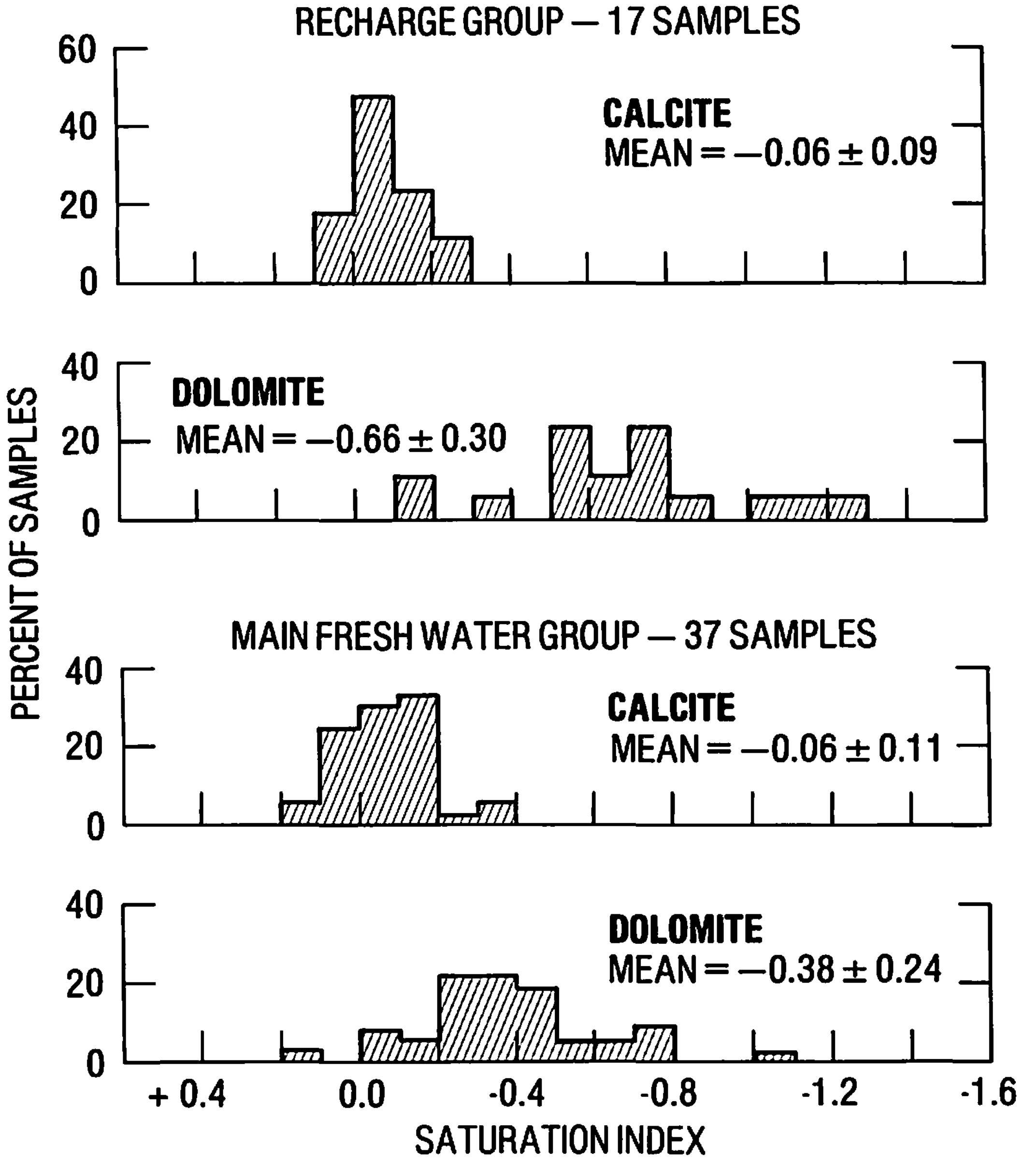

Figure 2: Distribution of saturation indices - recharge and main fresh water groups

