

Report of Investigations 8008

**Determination of Carbonate Minerals
of Green River Formation Oil Shales,
Piceance Creek Basin, Colorado**

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DETERMINATION OF CARBONATE MINERALS OF GREEN RIVER
FORMATION OIL SHALES, PICEANCE CREEK
BASIN, COLORADO

by

Neil B. Young,¹ John Ward Smith,² and William A. Robb¹

ABSTRACT

Carbonate minerals constitute a major fraction of the oil shale in Colorado's Green River Formation. Quantification of carbonate minerals is important for the characterization of oil shale, particularly because of their thermal activity in production of oil from shale. The carbonate minerals found in this oil shale are nahcolite (NaHCO_3), dawsonite [$\text{NaAl}(\text{OH})_2\text{CO}_3$], dolomite [$(\text{Mg}_{1-x}\text{Fe}_x)\text{Ca}(\text{CO}_3)_2$], calcite (CaCO_3), and ferroan [$(\text{Mg}_{1-x}\text{Fe}_x)\text{CO}_3$]. Although carbonate minerals can be removed by acid extraction from the balance of the oil shale, direct determination of carbonate minerals is complicated by the occurrence of the same cations in more than one mineral. A method for assigning the acid-soluble cations to the individual carbonate minerals was developed from two assumptions based on oil shale geochemistry: (1) Calcite and ferroan do not occur together, and (2) the ratio of iron and magnesium is the same in dolomite and ferroan. These assumptions were tested by the Bureau of Mines by applying the technique for assigning cations to 219 samples from the saline section of the formation. The reported carbonate mineral amounts were compared statistically with X-ray diffraction peak heights, verifying the cation assignment method.

INTRODUCTION

Carbonate minerals are major components of the oil shales in Colorado's Eocene Green River Formation. The oil shales have been described as dolomitic marlstones (15).³ However, appreciable amounts of several carbonate minerals besides dolomite occur in the shale (12). Carbonate minerals influence both the thermal and physical properties of oil shale and some may have resource value; consequently, a knowledge of the composition and quantity of the carbonate minerals is essential in characterizing oil shales. Only limited information on amounts of dolomite and the other carbonates has been available because of the common cation problems inherent in analysis of the shale. This paper presents a technique for assignment of acid-extractable cations to the

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³Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

specific carbonate minerals present in Green River Formation oil shale. The technique is applied to samples from Colorado's saline mineral section, which contains the most complex carbonate mineral composition in the Green River Formation. Validity of the cation assignment technique is demonstrated by comparing determined with calculated carbonate CO_2 and by correlating X-ray diffraction results with calculated carbonate mineral amounts.

CARBONATE ANALYSIS PROBLEM

Dolomite, calcite, and ferroan are the minerals posing the major analytical problem in determining amounts of the carbonates in oil shales. These minerals share the same cations. Dolomite is ubiquitous in Green River oil shales (12), and virtually all of this dolomite contains ferrous iron substituting for magnesium (11). The general formula for Green River dolomite is $(\text{Mg}_{1-x}\text{Fe}_x)\text{Ca}(\text{CO}_3)_2$. For example, x in Mahogany zone oil-shale dolomite averages 0.15 (11). Calcite, hexagonal CaCO_3 , is widespread in Green River oil shales, and aragonite, orthorhombic CaCO_3 , occurs in some oil shales as a matrix mineral (12). These chemically equivalent minerals contain calcium in common with dolomite. Ferroan is a popular name used to designate the carbonate series $[(\text{Mg}_{1-x}\text{Fe}_x)\text{CO}_3]$. Both end members have been detected, and X-ray diffraction spacings indicating the complete range of composition from x = 0 (magnesite) to x = 1 (siderite) have been found. Ferroan, sharing ferrous and magnesium cations with dolomite, occurs commonly in Green River Formation oil shales. Maximum amounts of ferroan appear in the saline mineral zone of Colorado.

These carbonate minerals can be extracted quantitatively from the rest of the oil shale by acid treatment. No noncarbonate mineral yielding acid-extractable calcium, magnesium, or iron exists in quantity in the oil shales. Consequently, the acid-soluble calcium, magnesium, and iron stem from dolomite, calcite, and ferroan. The basic problem in quantifying these three carbonates is determining distribution of their shared cations.

Colorado's Green River Formation oil shale contains substantial quantities of two more carbonate minerals, dawsonite and nahcolite. Dawsonite, $\text{NaAl}(\text{OH})_2\text{CO}_3$, exists as a matrix mineral in oil shales several hundred feet thick underlying 600 square miles of the Piceance Creek Basin (8, 10, 16). Dawsonite content may exceed 15 weight-percent of the oil shale in certain zones (16). Nahcolite, NaHCO_3 , occurs primarily as nodules in oil shale and is nearly pure sodium bicarbonate. Nahcolite occurs with dawsonite in an area larger than 500 square miles (16) in zones several hundred feet thick (13). Part of the nahcolite originally in place has been removed by subsurface leaching (15).

A complete carbonate balance requires determination of these two minerals. Smith and Young (14) developed a method for determining dawsonite and nahcolite and have published analyses by their method (14, 16). Their analytical technique, depending on selective solubility of dawsonite and nahcolite, was used to obtain the analyses necessary for completing the carbonate balance in this paper.

EXPERIMENTAL PROCEDURES

A total of 219 samples were selected from three coreholes from the saline section (16) of the Green River Formation, Piceance Creek Basin the northwestern Colorado (fig. 1).

Sample Sources

Sample Set 1. --Colorado Corehole No. 3 was drilled by Federal Bureau of Mines-Atomic Energy Commission in NW1/4SW1/4SW1/4, sec 14, T 1 N, R 98 W, Rio Blanco County, Colo. Determinations were made on section between 1,743.5 and 2,721.0 feet below the Kelly bushing.

Sample Set 2. --Colorado Corehole No. 2 was drilled by Federal Bureau of Mines-Atomic Energy Commission in NE1/4SW1/4NW1/4, sec 14, T 1 S, R 99 W, Rio Blanco County, Colo. Determinations were made on section between 1,616.0 and 2,409.3 feet below the Kelly bushing.

Sample Set 3. --Piceance Creek Unit No. 11-24 was drilled by General Petroleum Corp. in NW1/4NW1/4NW1/4, sec 24, T 2 S, R 96 W, Rio Blanco County, Colo. Determinations were made on section between 2,195.0 and 2,570.0 feet below Kelly bushing.

Sample Preparation

Sample set 1 samples, each representing approximately 10 feet, were prepared from quarter core. The quarter core was crushed to pass an 8-mesh screen and thoroughly blended. A sample of approximately 1 kilogram, split by riffle from the minus 8-mesh shale, was crushed to pass a 100-mesh screen. The resulting samples are numbered 1 to 106 (table A-1).

Sample set 2 samples were composited to represent approximately 10 feet of core from crushed (minus 8-mesh) 1-foot sections of core. The samples were combined according to each sample's volume based on specific gravity (7). The resulting samples were crushed to pass a 100-mesh screen and blended. The composite samples produced are equivalent to a sample obtained by crushing a small-diameter core representing the complete 10-foot thickness of each composite. The resulting samples are numbered 107 to 181 inclusive (table A-1).

Sample set 3 samples were composited to represent approximately 10 feet of core from crushed core sections (minus 8 mesh) approximately 1 foot long. The method is the same as used in preparation of sample set 2. The resulting samples are numbered 182 to 219 inclusive (table A-1).

Chemical Analytical Methods

The carbonate cations were extracted by successively leaching each sample with water and acid (14). The water extracts sodium from nahcolite. The acid treatment extracts sodium from dawsonite, and calcium, magnesium, and iron from dolomite, calcite, and ferroan. To perform these extracts a 1-gram sample of oil shale was stirred in approximately 100 milliliters of water for

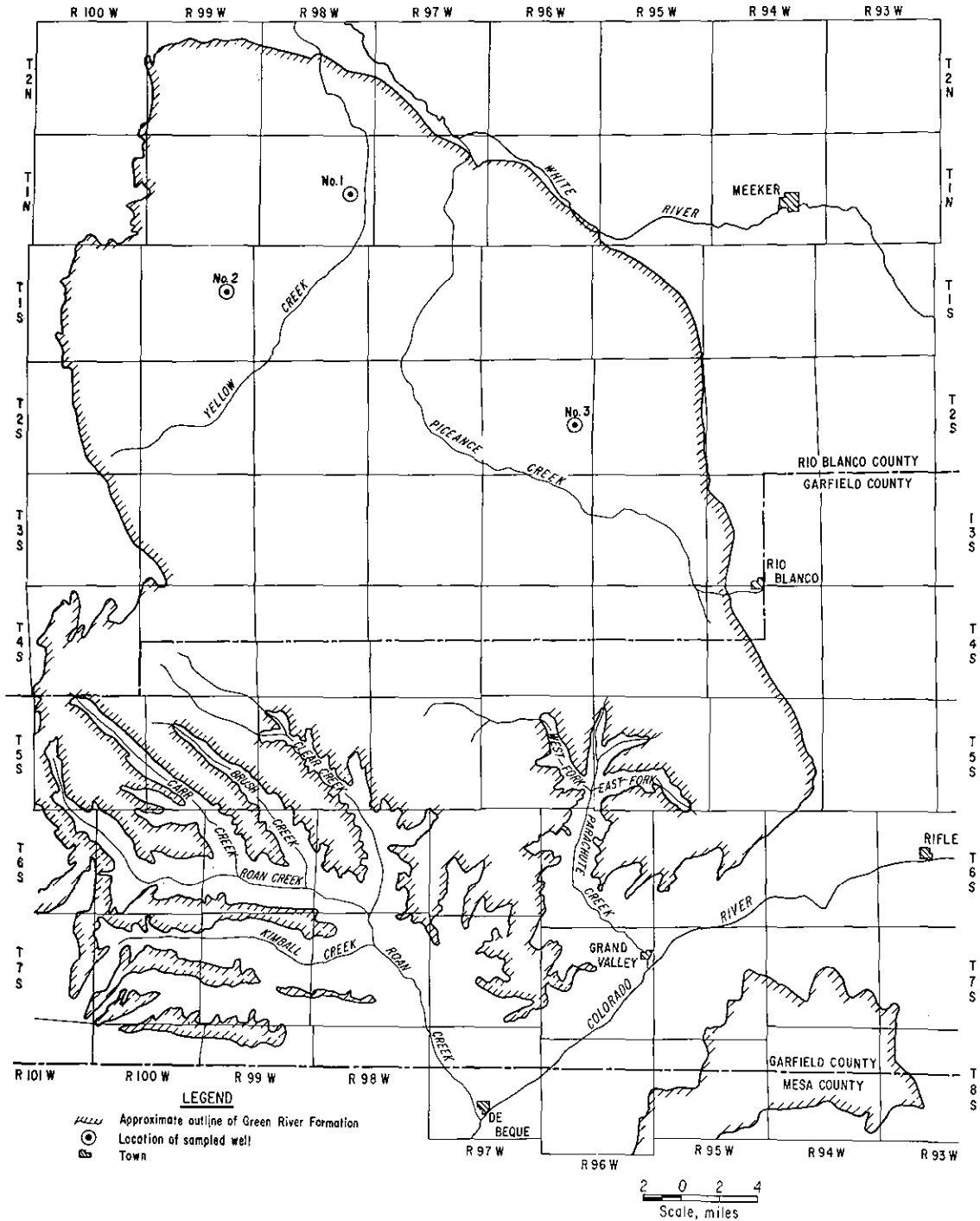


FIGURE 1. - Sample locations, Piceance Creek Basin, Colorado.

30 minutes at room temperature. The sample was filtered and washed with distilled water; filtrate and washings were combined and adjusted to a known volume. Water-soluble sodium was determined by flame emission spectrophotometry (3). The filter paper and sample from the water extraction were treated with

approximately 75 milliliters of 6 N HCl, heated to boiling and constantly stirred for 15 minutes, allowed to cool, filtered, and washed with distilled water. The filtrate was adjusted to a known volume, and aluminum, calcium, magnesium, and iron were determined on aliquots by atomic absorption spectrophotometry (6). Acid-soluble sodium was determined by flame emission spectrophotometry. Results of these determinations are given in table A-1.

X-Ray Diffraction Methods

Three-gram samples of minus 100-mesh oil shale were machine ground for 1 minute to provide samples of approximately uniform particle size distribution. The ground samples, uniformly packed in a holder, were examined by X-ray diffraction under standardized instrument settings and conditions. The X-ray diffraction charts were obtained with a goniometer-equipped diffractometer using $\text{CuK}\alpha$ radiation and a proportional detector at a scanning speed of $2^\circ 2\theta$ per minute.

The X-ray diffraction peak height for a mineral varies with mineral amounts if the matrixes for all samples are similar. The peak heights of the various minerals were counted above background with the scaler set for 100 counts full scale and a time constant of 5. Any peaks off scale were attenuated with the multiplier and converted to 100 counts full scale, producing some peak heights greater than 100.

Heights of the primary or most intense reflections of each mineral were determined: The d_{110} of dawsonite at $15.67^\circ 2\theta$, the d_{111} of nahcolite at $30.42^\circ 2\theta$, and the d_{104} of calcite at $29.40^\circ 2\theta$, the d_{104} of dolomite at $30.9^\circ 2\theta$, and the d_{104} of ferroan between siderite at $32.05^\circ 2\theta$ and magnesite at $32.63^\circ 2\theta$. To compensate for some X-ray interferences, the second most intense peak of dawsonite at $32.12^\circ 2\theta$ and the primary peak for quartz at $26.6^\circ 2\theta$ were also measured. Tables A-2 and A-3 list the peak heights used to compare with the chemically determined mineral amounts.

CALCULATION OF CARBONATE MINERALS

Quantitative assignment of the water- and acid-soluble cations to their respective carbonate minerals is required in order to calculate quantities of the carbonate minerals. Smith and Young (14) presented a method for assignment of water-soluble sodium and acid-soluble sodium to nahcolite and dawsonite, respectively. However, the assignment of calcium, magnesium, and iron to dolomite, calcite, and ferroan presents difficulties not encountered with the sodium carbonates. Green River dolomite, $(\text{Mg}_{1-x}\text{Fe}_x)\text{Ca}(\text{CO}_3)_2$, has Fe^{++} substituting for Mg^{++} . The ratio of magnesium to iron in the mineral is not known, so the true molecular weight (MW) of dolomite is not known. In addition, only part of the calcium, magnesium, and iron occurs in dolomite, so the entire amount of any cation cannot be specifically assigned to dolomite. Ferroan, as indicated by its formula $[(\text{Mg}_{1-x}\text{Fe}_x)\text{CO}_3]$, represents any composition in the magnesite (MgCO_3)-siderite (FeCO_3) series (15). Calculations of the amounts of ferroan suffer the same difficulty as dolomite because the true molecular weight of ferroan is not known and because its cations also occur in dolomite. Calcite, CaCO_3 , has only one cation with no major substitution by

other cations. There is, however, the problem of assigning part of the determined calcium to calcite.

Based on two geochemically derived assumptions, a method was developed for the assignment of portions of the determined cations to the carbonate minerals. The first assumption is that calcite and ferroan were not precipitated or deposited together. Smith and Robb (12) postulated conditions necessary for the formation and deposition of dolomite and calcite. They proposed that first aragonite and then calcite combine with available Mg^{++} and Fe^{++} to form dolomite. If an excess of calcium carbonate was present, all available Mg^{++} and Fe^{++} was used for the formation of dolomite. If an excess of Mg^{++} and Fe^{++} were present during deposition, all calcium carbonate was dolomitized and the excess Mg^{++} and Fe^{++} became available for the formation of ferroan. Mineral surveys of thousands of 1-foot samples from several wells indicate that calcite and ferroan do not occur together. The second assumption is that the ratio of iron to magnesium is the same in both ferroan and dolomite.

On the basis of these two assumptions, the determined acid-soluble calcium, magnesium, and iron can be apportioned among the dolomite, calcite, and ferroan minerals. The mole fraction (MF) of calcium is calculated and compared with the sum of the mole fractions of magnesium and iron. From the first assumption, if calcium is in excess, the limiting factor on dolomite is the amount of iron and magnesium, and the excess calcium is calculated as calcite. If iron plus magnesium is in excess, the calcium is the limiting factor on the amount of dolomite and the excess magnesium and iron are calculated as ferroan. The second assumption eliminates the need for distinguishing between the proportions of magnesium and iron in dolomite and ferroan.

Application of the technique is illustrated in the following two examples, one for a sample containing calcite and one for a sample containing ferroan.