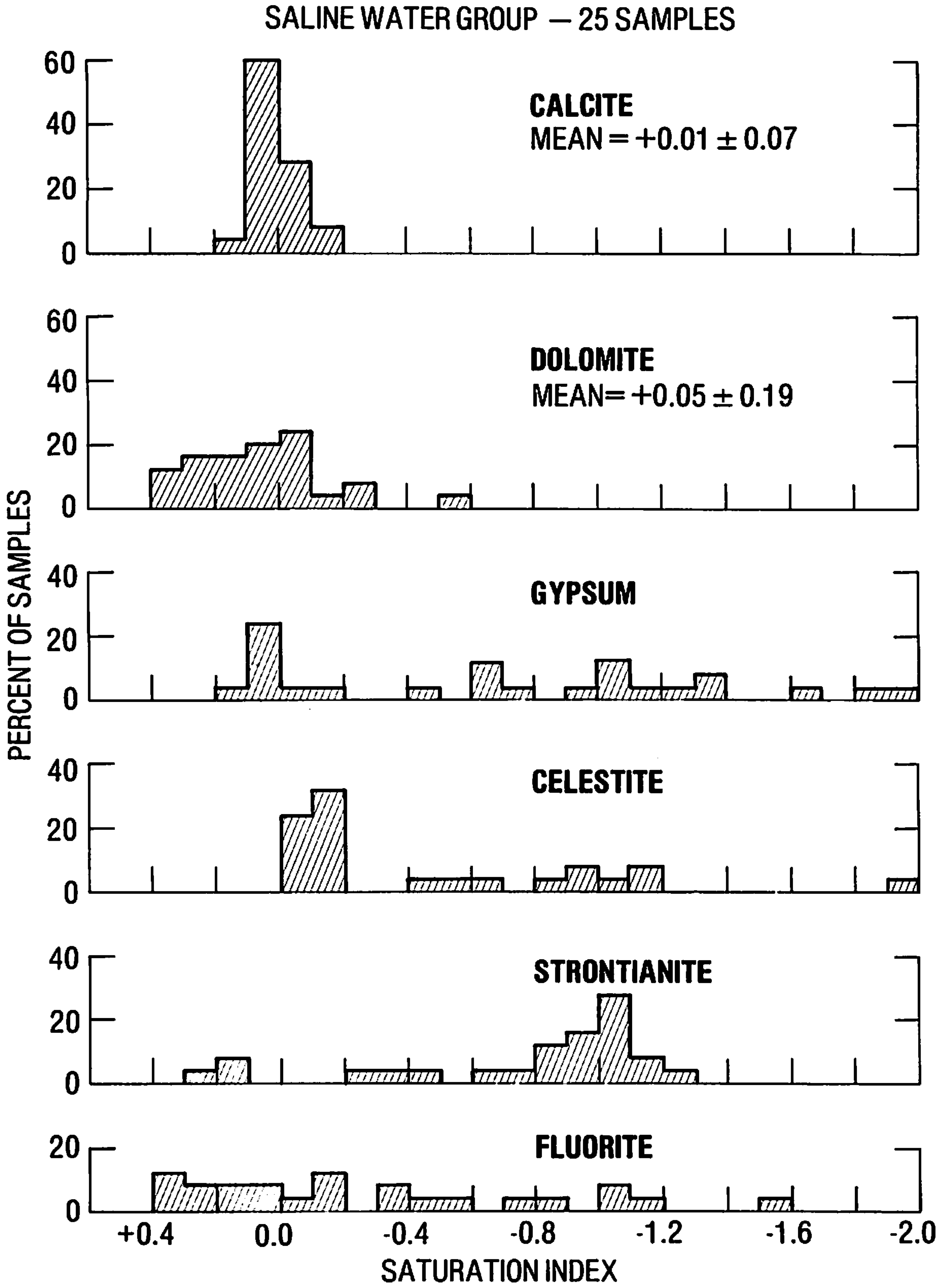

Figure 3 : Distribution of saturation indices - transitional land saline water groups

The group means and standard deviations for $SI_{calcite}$ and $SI_{dolomite}$ are given in figures 2 and 3. The mean values of $SI_{calcite}$ range from -0.06 to +0.01, and none depart from zero by more than 0.7 standard deviations. Furthermore, the largest standard deviation of any group is ±0.11, about that expected from chemical analytical errors. Thus, although individual samples may have $SI_{calcite}$ values departing from zero by more than ±0.3, their apparent deviations from saturation could be due to statistically expectable errors in the analytical values used to calculate them. These data, then, provide no unequivocal evidence that any samples are other than saturated with respect to calcite.

By the same reasoning, the means and standard deviations of $SI_{dolomite}$ for transitional and saline water groups (0.05 ± 0.19, figure 3) provide no evidence that any waters of these groups are other than saturated with respect to dolomite.

The $SI_{dolomite}$ values for the samples comprising the main fresh water and recharge groups are -0.38 ± 0.24 and -0.66 ± 0.30, respectively (figure 2). Both are negative, the former by 1.6 standard deviations and the latter by 2.2 standard deviations, suggesting that samples from both groups are undersaturated with dolomite and that those of the recharge group tend to be more undersaturated than those of the fresh-water group. The standard deviation of $SI_{dolomite}$ in each group also is larger than that expected from analytical imprecisions alone, which suggests that samples in each group are undersaturated with respect to dolomite by varying amounts.

Figure 3 also shows the distribution of saturation indices for the minerals gypsum ($CaSO_4 \cdot 2H_2O$), celestite ($SrSO_4$), strontianite ($SrCO_3$), and fluorite (CaF_2) in samples from the transitional and saline water groups. Petrographic study suggests that the presence or absence of these minerals at various places in the Edwards Limestone is related to the chemistry of the water it contains (R. G. Deike, written commun., 1975).

In the saline water group (figure 3), a number of samples have SI_{gypsum} and $SI_{celestite}$ values close to zero, and are evidently saturated with these minerals, while other samples have more negative SI values. Waters saturated with these minerals have the highest salinities of any sampled and are most distant from the main fresh-water portion of the aquifer. Those less than saturated are transitional between the highly saline waters and the main fresh-water types. The areal distribution of waters with varying degrees of strontianite saturation is similar, although few samples reach saturation with respect to this minerals.

The $SI_{fluorite}$ values are not strongly grouped about any value. This suggests rather that the fluoride analytical results may not be as precise as are those for the other dissolved constituents (D. W. Fisher, oral commun., 1975).

CONCLUSIONS

The analyses presented here are of sufficient quality that they can be used for interpretations of the aqueous geochemistry of the Edwards aquifer system. Mineral equilibrium calculations show that the recharge, main fresh water, and transitional and saline parts of the aquifer contain calcite saturated water, and that while the recharge and main fresh waters are undersaturated with dolomite, the transitional and saline waters are saturated with respect to this mineral. Some of the saline waters also are saturated with gypsum, celestite, strontianite, and fluorite.

The methods of collection and analyses of samples for stable sulfur and carbon isotope ratios and for ^{14}C content are of sufficient quality that the data, with proper interpretation, may be useful in studies of water ages, and mixing, and in testing hydrologic and geochemical concepts developed from the chemical data alone.

REFERENCES

Back, William, and Barnes, Ivan, 1961, Equipment for field measurement of electrochemical potentials: U.S. Geol. Survey Prof. Paper 424-C, p. C366-368.

______1965, Relation of electrochemical potentials and iron content to ground-water flow patterns: U.S. Geol. Survey Prof. Paper 498-C, p. C1-C16.

Berner, R. A., 1967, Comparative dissolution characteristics of carbonate minerals in the presence and absence of aqueous magnesium ion: Am. Jour. Sci., v. 265, p. 45-70.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geol. Survey Techniques of Water-Resources Inv., chap. A1, 160 p.

Craig, H., 1957, Isotopic standard for carbon and oxygen and correction factors for mass spectrometric analysis of carbon dioxide: Geochim Cosmochim Acta, v. 12, p. 133-149.

Gleason, J. D., Friedman, Irving, and Hanshaw, B. B., 1969, Extraction of dissolved carbonate species from natural water for carbon isotope analysis: U.S. Geol. Survey Prof. Paper 650-D, p. D248-D250.

Harmon, R. S., White, W. B., Drake, J. J., and Hess, J. W., 1975, Regional hydrochemistry of North American carbonate terrains: Water Resources Research, v. 11, p. 963-967.

Harned, H. S., and Davis, R., Jr., 1943, The ionization constant of carbonic acid in water and the solubility of carbon dioxide in water and aqueous salt solutions from 0 to 50°: Am. Chem. Soc. Jour., v. 65, p. 2030-2037.

REFERENCES--Continued

Harned, H. S., and Scholes, S. R., Jr., 1941, The ionization constant of HCO_3^- from 0 to 50°: Am. Chem. Soc. Jour., v. 63, p. 1706-1709.

Helgeson, H. C., 1969, Thermodynamics of hydrothermal systems at elevated temperatures and pressures: Am. Jour. Sci., v. 267, p. 729-804.

Helgeson, H. C., 1969, Thermodynamics of hydrothermal systems at elevated temperatures and pressures: Am. Jour. Sci., v. 267, p. 729-804.

Kennedy, V. C., Zellweger, G. W., and Jones, B. F., 1974, Filter pore-site effects on the analysis of Al, Fe, Mn, and Ti in water: Water Resources Research, v. 10, p. 785-790.

McCrea, J. M., 1950, On the isotopic chemistry of carbonates and a paleotemperature scale: Jour. Chem. Physics, v. 18, p. 849-857.

Parker, V. B., Wagman, D. D., and Evans, W. H., 1971, Selected values of chemical thermodynamic properties: U.S. National Bur. Standards Tech. Note 270-6, 106 p.

Pearson, F. J., Jr., and Bodden, Martha, 1975, U.S. Geological Survey Water Resources Division Radiocarbon measurements I: Radiocarbon, v. 17, p. 135-148.

Pearson, F. J., Jr., Rettman, P. L., and Wyerman, T. A., 1975, Environmental tritium in the Edwards aquifer, Central Texas, 1963-1971: U.S. Geol. Survey open-file rept. 74-362, 32 p.

Plummer, L. N., and Mackenzie, F. T., 1974, Predicting mineral solubility from rate data. Application to the dissolution of magnesian calcites: Am. Jour. Sci., v. 274, p. 61-83.

REFERENCES--Continued

Rafter, T. A., 1957a, Sulphur isotopic variations in nature: Part 1 - The preparation of sulphur dioxide for mass spectrometer examination: New Zealand Jour. of Sci. and Technology, Section B., v. 38, p. 849-857.

______1957b, Sulphur isotopic variations in nature: Part 2 - A quantitative study of the reduction of barium sulphate by graphite for recovery of sulphide - sulphur for isotopic measurements: New Zealand Jour. of Sci. and Technology, Section B., v. 38, p. 955-968.

Rettman, Paul, 1969, Records of wells and springs, San Antonio area, Texas: Edwards Underground Water District rept., 28 p.

Rightmire, C. T., Pearson, F. J., Jr., Back, W., Rye, R. O., and Hanshaw, B. B., 1974, Distribution of sulphur isotopes in ground waters from the principal aquifer of Florida and the Edwards aquifer of Texas, United States of America _in_ Isotope techniques in ground water hydrology, 1974: v. II, p. 191-207, IAEA, Vienna.

Robie, R. A., and Waldbaum, D. R., 1968, Thermodynamic properties of and related substances at 298.15°K (25.0°C) and one atmosphere (1.013 Bars) pressure and at higher temperatures: U.S. Geol. Survey Bull. 1259, 256 p.

Stumm, Werner, and Morgan, J. J., 1970, Aquatic chemistry: Wiley Interscience, New York, 583 p.

Truesdell, A. H., and Jones, B. F., 1974, WATEQ, a computer program for calculating chemical equilibrium of natural waters: U.S. Geol. Survey Jour., v. 2, p. 233-248.

Wagman, D. D., Evans, W. H., Parker, U. B., Halow, I., Bailey, S. M., and Schumm, R. H., 1968, Selected values of chemical thermodynamic properties: U.S. National Bur. Standards Tech. Note 270-3, 264 p.

Table 1.--Results of chemical analyses of samples from the Edwards Aquifer
[Total concentrations in milligrams per litre]