Example 1 (sample 79), calcite present:

<u>Analyses</u>	<u>Weight-percent</u>
Water-soluble sodium.....	7.5
Acid-soluble sodium.....	.66
Acid-soluble calcium.....	7.76
Acid-soluble magnesium.....	2.91
Acid-soluble iron.....	.84

Nahcolite - $NaHCO_3$

$$7.5 \text{ weight-percent Na} \times 3.654 \text{ (gravimetric factor)}$$

$$= 27.4 \text{ weight-percent nahcolite.}$$

Dawsonite - $NaAl(OH)_2CO_3$

$$0.66 \text{ weight-percent Na} \times 6.263 \text{ (gravimetric factor)}$$

$$= 4.13 \text{ weight-percent dawsonite.}$$

Dolomite - $(\text{Mg}_{1-x}\text{Fe}_x)\text{Ca}(\text{CO}_3)_2$

$$\frac{\text{Weight-percent}}{\text{Atomic weight cation}} = \text{Mole fraction of cation.}$$

$$\text{MF Ca} = 0.1936$$

$$\text{MF Mg} = 0.1197$$

$$\text{MF Fe} = 0.0150$$

$$\frac{\text{MF cation} \times \text{MW cation}}{\text{MF Mg} + \text{MF Fe}} = \text{MW of the cation in dolomite.}$$

21.60 MW Mg_{1-x} is the contribution of magnesium to the molecular weight dolomite.

6.23 MW Fe_x is the contribution of iron to the molecular weight or dolomite.

The molecular weight of dolomite for this sample is as follows:

$$\begin{array}{rcl} \text{MW Ca} & = & 40.08 \\ \text{MW Fe}_{0.22} & = & 6.23 \\ \text{MW Mg}_{0.78} & = & 21.60 \\ \text{MW } 2\text{CO}_3 & = & 120.02 \\ \hline \text{MW dolomite} & = & 187.93 \end{array}$$

$$\begin{aligned} (0.1197 \text{ MF Mg} + 0.0150 \text{ MF Fe}) \times 187.93 \text{ MW dolomite} \\ = 25.3 \text{ weight-percent dolomite.} \end{aligned}$$

Calcite - CaCO_3

$$\begin{aligned} 0.1936 \text{ MF Ca} - (0.1197 \text{ MF Mg} + 0.0150 \text{ MF Fe}) \times 100.09 \text{ MW calcite} \\ = 5.9 \text{ weight-percent calcite.} \end{aligned}$$

Carbonate minerals in this sample are

	<u>Weight-percent</u>
Nahcolite - NaHCO_3	27.4
Dawsonite - $\text{NaAl}(\text{OH})_2\text{CO}_3$	4.13
Dolomite - $(\text{Mg}_{0.78}\text{Fe}_{0.22})\text{Ca}(\text{CO}_3)_2$	25.3
Calcite - CaCO_3	5.9
Ferroan - $(\text{Mg}_{1-x}\text{Fe}_x)\text{CO}_3$	0.0

Example 2 (sample 34), ferroan present:

<u>Analyses</u>	<u>Weight-percent</u>
Water-soluble sodium.....	3.2
Acid-soluble sodium.....	0.60
Acid-soluble calcium.....	3.62
Acid-soluble magnesium.....	2.45
Acid-soluble iron.....	1.11

Nahcolite - NaHCO_3

3.2 weight-percent Na \times 3.654 = 11.7 weight-percent nahcolite.

Dawsonite - $\text{NaAl(OH)}_2\text{CO}_3$

0.60 weight-percent Na \times 6.263 = 3.76 weight-percent dawsonite.

Dolomite - $(\text{Mg}_{1-x}\text{Fe}_x)\text{Ca}(\text{CO}_3)_2$

$$\text{MF Ca} = 0.0903$$

$$\text{MF Mg} = 0.1008$$

$$\text{MF Fe} = 0.0199$$

20.30 MW Mg_{1-x} is the contribution of magnesium to the molecular weight of dolomite and ferroan.

9.21 MW Fe_x is the contribution of iron to the molecular weight of dolomite and ferroan.

Calculated molecular weight of dolomite:

MW	=	40.08
MW $\text{Mg}_{0.69}$	=	20.30
MW $\text{Fe}_{0.31}$	=	9.21
MW 2CO_3	=	120.02
<hr/>		
MW dolomite	=	189.61

0.0903 MF Ca \times 189.61 MW dolomite = 17.1 weight-percent dolomite.

Ferroan - $(\text{Mg}_{1-x}\text{Fe}_x)\text{CO}_3$

As stated in the second assumption, the ratio of magnesium to iron is the same in ferroan as in dolomite. Therefore, the calculated molecular weight of ferroan is as follows:

MW $\text{Mg}_{0.69}$	=	20.30
MW $\text{Fe}_{0.31}$	=	9.21
MW CO_3	=	60.01
<hr/>		
MW ferroan	=	89.52

The weight-percent ferroan is as follows:

$$(0.1008 \text{ MF Mg} + 0.0199 \text{ MF Fe} - 0.0903 \text{ MF Ca})(89.52) = 2.70 \text{ weight-percent ferroan.}$$

Carbonate minerals for this sample are as follows:

	<u>Weight-percent</u>
Nahcolite.....	11.7
Dawsonite.....	3.76
Dolomite.....	17.1
Calcite.....	0.0
Ferroan.....	2.7

The results of the carbonate mineral calculations on 219 samples are shown in table A-1. Nahcolite and dawsonite values are rounded as proposed by Smith and Young (14). Calcite, dolomite, and ferroan are reported to the first decimal place.

The carbon dioxide released by acid treatment of the carbonates can be computed from the calculated mineral amounts. This involves multiplication of the calculated weight-percent of the mineral by an appropriate gravimetric factor. For nahcolite, dawsonite, and calcite, this gravimetric factor is the same for all samples. However, for dolomite and ferroan, the gravimetric factor varies with each sample. The results of example 2 are used to demonstrate CO₂ calculations:

Nahcolite - 11.7 weight-percent	$\times 0.5239$	= 6.1 weight-percent CO ₂
Dawsonite - 3.76 weight-percent	$\times 0.3056$	= 1.1 weight-percent CO ₂
Calcite - 0.0 weight-percent	$\times 0.4397$	= 0.0 weight-percent CO ₂
Dolomite - 17.1 weight-percent	$\times \frac{88.02 \text{ MW } 2\text{CO}_2}{189.61 \text{ MW dolomite}}$	= 7.9 weight-percent CO ₂
Ferroan - 2.7 weight-percent	$\times \frac{44.01 \text{ MW CO}_2}{89.52 \text{ MW ferroan}}$	= 1.3 weight-percent CO ₂
Total CO ₂		16.4 weight-percent CO ₂

Table A-4 shows the results of the CO₂ calculations for the 219 samples.

EVALUATION OF MINERAL CARBONATE BALANCE

Validity of the carbonate quantities calculated and consequently the validity of the two assumptions required for the calculation were tested by two methods. The first method involved comparing the calculated carbonate quantities with X-ray diffraction responses specific for each mineral. The second method involved comparing the sum of the CO₂ available from the calculated amounts of the individual carbonate minerals with the amount of CO₂ analytically determined on each sample.

First Method

X-ray diffraction responds specifically to individual minerals, and the response is largely independent of the rest of the sample. The presence of a mineral in amounts above its detection limit is demonstrated by a definite X-ray diffraction peak. In addition, peak heights measured from X-ray diffraction corresponds to relative amounts of the individual minerals. These facts were used to test the calculation procedures for carbonate minerals.

The first assumption implies that calcite and ferroan do not form together in the same oil-shale layer. However, inspection of peak heights for calcite (table A-2) and ferroan (table A-3) shows that both were detected in 18 of the 219 samples. Although these 18 samples represent a small part of the total number of samples, the detection of both calcite and ferroan together is a direct contradiction of the first assumption. Reasons for this will be discussed later.

Peak heights of individual minerals measured by X-ray diffraction provide an evaluation of relative amounts of the carbonates independent of the analytical and calculation procedures. Consequently, the peak heights measured for each mineral were compared statistically with the calculated amounts for each mineral. Standard linear and multiple linear regression techniques were used (1, 5). Results of this comparison for each mineral are presented with an explanation of the selection of samples used for the comparison.

Nahcolite

Of the 219 samples analyzed, only 118 were used to compare the determined weight-percent nahcolite with peak height by X-ray diffraction. Water-soluble sodium, found in all samples, was calculated as nahcolite (table A-1); however, X-ray diffraction detected nahcolite in only 94 samples (table A-2). Of the remaining 125 samples, 120 contained less than 1 weight-percent nahcolite by analysis. The nahcolite content of these samples is apparently below the detection limit of X-ray diffraction. To prevent the distribution bias that would result if all of these samples were included, two representative groups were selected. These were samples 15 through 94 and samples 139 through 176. All samples in these two groups, a total of 118 samples, were used for statistical comparison.

Linear regression on these results yielded the following equation:

$$Y = 1.440 + 0.207X, \quad (1)$$

where X = peak height for nahcolite

and Y = weight-percent nahcolite.

Averages for the variables and the coefficient of determination (R^2) and the standard error of estimate (S) were $\bar{X} = 62.5$, $\bar{Y} = 14.37$ weight-percent, $N = 118$, $R^2 = 0.87$, and $S = 4.86$. The coefficient of determination (R^2), indicating the fraction of variation in peak height associated with variation

in mineral amounts, is sufficiently high for the equation to be useful as a predictor for nahcolite amounts.

Dawsonite

All 219 samples contain acid-soluble sodium calculated as dawsonite (table A-1), and dawsonite was detected by X-ray diffraction in 172 samples (table A-2). Forty-seven samples showing no dawsonite by X-ray diffraction were not included in the linear regression analysis to minimize the bias they would introduce into the lower end of the dawsonite range. The resulting linear equation is:

$$Y = 1.106 + 0.092X, \quad (2)$$

where X = peak height of dawsonite by X-ray diffraction

and Y = weight-percent dawsonite,

with $\bar{X} = 55.07$,

$\bar{Y} = 6.204$ weight-percent,

$N = 172$,

$R^2 = 0.76$,

and $S = 1.52$.

The coefficient of determination (R^2) is considered sufficiently good for the equation to be used as a predictor for dawsonite content in Green River oil shale.

Dolomite

Dolomite was found in all 219 samples by both X-ray diffraction and chemical analysis (table A-3). The apparent interaction of dolomite, nahcolite, and quartz peaks in X-ray diffraction was corrected for in the following multi-variable linear equation by regression:

$$Y = 10.097 + 0.229X_1 - 0.075X_2 - 0.037X_3, \quad (3)$$

where X_1 = X-ray diffraction peak height of dolomite,

X_2 = X-ray diffraction peak height of nahcolite,

X_3 = X-ray diffraction peak height of quartz,

and Y = weight-percent dolomite.

Statistical constants from this regression include $\bar{X}_1 = 86.12$, $\bar{X}_2 = 33.69$, $\bar{X}_3 = 114.22$, $\bar{Y} = 23.025$ weight-percent, $N = 219$, $R^2 = 0.83$, and $S = 2.54$. T

coefficient of determination is considered sufficiently good for the equation to be used as a predictor for dolomite in Green River oil shale. A plot of dolomite from analysis to dolomite estimated from X-ray diffraction peak heights using equation 3 is shown on figure 2. The equation relating these values (shown on fig. 2) is very close to the ideal one-to-one equation.

Calcite

Forty-five samples were used to evaluate correspondence between the two methods. In these samples calcite was detected by both methods. The other

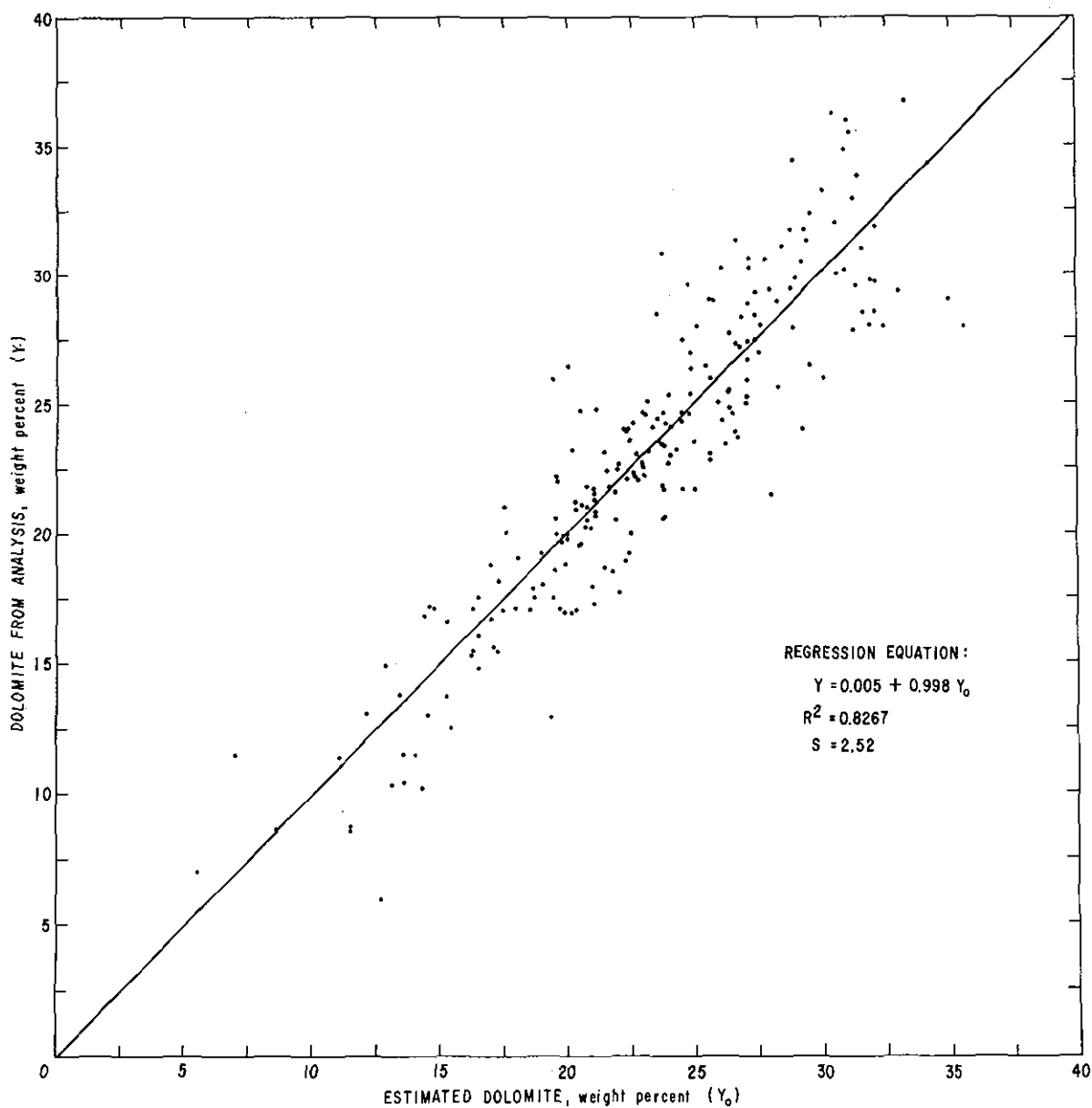


FIGURE 2. - Relationship of dolomite from analysis to dolomite estimated from X-ray diffraction.

samples were eliminated to avoid introducing a statistical bias created by massing points at the lower end.

$$Y = 0.900 + 0.153X, \quad (4)$$

where X = X-ray diffraction peak height of calcite

and Y = weight-percent calcite.

The statistical factors from this regression include $\bar{X} = 20.84$, $\bar{Y} = 4.096$ weight-percent, $N = 45$, $R^2 = 0.28$, and $S = 2.34$.

Because R^2 is relatively small, a Z test was done to determine its significance. The method involves transforming the value R into a value Z whose distribution is normal and whose standard error is $\sigma_z = \frac{1}{\sqrt{N-3}}$, where N is the number of samples (1). The probability of R (and Z) being zero requires only referring the ratio $\frac{Z}{\sigma_z}$ to a table of normal curve areas expressed as functions of standard deviations. After the necessary calculations, $\frac{Z}{\sigma_z}$ is determined as 3.78. The table of normal distributions shows there are 2 chances out of 10,000 that R^2 is not significant. Although the equation does not fit well enough to be used as a predictor for calcite, both methods are measuring the same thing--the amount of calcite. A plot of calcite from analysis to calcite estimated from X-ray diffraction peak heights using equation 4 is shown on figure 3. The equation relating these values (shown on fig. 3) is very close to the ideal one-to-one equation.

Ferroan

Of the 219 samples, ferroan was detected in 88 samples by both X-ray diffraction and calculation from chemical analysis (table A-3). Only samples showing ferroan by both methods were used in the statistical comparison to avoid introduction of distribution bias. Ferroan, like dolomite, showed some apparent interaction from an adjacent X-ray diffraction peak, a secondary dawsonite peak. The following two-variable linear equation was generated by regression analysis.

$$Y = -0.347 + 0.176X_1 - 0.041X_2, \quad (5)$$

where X_1 = X-ray diffraction peak height of ferroan,

X_2 = X-ray diffraction peak height of dawsonite,

and Y = weight-percent ferroan.