Sample No.	Well or stream station number	Date	Depth (m)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Alkalinity (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sulfide (H_2S)	Total solids	pH	Temperature (°C)
RECHARGE GROUP																				
A	08190000	7-71	Stream	12	0.00	56	14	0.3	7.4	1.0	224	13	14	0.2	4.0	--	--	223	8.00	25.2
B	08195000	7-71	Stream	12	.00	54	15	.4	7.8	1.1	208	16	14	.2	1.4	--	--	223	8.00	27.7
1	RP-70-45-501	10-72	Spring	11	.00	78	6.2	.12	5.6	1.2	247	7.2	9.6	.1	9.3	0.00	--	249	7.25	24.0
2	RP-70-45-501	2-73	Spring	11	.00	77	6.6	.20	5.4	.8	229	6.6	11	.2	10	.00	--	242	7.40	22.0
3	RP-70-45-601	10-72	451	6.5	.00	79	5.8	3.5	6.2	1.3	249	14	9.7	.4	3.8	.00	--	249	7.00	25.5
4	YR-70-41-301	10-72	Spring	9.1	.00	80	7.2	.15	5.8	1.3	253	7.0	8.9	.2	5.7	.00	--	249	7.20	23.5
5	YR-70-41-301	2-73	Spring	13	.00	80	7.2	.20	5.6	1.0	235	7.6	11	.2	9.7	.00	--	258	7.25	23.0
6	YR-70-41-301	10-73	Spring	12	.00	72	9.3	.30	5.2	1.0	243	8.4	10	.3	11	.00	--	248	7.30	23.5
7	YP-69-50-101	7-71	30	12	.24	80	9.5	.2	8.1	1.1	262	10	17	.2	5.9	--	--	273	7.20	23.6
8	TD-69-39-501	2-74	207	12	.00	74	11	.10	7.4	1.2	249	11	13	.2	5.5	.00	--	276	7.01	23.0
9	AY-68-29-104	3-72	183	13	.00	110	21	.84	5.8	1.2	372	12	13	.2	4.0	.00	--	361	6.90	23.0
10	AY-68-29-109	7-70	140	13	.01	96	10	.20	6.9	.8	340	7.8	14	.2	3.9	.05	--	282	6.94	22.8
11	DX-68-15-901	10-72	Spring	11	.00	97	15	.39	7.5	1.4	346	14	11	.2	8.5	.00	--	336	7.00	22.0
12	DX-68-15-901	5-73	Spring	10	.00	110	10	.21	7.2	1.1	330	16	14	.2	2.5	.00	--	329	7.05	21.0
13	DX-68-15-901	11-73	Spring	11	.00	100	11	.10	8.1	1.4	335	14	13	.2	1.8	.00	--	325	7.00	22.0
14	AY-68-27-515	7-70	109	10	.00	80	15	.29	7.1	1.1	293	21	14	.2	6.3	.01	--	297	7.20	22.4
58	YP-70-56-201	10-72	37	21	--	130	4.8	.31	17	2.7	390	18	24	.2	11	.00	--	425	6.80	24.0
MAIN FRESH WATER GROUP																				
15	AY-68-29-702	3-72	266	12	.00	89	14	.40	7.4	1.2	296	23	14	.2	6.3	--	--	313	7.20	22.5
16	AY-68-29-913	3-72	239	13	.00	70	15	.54	8.0	1.3	260	21	12	.2	5.8	--	--	274	7.20	25.0
17	AY-68-30-104	3-72	259	14	.00	94	17	.55	12	2.3	326	27	17	.3	15	--	--	359	7.00	22.0
18	AY-68-35-904	7-71	206	12	.00	63	16	.8	7.5	1.2	246	15	11	.3	4.3	--	--	252	7.29	25.4
19	AY-68-36-102	7-71	240	11	.00	79	16	.5	8.2	1.4	290	29	14	.3	6.2	--	--	300	7.25	22.5
20	AY-68-36-601	11-73	Spring	12	.00	72	15	.33	8.7	1.4	256	20	14	.2	1.8	.02	--	279	7.05	24.0
21	AY-68-36-908	12-73	521	12	.00	65	17	1.3	8.3	1.2	248	23	15	.2	1.4	.00	--	270	7.20	27.0
22	AY-68-37-104	7-70	303	12	.00	70	17	.44	7.3	1.4	258	31	12	.3	4.3	.03	--	275	7.20	22.4
23	AY-68-37-115	11-73	Spring	14	10	76	16	.50	9.3	1.5	267	22	15	.2	1.4	.02	--	295	7.10	24.0
24	AY-68-37-202	3-12	214	12	.00	66	15	.94	7.8	1.2	248	17	14	.2	6.2	--	--	261	7.40	23.5

Table 1.--Results of chemical analyses of samples from the Edwards Aquifer--Continued

[Total concentrations in milligrams per litre]

Sample No.	Well or stream station number	Date	Depth (m)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Alkalinity (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sulfide (H_2S)	Total solids	pH	Temperature (°C)
MAIN FRESH WATER GROUP--Continued																				
25	AY-68-37-701	7-70	482	12	0.01	62	17	1.7	8.9	1.3	242	26	15	0.4	3.5	0.03	--	262	7.20	27.4
26	AY-68-42-312	3-72	417	13	.00	68	14	.82	7.5	1.1	248	15	15	.2	7.0	--	--	263	7.25	25.0
27	AY-68-42-804	3-72	701	12	.00	63	16	3.9	6.7	1.1	242	18	13	.3	4.7	--	--	254	7.50	27.5
28	AY-68-43-601	9-73	582	12	.01	66	16	1.4	8.2	1.3	251	21	17	.5	4.1	.00	--	266	7.26	27.0
29	AY-68-44-301	12-72	418	7.8	.00	70	17	1.8	10	1.5	246	36	16	.4	2.8	.00	--	284	7.35	28.0
30	AY-68-44-401	7-70	467	12	.00	62	17	1.7	8.7	1.2	243	25	15	.4	3.6	.03	--	267	7.20	27.4
31	DX-68-23-301	7-71	Spring	11	--	75	16	.6	8.1	1.3	288	23	12	.3	5.5	--	--	289	7.26	23.4
32	DX-68-23-301	5-73	Spring	12	--	80	16	.61	7.6	1.2	283	25	14	.3	3.4	.00	--	298	7.20	23.5
33	DX-68-23-301	11-73	Spring	12	--	79	17	.50	8.1	1.4	280	22	13	.2	1.9	.02	--	309	7.10	24.0
34	DX-68-30-312	7-71	197	12	.00	74	17	.5	8.5	1.5	264	29	13	.3	3.7	--	--	290	7.15	24.4
35	LR-67-01-801	3-73	Spring	11	.01	84	18	--	10	1.6	305	26	19	.3	5.8	.07	--	327	7.10	22.0
36	LR-67-01-801	5-73	Spring	11	.00	86	17	.61	9.6	1.4	306	25	20	.2	4.8	.00	00	325	7.20	22.0
37	TD-68-41-303	7-71	218	12	.00	67	15	.5	7.8	1.2	250	14	14	.2	5.7	--	--	259	7.20	24.5
38	TD-68-42-503	8-72	418	12	.01	60	15	1.4	6.9	1.1	244	13	12	.3	5.4	.02	00	245	7.05	26.0
39	TD-68-42-806	7-71	623	14	.00	56	15	2.0	7.2	1.0	224	15	14	1.8	.7	--	--	238	7.30	33.6
40	TD-69-40-901	7-70	371	12	.01	69	11	.24	5.6	1.0	249	22	10	.2	1.4	.03	--	254	7.02	23.4
41	TD-69-46-601	4-72	393	12	.00	70	14	.33	6.8	1.0	256	16	14	.2	5.8	.01	--	266	7.21	24.0
42	TD-69-46-402	4-72	604	12	.00	66	15	.35	7.2	1.1	248	17	15	.2	6.6	.01	--	262	7.45	23.5
43	TD-69-46-903	4-72	--	12	.01	71	14	.53	9.2	1.0	247	15	19	.2	10	.01	--	273	7.15	23.5
44	TD-69-47-301	7-70	460	12	.00	64	15	.28	6.6	1.2	253	16	12	.3	5.1	.00	--	255	7.23	25.2
45	TD-69-47-301	7-71	460	12	.00	65	16	.3	6.8	1.2	256	16	12	.2	4.0	--	--	256	7.30	24.8
46	TD-69-47-501	10-73	506	12	.01	69	16	.50	6.5	1.2	249	16	15	.3	9.7	.00	--	268	7.25	23.5
47	TD-69-48-102	4-72	504	12	.01	62	17	.75	7.0	1.1	248	17	13	.3	4.4	.01	--	257	7.40	26.0
48	YP-69-43-102	10-72	209	7.7	.00	73	15	.27	6.9	1.3	252	12	17	.1	6.4	.00	00	263	7.35	22.5