The statistical constants include $\bar{X}_1 = 17.36$, $\bar{X}_2 = 14.89$, $\bar{Y} = 2.099$ weight-percent, $N = 88$, $R^2 = 0.55$, and $S = 1.04$.

As with calcite, a Z test was used to determine the probability that the apparent correlation might be zero. The $\frac{Z}{\sigma_z}$ ratio is 8.79. The probability is substantially less than 1 in 10,000 that no correlation exists between the ferroan peak height and the calculated amount of ferroan. Although equation 5 does not fit well enough to be used as a predictor for ferroan, both methods are measuring the amount of ferroan. A plot of ferroan from analysis to ferroan estimated

from X-ray diffraction peak heights using equation 5 is shown on figure 4. The equation relating these values (shown on fig. 4) is very close to the ideal one-to-one equation.

Results of the First Evaluation Method

The significant correlations developed between results of the two independent measurements of the minerals indicate that both are measuring the same thing. Although X-ray diffraction is subject to many variables, the equations relating peak heights to mineral amounts for nahcolite, dawsonite, and dolomite were accurate enough for the peak heights to be used as predictors for estimating mineral amounts. This verified the accuracy of the

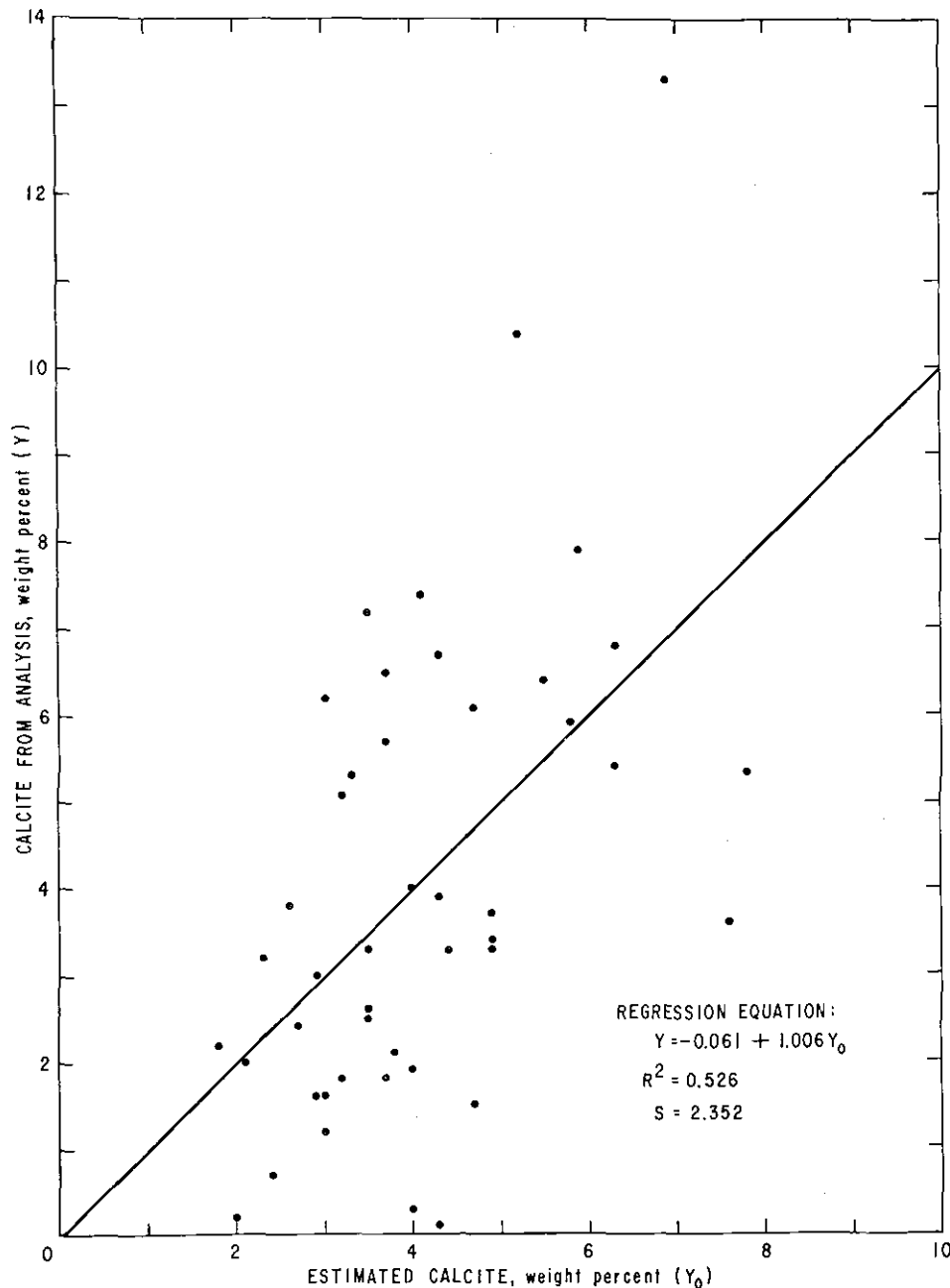


FIGURE 3. - Relationship of calcite from analysis to calcite estimated from X-ray diffraction.

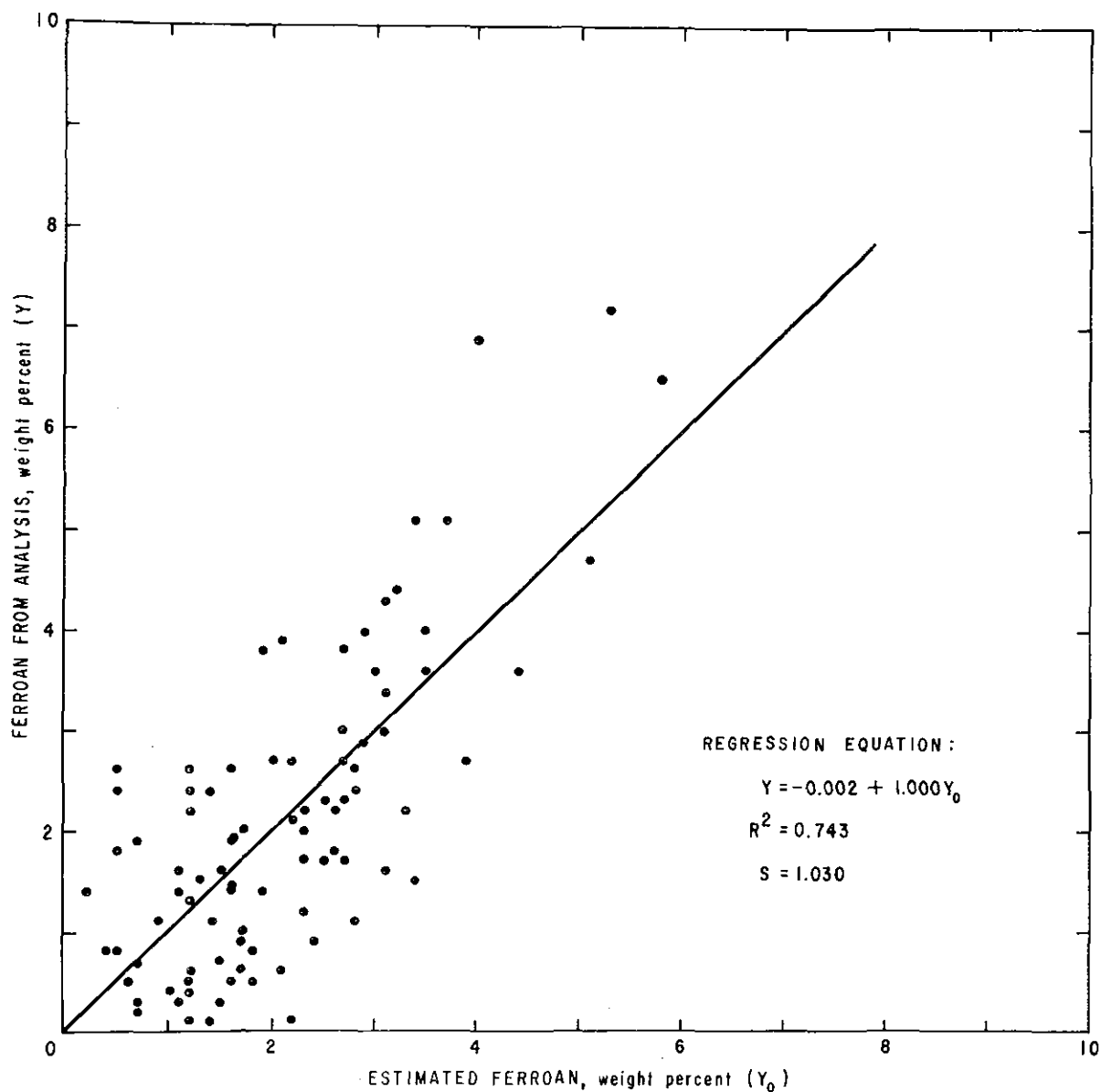


FIGURE 4. - Relationship of ferroan from analysis to ferroan estimated from X-ray diffraction

determined amounts of nahcolite, dawsonite, and dolomite. Calculated values of calcite and ferroan from cation assignment show lower correspondence with X-ray diffraction peak heights. However, the relationships demonstrate significant direct correlations between peak height and the calculated mineral amounts. These correlations demonstrate the validity of the calculated mineral amounts, but the lower values point out that their accuracy is substantially lower.

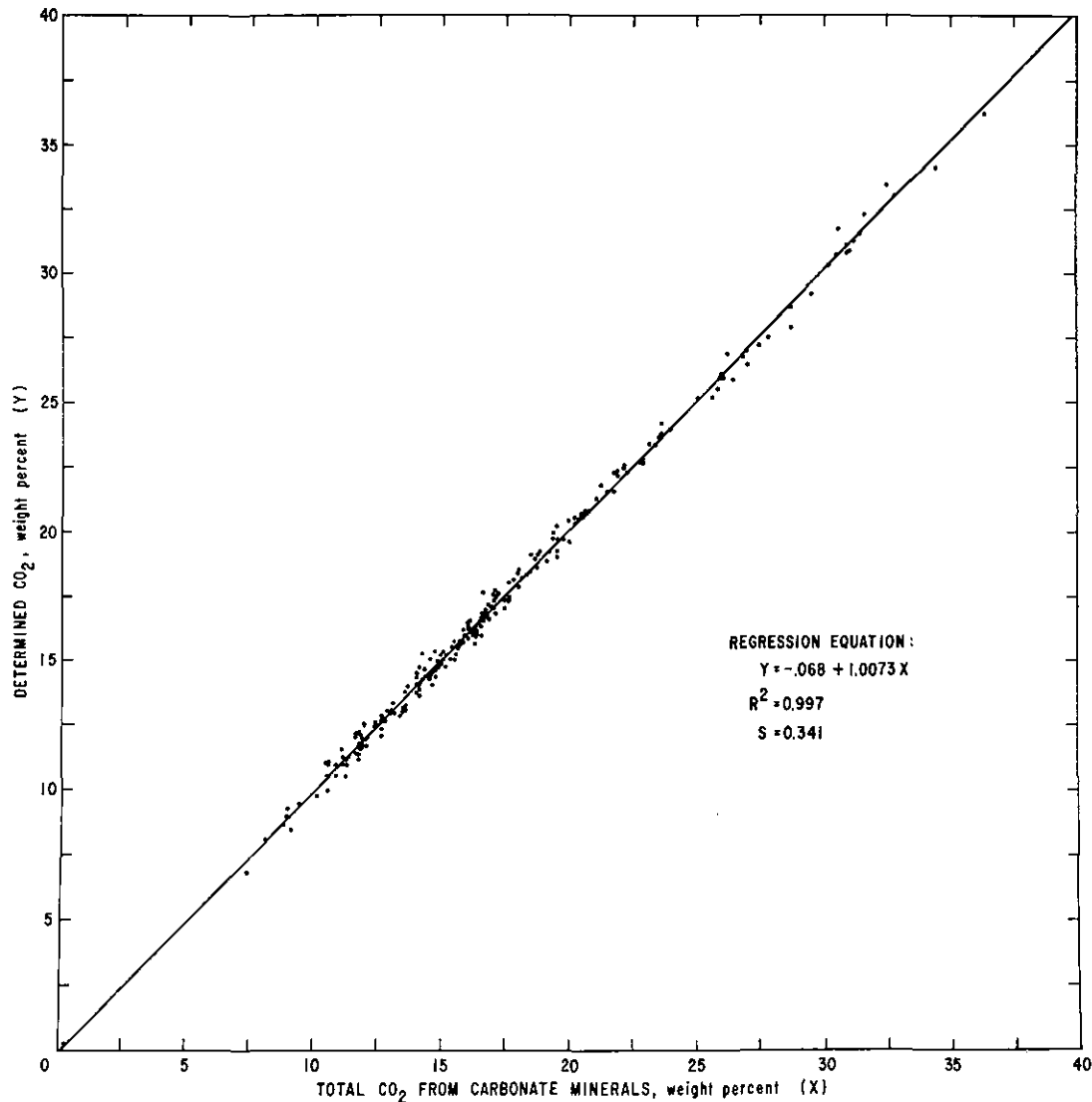


FIGURE 5. - Relationship of CO₂ from determined carbonate minerals to determined CO₂.

Second Method

The second method tests that all the cations from water and acid treatment are from carbonate minerals and test the assignment of all cations to the carbonate minerals. This method compares the total CO₂ calculated from carbonate minerals with the total CO₂ determined by a standard analytical method (4). Data for this comparison is given in table A-4. Linear regression analysis of the results of 219 samples gave the equation:

$$Y = -0.068 + 1.007X, \quad (6)$$

where X = weight-percent total CO_2 calculated from carbonate minerals

and Y = weight-percent determined CO_2 ,

with \bar{X} = 17.41 weight-percent,

\bar{Y} = 17.47 weight-percent,

N = 219,

R^2 = 0.997,

and S = 0.341.

A plot of the data points from table A-4 and the line representing the equation are shown on figure 5, graphically illustrating the high degree of correlation. This demonstrates that the calculated content of carbonate minerals corresponds precisely to the total carbonate content of these samples.

DISCUSSION

The technique presented gives a good measure of the carbonate mineral composition of the saline section of the Green River oil shale. The method also accounts for virtually all the carbon dioxide determined from oil shale. Two of the five major carbonate minerals are determined directly by their sodium content--nahcolite, from water-soluble sodium, and dawsonite, from acid-soluble sodium. Smith and Young (14) have demonstrated the validity of these determinations.

The other three carbonate minerals are calculated from the determined iron, calcium, and magnesium based on two assumptions that warrant discussion. The first was that when ferroan is present, calcite is not present. Smith and Robb (12) describe the conditions necessary for the formation and deposition of dolomite, calcite, and aragonite. They state that dolomite was formed by dolomitization of aragonite and calcite. Sufficient iron and magnesium must be present for complete dolomitization of all the calcium carbonate minerals or some calcite would remain. If an excess of iron and magnesium were present after complete dolomitization, ferroan would be formed. The validity of this assumption is bolstered by X-ray diffraction analyses on literally thousands of oil-shale samples representing thicknesses of 1 foot or less, indicating ferroan and calcite are not deposited together.

Why then are ferroan and calcite detected together by X-ray diffraction in 18 of the 219 samples? The explanation is that the samples represent thicknesses of approximately 10 feet. If the samples investigated were limited to one season's layer, 20 to 30 micrometers (2, 9), the assumption would be valid. A 10-foot sample, however, represents thousands of depositional cycles with varying depositional conditions. Consequently, the assumption can only approximate the composition of a 10-foot sample. Although the assumption is not perfect, it is reasonably valid because the ferroan and calcite amounts correlated significantly with the X-ray diffraction peak heights.

The second assumption that the mole fraction ratio of magnesium to iron is the same in dolomite as it is in ferroan may or may not be true. Even if it is untrue, the total effect on carbonate balance is small. The assumption is usable as indicated by the high degree of correlation between X-ray diffraction peak height and the calculated weight-percent dolomite. Although the correlation for ferroan is not as good as that of dolomite, the Z test proves that ferroan is being measured by both X-ray diffraction and calculation from determined cations.

The high correlation demonstrated between the amounts of CO_2 calculated from the cation values and the amounts of CO_2 actually released by acid treatment (fig. 5) is solid proof that the acid-soluble cations arise only from carbonate minerals. It also demonstrates that all the carbonate minerals are being accounted for. However, if the deviations between the determined and calculated CO_2 values given in table A-4 are averaged, a small negative bias is detected. The determined CO_2 is 0.056 weight-percent higher than the calculated CO_2 . The intercept constant (-0.068) in equation 6 also indicates the same discrepancy. This bias probably represents the average amounts of trace metals present in the carbonates. Strontium (to 0.06 weight-percent) and manganese (to 0.03 weight-percent) appear to account for most of this bias.