Table 1.--Results of chemical analyses of samples from the Edwards Aquifer--Continued
[Total concentrations in milligrams per litre]

Sample No.	Well or stream station number	Date	Depth (m)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Alkalinity (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sulfide (H_2S)	Total solids	pH	Temperature (°C)
MAIN FRESH WATER GROUP--Continued																				
49	YP-69-43-107	2-74	268	11	0.02	70	13	0.40	6.4	0.9	247	11	13	0.1	3.4	.00	--	261	7.15	22.5
50	YP-69-44-101	2-73	171	13	.00	64	15	.40	7.0	1.1	229	11	19	.2	9.1	.00	--	253	7.35	22.0
51	YP-69-45-704	10-72	504	9.0	.00	76	13	.28	8.2	1.3	257	12	19	.2	7.3	.00	--	272	7.35	23.5
WESTERN VARIED GROUP																				
69A	ZX-69-61-526	3-75	1063	19	.15	660	120	13	190	13	230	1800	370	3.0	.1	--	(a)	3300	6.20	46.5
52	RP-70-44-801	10-72	424	16	.08	680	55	9.4	13	2.8	226	1700	7.1	2.3	.00	.00	(a)	2600	6.70	33.5
53	YP-69-43-908	4-72	308	15	.04	310	49	4.3	130	3.0	246	180	600	.3	56	.01	--	1470	6.90	24.0
54	YP-69-43-909	10-73	398	13	.06	140	30	5.2	48	3.9	252	170	140	.9	.9	.00	(a)	664	7.08	28.5
55	YP-69-53-703	4-72	607	14	.32	92	23	24	28	2.2	232	130	50	3.7	.0	.00	(a)	484	7.15	36.0
56	YP-69-51-401	4-72	725	14	.05	120	12	2.0	29	1.5	296	59	73	.4	15	.01	--	471	6.98	25.0
57	YP-69-51-103	4-72	154	17	.01	120	15	4.7	18	1.8	288	110	29	.7	1.6	.00	--	458	7.00	25.5
79	YP-69-45-404	7-71	455	12	--	77	22	.7	19	2.7	256	83	18	.4	5.7	--	--	369	7.30	23.4
59	YP-69-50-105	10-72	291	7.6	.00	94	11	.31	9.2	1.5	248	15	45	.2	6.4	.00	--	312	7.15	24.0
60	TD-68-41-801	7-70	490	12	1.9	42	22	3.0	38	2.5	266	10	35	3.3	--	.02	.045	299	7.62	23.8
61	TD-68-34-103	8-72	309	11	.01	66	19	.74	6.8	1.4	242	50	12	.4	2.4	.01	--	285	7.35	23.0
62	YP-69-44-502	4-72	421	12	.00	71	14	4.8	9.2	1.1	246	21	23	.4	5.0	.00	--	282	7.25	29.5
63	TD-68-41-401	8-72	601	12	.01	75	14	1.1	7.2	1.1	258	12	26	.3	5.8	.01	--	279	7.45	25.0
WESTERN SALINE AND TRANSITIONAL WATER GROUP																				
64	AY-68-45-101	7-71	572	21	.02	620	231	13	449	28	292	2000	871	4.5	.1	.01	53	4430	6.67	39.0
65	AY-68-45-301	7-70	662	24	.05	620	212	15	462	38	282	1850	934	5.0	--	.00	50	4280	6.65	42.4
66	AY-68-45-802	7-70	745	24	.01	620	214	14	442	34	286	1780	940	5.0	--	.00	63	4290	6.58	47.2
67	AY-68-45-802	7-71	745	24	.01	635	209	14	455	27	282	1900	800	4.4	.6	--	67	4270	6.60	47.0
68	AY-68-45-901	1-73	890	24	.40	680	210	13	340	17	258	2000	750	3.5	.00	.00	(a)	4150	6.60	48.0
69	AY-68-51-201	9-73	676	20	.51	540	200	13	350	19	275	1600	780	5.1	.8	.00	(a)	3660	6.70	40.5

a Sulfide (H_2S) odor noted at time of sampling; no analysis made.

Table 1.--Results of chemical analyses of samples from Edward Aquifer--Continued

[Total concentrations in milligrams per litre]