Interferences in determination of carbonate minerals may be caused by halite (NaCl), analcime ($\text{NaAlSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$), and epigenetic calcite. Halite occurrence is restricted both geographically and stratigraphically (15). Halite occurs in alternating bands (up to 5 or 6 inches) in zones up to 65 feet thick in the northern part of the Piceance Creek Basin (15). Halite was determined and reported in sample set 1 (samples 1 through 106) by Smith and Young (14). This mineral can be easily detected by X-ray diffraction analysis. If undetected, halite yielding water-soluble sodium would result in high nahcolite values.

Analcime occurs rarely in the saline section, although it is common in the sections not bearing dawsonite. Analcime yields acid-soluble sodium that would be calculated as dawsonite (14). Analcime did not occur in any of the samples analyzed for this report. X-ray diffraction examination of analyzed samples will protect against this interference in carbonate mineral determination.

Epigenetic calcite is the third interference that may be encountered. This is calcite deposited from solution in fractures of the rock through which the solution is percolating. Presence of secondary calcite may override the geochemistry on which the assumptions were made. Results of carbonate mineral calculations when secondary calcite is present are an increase in the amount of dolomite and a decrease in the amount of ferroan. Secondary calcite is not common in the saline section but may occur where the deposit has been contorted or uplifted. Secondary calcite can be detected by visual examination of the rock. X-ray diffraction analysis cannot detect the difference between primary and secondary calcite. Interference by secondary calcite can be suspected when ferroan is detected by X-ray diffraction but is absent in carbonate mineral calculation. The high calcite values calculated in sample set 3 (samples 182 through 219) may represent epigenetic calcite.

CONCLUSIONS

Nahcolite and dawsonite are determined from water-soluble sodium and acid-soluble sodium, respectively, by accepted chemical methods. Dolomite, calcite, and ferroan are calculated from determined calcium, magnesium, and iron based on two assumptions. First, if calcite is present, ferroan is not present; and second, the ratio of magnesium to iron is the same in both dolomite and ferroan.

Statistical comparison of individual carbonate mineral amounts with their respective X-ray diffraction peak heights proves that the same thing is being measured by both methods. Statistical comparison of the carbon dioxide available from the carbonate minerals for each sample with the chemically determined carbon dioxide shows a high degree of agreement. Therefore, the assumptions are of such validity that they are usable, without X-ray diffraction, for the determination of the carbonate minerals found in the saline section of Green River Formation oil shale in Colorado's Piceance Creek Basin.

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APPENDIX

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ^s	Na ^s	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
1	0.07	0.08	6.58	3.30	0.72	0.26	0.50	27.8	1.6	-
2	.08	.07	3.84	2.00	.66	.29	.44	17.7	.2	-
3	.08	.10	5.74	2.98	.74	.29	.63	25.5	.7	-
4	.07	.09	7.56	3.70	.66	.26	.56	30.6	2.5	-
5	.08	.10	6.56	3.58	.84	.29	.63	30.4	.1	-
6	.13	.15	5.26	3.12	1.76	.48	.94	25.0	-	2.6
7	.16	.28	4.50	2.32	2.06	.58	1.75	21.7	-	1.9
8	.09	.11	6.25	2.85	1.88	.33	.69	28.9	.5	-
9	.11	.14	4.23	3.00	1.40	.40	.88	20.0	-	3.8
10	.09	.09	6.79	3.78	.78	.33	.56	31.7	-	-
11	.14	.09	6.89	4.34	.52	.51	.56	32.0	-	1.4
12	.14	.09	7.25	3.95	.76	.51	.56	32.9	.5	-
13	.20	.14	6.64	4.11	.92	.73	.88	31.0	-	1.7
14	.20	.75	5.26	3.57	.84	.73	4.70	24.6	-	2.7
15	1.08	.82	4.23	2.58	1.24	3.95	5.14	20.0	-	2.0
16	.18	.74	5.12	2.94	1.66	.66	4.63	24.3	-	2.1
17	.78	.74	5.79	2.78	1.45	2.85	4.63	26.7	.4	-
18	.13	.88	6.06	2.85	1.58	.48	5.51	27.7	.6	-
19	.22	.60	6.92	3.45	1.58	.80	3.76	32.3	.2	-
20	6.0	.60	6.29	2.83	1.14	21.9	3.76	25.9	2.0	-
21	3.9	.56	5.84	2.79	1.22	14.3	3.51	25.9	.9	-
22	4.0	.70	5.33	2.50	1.24	14.6	4.38	23.8	.8	-
23	3.6	.47	5.08	2.36	1.11	13.2	2.94	22.2	1.0	-
24	.14	1.16	6.06	2.46	1.56	.51	7.26	24.7	2.2	-
25	.85	1.38	5.64	2.69	1.56	3.11	8.64	26.4	.2	-
26	.20	.73	5.80	2.86	1.21	.73	4.57	26.4	.5	-
27	.30	.98	6.91	2.96	1.24	1.10	6.14	27.2	2.8	-
28	1.90	1.10	5.12	2.55	1.62	6.94	6.89	24.4	-	.6
29	2.2	.82	7.40	3.12	1.35	8.0	5.14	28.9	3.2	-
30	3.5	1.08	6.30	2.90	1.13	12.6	6.76	26.4	1.8	-
31	8.7	.69	5.14	2.37	.88	31.8	4.32	21.4	1.5	-
32	3.9	.91	5.23	2.64	1.31	14.4	5.70	24.8	-	.1
33	3.1	.47	5.06	3.04	1.26	11.3	2.94	23.9	-	1.9
34	3.2	.60	3.62	2.45	1.11	11.7	3.76	17.1	-	2.7
35	.29	.88	2.12	1.89	1.68	1.06	5.51	10.2	-	5.1
36	9.0	1.22	2.38	1.68	1.22	32.6	7.64	11.4	-	2.9
37	11.4	.45	3.81	2.50	.92	39.6	2.82	17.9	-	2.2
38	4.1	.16	1.24	.70	.34	15.0	1.00	5.9	-	.4
39	9.8	.24	1.84	1.20	.63	35.8	1.50	8.7	-	1.3
40	2.8	.12	4.35	2.82	1.08	6.8	.75	20.5	-	2.4
41	9.0	.14	4.78	2.48	.69	32.9	.88	21.5	-	.5

See footnotes at end of table.

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation--Continued

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ²	Na ³	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
42	7.1	1.23	4.42	2.36	1.26	15.5	7.70	21.0	-	0.8
43	9.6	.96	4.64	2.57	1.34	34.9	6.01	22.0	-	1.3
44	6.1	.70	4.46	2.30	.96	22.1	4.38	21.1	-	-
45	14.4	.66	2.58	1.22	.57	52.7	4.13	11.5	0.4	-
46	2.1	1.12	4.89	2.91	1.57	7.7	7.01	23.2	-	2.3
47	7.5	1.26	3.94	2.25	1.40	27.4	7.89	18.8	-	1.8
48	1.08	1.64	4.84	2.76	2.03	3.95	10.27	23.2	-	2.7
49	6.7	.82	6.72	2.98	1.26	24.5	5.14	27.5	2.3	-
50	.84	1.45	5.77	3.27	1.57	3.07	9.08	27.3	-	1.7
51	.64	1.36	6.35	3.21	1.33	2.34	8.52	29.5	.3	-
52	5.7	1.04	5.96	3.14	1.02	20.8	6.51	27.8	.1	-
53	5.6	.92	4.72	2.60	1.15	20.5	5.76	22.3	-	.9
54	9.8	.74	5.36	2.56	.76	35.8	4.63	22.4	1.5	-
55	11.7	.74	4.36	2.08	.62	42.8	4.63	18.2	1.2	-
56	14.6	.58	3.46	1.76	.40	53.3	3.63	14.9	.7	-
57	5.4	1.46	3.60	2.10	1.19	19.7	9.14	17.1	-	1.6
58	2.7	1.46	4.26	2.65	1.36	9.9	9.14	20.2	-	2.4
59	6.5	1.10	5.20	2.68	.98	23.8	6.89	24.1	.2	-
60	4.1	1.21	5.36	2.44	.96	15.0	7.58	22.2	1.6	-
61	4.6	1.48	4.37	1.70	.82	16.8	9.27	16.1	2.4	-
62	3.9	1.44	5.06	1.92	.87	14.1	9.02	17.9	3.2	-
63	3.2	1.58	4.92	2.22	1.14	11.6	9.90	21.2	1.1	-
64	.87	1.58	4.89	1.95	1.12	3.18	9.90	19.1	2.2	-
65	.14	.96	4.35	.80	.66	.51	6.01	8.6	6.4	-
66	7.9	.88	3.76	1.27	.47	28.7	5.51	11.5	3.3	-
67	4.1	1.25	5.51	2.72	1.02	15.0	7.83	24.6	.7	-
68	4.5	1.59	3.66	1.96	1.31	16.5	9.96	17.5	-	1.2
69	2.8	1.85	4.70	2.42	1.40	10.3	11.59	22.4	-	.7
70	2.6	1.40	4.10	2.54	1.32	9.5	8.77	19.5	-	2.3
71	9.1	.85	3.25	1.77	.66	33.3	5.32	15.3	-	.3
72	3.8	1.62	3.70	2.00	.93	13.7	10.15	17.5	-	.6
73	.06	1.46	5.92	2.51	1.34	.22	9.14	24.2	2.0	-
74	.08	1.00	4.08	2.26	.90	.29	6.26	19.2	-	.6
75	.06	1.08	2.85	2.09	1.79	.22	6.76	13.7	-	4.4
76	.07	2.14	2.13	2.04	2.16	.26	13.40	10.3	-	6.5
77	.12	2.13	5.14	2.85	1.98	.44	13.34	24.6	-	2.2
78	2.2	1.59	5.76	2.63	1.34	8.0	9.96	25.1	1.2	-
79	7.5	.66	7.76	2.91	.84	27.4	4.13	25.3	5.9	-
80	10.0	.56	5.44	2.13	.65	36.5	3.51	18.7	3.7	-
81	4.7	1.10	5.94	2.43	.86	17.1	6.89	21.8	3.3	-
82	7.1	.97	3.23	1.82	1.00	25.9	6.08	15.4	-	1.1
83	11.2	.76	4.26	1.88	.76	40.9	4.76	17.2	1.5	-
84	10.3	.71	4.34	2.20	.84	37.6	4.45	19.9	.3	-