Sample No.	Well or stream station number	Date	Depth (m)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Alkalinity (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Sulfide (H_2S)	Total solids	pH	Temperature (°C)
WESTERN SALINE AND TRANSITIONAL WATER GROUP--Continued																				
70	AY-68-44-404	7-70	506	21	0.05	270	104	8.9	188	14	280	730	376	4.0	--	0.00	22	1880	7.00	30.8
71	AY-68-43-702	7-70	626	18	.35	210	61	6.9	121	9.0	253	466	244	2.5	--	.02	13	1280	6.85	37.8
72	AY-68-43-703	7-71	619	17	.15	196	59	7.8	106	7.5	244	490	204	1.6	0.3	.04	11	1220	7.02	35.8
73	AY-68-44-210	7-71	510	13	.51	111	40	4.2	55	4.2	244	211	97	1.6	.1	.00	1.3	661	7.20	31.3
74	AY-68-43-809	7-71	580	14	.10	112	34	5.3	49	4.0	232	220	86	1.2	.9	.04	3.2	646	7.00	35.3
75	AY-68-43-810	7-70	567	14	.05	100	37	7.4	45	4.5	243	187	85	1.3	--	.02	3.7	607	7.08	35.5
76	TD-68-49-813	3-73	975	23	.04	81	27	38	43	3.9	256	170	63	4.2	.0	.00	(a)	562	7.35	46.0
77	TD-68-49-813	3-73	975	23	.08	80	27	41	43	3.5	248	170	50	4.4	.3	.00	(a)	544	7.15	44.0
78	AL-68-50-201	7-70	725	16	.40	83	32	34	24	3.0	240	169	44	2.8	--	.02	.5	529	7.15	38.9
EASTERN SALINE AND TRANSITIONAL WATER GROUP																				
80	DX-68-16-602	11-72	101	15	.00	790	410	17	1500	62	454	2800	2800	2.5	.2	1.3	(a)	8510	6.65	24.0
81	AY-68-38-301	7-71	260	19	.06	560	204	13	953	62	320	1880	1560	4.1	.2	.02	19	5440	6.69	32.0
82	AY-68-37-702	7-70	649	22	2.7	460	213	14	596	37	403	1440	1050	5.0	--	.00	55	4100	6.80	28.0
83	DX-68-23-807	10-72	157	11	.98	150	120	21	450	24	396	540	740	3.0	.0	.00	(a)	2250	7.70	24.0
84	KX-68-30-601	7-71	172	13	.07	188	110	21	329	19	282	619	552	3.9	.1	.06	6.6	2000	7.12	25.2
85	AY-68-37-602	1-73	335	13	--	130	61	3.9	150	8.6	255	320	260	2.1	.5	.00	(a)	1070	7.20	28.0
86	AY-68-38-101	7-71	275	8.6	6.2	93	37	2.9	95	7.7	238	195	147	1.2	.0	.01	.04	713	7.20	31.3
87	AY-68-37-706	12-73	464	12	.00	70	20	1.7	15	1.7	246	49	25	.4	1.0	.00	--	319	7.10	27.0
88	AY-68-37-704	12-63	493	12	.00	66	22	9.0	11	1.4	251	42	17	.8	.7	.00	(a)	307	7.15	32.0
89	AY-68-30-802	3-72	229	13	.00	68	17	1.6	13	1.4	244	34	23	.3	4.2	--	--	294	7.35	27.5

[a] Sulfide (H_2S) odor noted at time of sampling; no analysis made.

Table 2.--Results of isotope analyses

Sample No.	Well or stream station number	Date collected	Total dissolved carbonate (mM/l)	Carbon isotopes			Tritium	Sulfur isotopes				Other constituents		Redox potential
								Sulfate		Sulfide				
				$\delta^{13}C$ (‰)	^{13}C content (% modern ± 1σ)	^{13}C sample number WRD-	TU ± 1σ	Milligrams per litre	$\delta^{34}S$- (‰)	Milligrams per litre (H_2S)	$\delta^{34}S$- (‰)	Aluminum (mg/l)	Ammonium (mg/l)	Volts
A	08190000	7-71	3.76	-4.9	116.0±1.1	111	a30 ±2	13	+11.3	0.0	--	--	--	--
B	08195000	7-71	3.48	-9.3	118.0±1.1	110	a28 ±2	16	+10.9	.0	--	--	--	--
7	YP-69-50-101	7-71	4.83	-11.5	72.5±0.6	119	a21.0±1.5	10	+11.5	.0	--	--	--	--
10	AY-68-29-109	7-70	6.87	-10.8	73.8± .7	72	a5.4± .4	7.8	+15.2	.0	--	0.0	0.2	+0.547
14	AY-68-27-515	7-70	5.41	-10.3	--	--	a42.8±2.4	21	+8.6	.0	--	.0	.1	+.538
79	YP-69-45-404	7-71	4.60	-8.5	65.6± .7	115	a11.7± .8	83	+19.1	.0	--	--	--	+.546
18	AY-68-35-904	7-71	4.43	-8.5	59.9±1.0	118	1.9± .7	15	+10.6	.0	--	.0	.0	+.569
19	AY-68-36-102	7-71	5.29	-8.9	73.6± .6	112	13.9± .8	29	+13.3	.0	--	--	--	+.569
22	AY-68-37-104	7-70	4.77	-8.6	83.6±1.1	75	(a)	31	+11.5	.0	--	.0	--	+.566
25	AY-68-37-701	7-70	4.44	-8.1	55.6± .7	86	a <.7	26	+13.4	.0	--	.0	--	+.503
30	AY-68-44-401	7-70	4.52	-8.4	--	--	--	25	--	.0	--	.0	.0	+.487
31	DX-68-23-301	7-71	4.46	-9.2	65.1± .6	116	a6.7± .4	23	+12.8	.0	--	--	--	+.590
34	DX-68-30-312	7-71	4.93	--	--	--	(a)	29	+8.3	.0	--	--	--	--
37	TD-68-41-303	7-71	4.61	--	--	--	3.5± .5	14	+10.5	.0	--	--	--	+.580
39	TD-68-42-806	7-71	3.99	-5.7	24.5± .6	117	<.8	15	+14.9	.0	--	--	--	+.534
40	TD-69-40-901	7-70	4.87	-9.6	52.2± .7	85	a11.5±1.2	22	+14.0	.0	--	.0	.0	+.529
44	TD-69-47-301	7-70	4.97	--	--	--	a1.9± .4	16	--	.0	--	.0	.0	+.531
45	TD-69-47-301	7-71	4.57	-8.4	62.4± .6	114	a2.4± .3	16	+13.3	.0	--	--	--	-.587
60	TD-68-41-801	7-70	4.54	-6.2	5.8± .4	77	a <.8	10	--	.045	--	.0	.1	-.087
64	AY-68-45-101	7-71	5.12	-3.1	<2.2	128	--	2000	+20.6	53	-14.3	.5	2.2	-.154
65	AY-68-45-301	7-70	5.05	-4.6	<2.4	71	(a)	1850	+22.0	46	-14.4	.3	2.5	-.182
66	AY-68-45-802	7-70	5.35	-3.2	<1.0	84	--	1780	+21.7	63	-13.2	.3	2.5	-.195
67	AY-68-45-802	7-71	4.47	(-6.9)	<1.1	129	--	1900	+21.2	67	-13.3	.5	--	-.161
70	AY-68-44-404	7-70	4.85	-4.8	--	--	--	730	+22.5	22	-19.5	.2	1.1	-.155
71	AY-68-43-702	7-70	4.78	-4.7	22.3± .6	80	--	466	+21.1	13	-11.5	.1	.6	-.190
72	AY-68-43-703	7-71	4.35	--	22.8± .6	125	--	490	+20.1	11	-11.9	.1	--	-.005
73	AY-68-44-210	7-71	4.39	-5.4	32.0± .4	124	<1.0	211	+18.3	1.3	-17.6	.1	--	+.044
74	AY-68-43-809	7-71	4.37	-5.3	34.2± .6	122	--	220	+19.1	3.2	-12.3	.1	.3	--
75	AY-68-43-810	7-70	4.45	-6.5	--	--	--	187	+20.0	3.7	-14.6	.0	.0	-.145
78	AL-68-50-201	7-70	4.37	-2.9	2.7± .4	78	(a)	169	+21.8	.02	-24.0	.0	.0	-.083
81	AY-68-38-301	7-71	6.41	-4.0	<1.2	127	--	1880	+21.3	19	-15.1	.4	--	-.122
82	AY-68-37-702	7-70	7.35	.0	3.9± .6	82	<.6	1440	+22.2	55	-10.0	.3	3.2	-.320
84	KX-68-30-601	7-71	4.96	-3.3	<1.4	123	<1.8	619	+22.0	71	-27.1	.3	--	-.114
86	AY-68-38-101	7-71	4.32	-4.3	21.0± .6	121	--	195	+26.7	.04	-20.0	.0	.2	-.042

a Tritium analyses of samples from this source at other time; reported by Pearson, Rettman, and Wyerman (1975).

Table 3.--Calculated total dissolved carbonate contents, partial CO_2 pressures, and saturation indices of selected minerals in Recharge and Main fresh water groups

Sample No.	Date collected	Total dissolved carbonate (Mm/1)	Partial CO_2 pressure, atmospheres	Saturation indices	
				Calcite	Dolomite
		RECHARGE GROUP			
A[a]	7-71	3.68	0.002	+0.56	+0.93
A[b]		3.92	.008	+.03	-.14
B[a]	7-71	3.38	.002	+.65	+1.16
B[b]		3.63	.007	+.02	-.10
1	10-72	4.50	.013	-.01	-.71
2	2-73	4.05	.008	+.07	-.53
3	--	4.89	.024	-.23	-1.18
4	10-72	4.67	.015	-.05	-.74
5	2-73	4.29	.012	-.04	-.72
6	10-73	4.38	.012	-.01	-.50
7	7-71	4.83	.016	-.04	-.60
8	2-74	4.90	.023	-.29	-1.00
9	3-72	7.63	.043	-.10	-.51
10	7-70	6.87	.036	-.14	-.85
11	10-72	6.83	.032	-.09	-.58
12	5-73	6.40	.026	-.02	-.69
13	11-73	6.61	.030	-.08	-.73
14	7-70	5.41	.017	-.02	-.37
58	10-72	8.39	.057	-.10	-1.21
		MAIN FRESH WATER GROUP			
15	3-72	5.47	.017	+.02	-.36
16	3-72	4.79	.016	-.08	-.42
17	3-72	6.43	.030	-.13	-.60
18	7-71	4.43	.012	-.05	-.28
19	7-71	5.29	.015	+.01	-.26
20	11-73	4.95	.022	-.24	-.76
21	12-73	4.55	.015	-.10	-.37
22	7-70	4.77	.015	-.13	-.48
23	11-73	5.07	.020	-.16	-.58
24	3-72	4.37	.010	+.08	-.06

a Calculated with reported pH = 8.10.

b Calculated with estimated pH = 7.45.

Table 3.--Calculated total dissolved carbonate contents, partial CO_2 pressures, and saturation indices of selected minerals in Recharge and Main fresh water groups--Continued

Sample No.	Date collected	Total dissolved carbonate (Mm/1)	Partial CO_2 pressure, atmospheres	Saturation indices	
				Calcite	Dolomite
		MAIN FRESH WATER GROUP--Continued			
25	7-70	4.44	0.015	-0.13	-0.39
26	3-72	4.51	.013	-.06	-.39
27	3-72	4.19	.008	+.18	+.19
28	9-73	4.54	.014	-.03	-.26
29	12-72	4.36	.011	+.08	-.03
30	7-70	4.46	.015	-.12	-.39
31	7-71	5.23	.015	+.02	-.23
c32	5-73	5.24	.017	+.42	-.70
d32		5.22	.017	-.04	-.35
33	11-73	5.31	.021	-.12	-.50
34	7-71	4.93	.018	-.12	-.47
35	3-73	5.81	.022	-.10	-.47
36	5-73	5.65	.018	+.01	-.28
37	7-71	4.61	.015	-.12	-.48
38	8-72	4.70	.021	-.30	-.78
39	7-71	3.99	.012	-.01	-.14
40	7-70	4.87	.022	-.30	-1.00
41	4-72	4.71	.015	-.09	-.47
42	7-72	4.34	.008	+.10	-.04
43	4-72	4.62	.016	-.17	-.64
44	7-70	4.62	.014	-.09	-.40
45	7-71	4.69	.912	-.02	-.24
46	10-73	4.54	.013	-.08	-.39
47	4-72	4.36	.010	+.07	-.02
48	10-72	4.50	.010	+.04	-.22
49	2-74	4.63	.016	-.18	-.70
50	2-73	4.09	.009	-.06	-.36
51	10-72	4.58	.011	+.08	-.21

c Calculated with reported Ca^{+2} = 30 mg/1.
d Calculated with estimated Ca^{+2} = 77 mg/1.

Table 4.--Calculated total dissolved carbonate contents, partial CO_2 pressures, and saturation indices of selected minerals in Saline and Transitional water groups

Sample No.	Date collected	Total dissolved carbonate (Mm/1)	Partial CO_2 pressure, atmospheres	Saturation indices					
				Calcite	Dolomite	Gypsum	Celestite	Stron-tianite	Fluorite
				WESTERN VARIED GROUP					
a69A	3-75	6.83	0.149	-0.35	-0.98	+0.09	-0.03	-1.50	+0.10
b69A		5.13	.066	-.00	-.28	+.09	-.03	-1.15	+.10
52	10-72	4.80	.040	+.05	-.54	+.17	-.12	-1.17	+.09
53	4-72	4.93	.026	+.03	-.34	-.86	-1.32	-1.29	-1.74
54	10-73	4.74	.010	+.02	-.19	-1.06	-1.06	-.86	-1.60
55	4.72	4.25	.018	+.02	-.12	-1.30	-.44	-.07	-.03
56	4-72	5.83	.029	-.07	-.72	-1.49	-1.87	-1.30	-1.72
57	4.72	5.62	.027	-.07	-.61	-1.24	-1.22	-.92	-1.45
79	7-71	4.60	.012	-.01	-.16	-1.49	-2.13	-1.50	-1.89
59	10-72	4.63	.016	-.05	-.63	-2.12	-3.22	-2.00	-2.37
60	7-70	4.54	.006	+.10	+.33	-2.61	-2.36	-.50	-.29
61	8-72	4.31	.010	-.03	-.20	-1.74	-2.29	-1.43	-1.92
62	4-72	4.45	.014	+.02	-.24	-2.09	-1.85	-.65	-1.93
63	8-72	4.50	.009	+.19	+.07	-2.30	-2.74	-1.11	-2.12
				WESTERN SALINE AND TRANSITIONAL WATER GROUP					
64	7-71	5.12	.047	+.01	+.05	+.06	-.06	-1.09	+.31
65	7-70	5.06	.051	+.03	+.05	+.03	-.04	-1.04	+.42
66	7-70	5.00	.060	-.02	-.02	+.00	-.09	-1.14	+.38
67	7-71	4.75	.055	-.01	-.03	+.04	-.06	-1.13	+.27
68	1-73	5.52	.065	+.08	+.13	+.08	-.06	-1.10	+.13

a Calculated with reported pH = 6.20.
b Calculated with estimated pH = 6.55.

Table 4.--Calculated total dissolved carbonate contents, partial CO_2 pressures, and saturation indices of selected minerals in Saline and Transitional water groups--Continued

Sample No.	Date collected	Total dissolved carbonate (Mm/l)	Partial CO_2 pressure, atmospheres	Saturation indices					
				Calcite	Dolomite	Gypsum	Celestite	Strontianite	Fluorite
WESTERN SALINE AND TRANSITIONAL WATER GROUP--Continued									
69	9-73	5.70	0.052	+0.09	+0.21	-0.04	-0.12	-0.97	+.46
70	7-70	4.85	.023	+.09	-.20	-.43	-.42	-.81	+.12
71	7-70	4.79	.035	-.04	-.16	-.64	-.63	-1.00	-.23
72	7-71	4.35	.022	+.06	+.05	-.63	-.54	-.79	-.62
73	7-71	4.39	.015	+.06	+.11	-1.08	-1.05	-.83	-.70
74	7-71	4.37	.024	-.11	-.28	-1.06	-.92	-.92	-.98
75	7-70	4.45	.021	-.04	-.07	-1.16	-.84	-.66	-.95
c76	3-73	4.47	.014	+.28	+.58	-1.30	-.13	+.42	-.09
d76		4.72	.026	+.04	+.08	-1.30	-.13	+.18	-.09
77	3-73	4.52	.021	+.05	+.11	-1.30	-.10	+.24	-.03
78	7-70	4.37	.019	+.00	+.05	-1.26	-.18	+.11	-.37
EASTERN SALINE AND TRANSITIONAL WATER GROUP									
80	11-72	9.90	.074	+.10	+.36	+.14	-.06	-.95	-.06
81	7-71	6.42	.052	-.01	-.00	+.00	-.11	-1.04	+.22
82	7-70	7.20	.046	+.09	+.28	-.11	-.13	-.82	+.42
e83	10-72	6.62	.006	+.62	+1.56	-.78	-.18	+.36	-.22
d83		7.39	.027	+.03	+.39	-.78	-.18	-.23	-.22
84	7-71	5.06	.018	+.01	+.21	-.62	-.10	-.34	+.10
85	1-73	4.63	.015	+.04	+.19	-.92	-.98	-.92	-.46
86	7-71	4.32	.015	-.02	-.01	-1.18	-1.24	-1.00	-1.03
87	12-73	4.64	.019	-.19	-.51	-1.74	-1.95	-1.28	-1.94
88	12-73	4.63	.019	-.09	-.21	-1.85	-1.29	-.45	-1.41
89	3-72	4.33	.011	+.06	-.07	-1.90	-2.12	-1.05	-2.19

c Calculated with reported pH = 7.35.

e Calculated with reported pH = 7.70.

d Calculated with estimated pH - 7.10.

Table 5. Thermodynamic data used in WATEQ to calculate parameters in tables 3 and 4. Data for reactions not shown are as given by Truesdell and Jones (1974).

Mineral	Reaction	Log K_{25^oC}	ΔH-Kilocalories	Reaction Number 1/	References
Calcite	$CaCO_3 \rightarrow Ca^{+2}+CO_3^{=}$	-8.410	-3.19	12	c, e
Dolomite	$CaMg(CO_3)_2 \rightarrow Ca^{+2}+Mg^{+2}+2CO_3^{=}$	-17.00	-8.29	11	d, e
Gypsum	$CaSO_4 \cdot 2H_2O \rightarrow Ca^{+2}+SO_4^{=}+2H_2O$	-4.759	0.26	18	h, b, a
Celestite	$SrSO_4 \rightarrow Sr^{+2}+SO_4^{=}$	-6.465	-0.47	143	a, b
Strontianite	$SrCO_3 \rightarrow Sr^{+2}+CO_3^{=}$	-9.251	-0.69	142	a, b
Fluorite	$CaF_2 \rightarrow Ca^{+2}+2F^{-}$	-10.500	2.76	62	i, a, b

Reaction	Analytical Expression		
$H_2CO_3 \rightarrow HCO_3^{-}+H^{+}$	log KT=14.8435-0.032786T-3404.71/T	35	f
$HCO_3^{-} \rightarrow H^{+}+CO_3^{=}$	log KT= 6.498-0.02379T-2902.39/T	68	g

References

a) Wagman and others, 1968

b) Parker, Wagman and Evans, 1971

c) Plummer and Mackenzie, 1974

d) Berner, 1967

e) Helgeson, 1969

f) Harned and Davis, 1943

g) Harned and Scholes, 1941

h) Robie and Waldbaum, 1968

i) E. A. Jenne, oral commun., 1975

1/ in WATEQ (Truesdell and Jones, 1974)