See footnotes at end of table.

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation--Continued

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ²	Na ³	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
85	6.0	0.62	4.82	2.66	0.88	21.9	3.88	22.7	-	0.4
86	9.9	.41	3.12	1.90	.91	36.3	2.57	14.8	-	1.5
87	4.6	.91	5.62	2.55	1.12	16.8	5.70	23.7	1.5	-
88	5.6	1.18	4.31	1.78	.92	20.5	7.39	17.1	1.8	-
89	.09	1.30	4.82	2.44	1.48	.33	8.14	23.0	-	.6
90	.06	1.18	4.92	3.15	1.96	.22	7.39	23.5	-	3.8
91	.14	1.79	2.58	1.96	2.10	.51	11.21	12.5	-	5.1
92	5.6	1.24	3.76	2.00	1.57	20.5	7.77	18.0	-	1.5
93	.60	1.24	6.41	2.98	1.48	2.19	7.77	28.3	1.1	-
94	.32	1.18	6.37	2.91	1.12	1.17	7.39	26.4	1.9	-
95	.05	1.36	7.08	3.06	1.23	.18	8.52	28.0	2.9	-
96	.04	.80	5.14	2.66	1.00	.15	5.01	24.0	.1	-
97	.12	.68	3.54	2.12	1.63	.44	4.26	17.0	-	2.6
98	.06	.11	7.78	3.52	.50	.22	.69	28.6	4.0	-
99	.12	.11	4.38	2.52	.84	.44	.69	20.6	-	.8
100	.11	.06	6.54	2.72	.76	.40	.38	23.6	3.8	-
101	.20	.25	5.74	1.84	1.56	.73	1.57	20.0	4.0	-
102	.15	.10	4.30	2.12	1.29	.55	.63	20.5	-	.3
103	.18	.25	2.86	1.32	1.23	.66	1.57	13.8	-	.5
104	.22	.08	4.54	2.12	1.74	.80	.50	21.8	-	.5
105	.16	.09	5.62	2.58	.80	.58	.56	22.7	2.0	-
106	.16	.07	4.19	1.49	.46	.58	.44	13.1	3.5	-
107	.03	.09	5.45	3.20	.58	.11	.56	25.4	-	.5
108	.02	.07	7.81	3.68	.58	.07	.44	30.2	3.3	-
109	.02	.10	7.76	3.63	.58	.07	.63	29.8	3.4	-
110	.02	.10	5.14	3.44	.70	.07	.63	24.0	-	2.2
111	.02	.22	5.18	2.71	.87	.07	1.38	23.9	.2	-
112	.02	.07	6.96	4.27	.59	.07	.44	32.3	-	1.1
113	.01	.06	6.42	3.77	.38	.04	.38	29.7	-	.1
114	.01	.07	6.13	4.08	.70	.04	.44	28.5	-	2.4
115	.03	.12	4.84	3.52	1.20	.11	.75	22.8	-	4.0
116	.02	.12	5.34	2.96	1.49	.07	.75	25.3	-	1.4
117	.02	.08	5.14	2.70	1.30	.07	.50	24.3	-	.5
118	.02	.12	7.76	3.46	1.26	.07	.75	31.1	2.9	-
119	.01	.10	8.08	3.57	1.08	.04	.63	31.3	3.5	-
120	.02	.23	6.16	3.34	1.28	.07	1.44	29.0	-	.6
121	.03	.36	4.94	2.49	1.22	.11	2.25	23.4	-	.1
122	.03	.70	4.57	2.38	1.34	.11	4.38	21.7	-	.7
123	.03	.74	5.47	2.81	1.26	.11	4.63	25.9	-	.1
124	.04	.98	5.18	2.55	1.53	.15	6.14	24.7	-	.3
125	1.24	1.06	6.52	3.11	1.14	4.53	6.64	28.0	1.4	-
126	.04	1.04	7.24	3.38	1.02	.15	6.51	29.6	2.3	-
127	.04	.71	4.16	2.30	1.06	.15	4.45	19.7	-	.9

See footnotes at end of table.

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation--Continued

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ²	Na ³	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
128	0.03	0.09	4.70	2.60	0.81	0.11	0.56	22.1	-	0.4
129	.04	.69	3.56	2.56	1.56	.15	4.32	17.0	-	4.0
130	.06	.98	4.26	2.60	1.46	.22	6.14	20.3	-	2.4
131	.04	.10	5.75	3.26	1.00	.15	.63	27.0	-	.8
132	.07	.24	5.68	3.30	1.52	.26	1.50	26.9	-	1.9
133	.76	.98	5.15	2.41	.88	2.78	6.14	21.7	1.4	-
134	.05	1.48	4.68	2.91	1.44	.18	9.27	22.2	-	2.6
135	.04	.94	3.55	2.47	1.65	.15	5.89	17.0	-	3.9
136	.05	1.86	4.66	2.83	2.16	.18	11.65	22.4	-	3.6
137	.05	1.26	5.80	3.56	1.56	.18	7.89	27.4	-	2.7
138	.05	1.19	6.40	3.54	1.40	.18	7.48	30.2	-	1.0
139	1.56	.74	5.46	3.14	1.11	5.70	4.63	25.7	-	1.1
140	1.50	1.32	6.63	3.24	.99	5.48	8.27	28.4	1.4	-
141	.05	1.08	6.92	3.47	.94	.18	6.76	30.0	1.3	-
142	3.0	1.30	3.92	2.42	1.28	11.0	8.14	18.6	-	2.2
143	.05	1.80	4.92	3.22	1.32	.18	11.27	23.2	-	3.0
144	.04	1.47	6.38	3.34	1.06	.15	9.21	29.4	.3	-
145	.97	1.55	5.11	2.33	.78	3.54	9.71	20.7	1.8	-
146	5.1	1.12	4.07	1.87	.96	18.6	7.01	17.9	.7	-
147	.06	1.53	5.43	1.22	.98	.22	9.58	13.0	6.8	-
148	1.17	1.18	4.54	1.92	.77	4.28	7.39	17.5	2.1	-
149	.88	1.44	5.45	2.66	1.02	3.22	9.02	24.1	.8	-
150	1.86	1.46	4.81	2.68	1.12	6.80	9.14	22.7	-	.9
151	.07	1.89	5.24	3.10	1.42	.26	11.84	24.8	-	2.0
152	.74	1.48	4.20	2.72	1.48	2.70	9.27	20.0	-	3.0
153	1.65	1.26	3.54	2.05	1.23	6.03	7.89	16.9	-	1.6
154	1.82	1.56	3.27	2.10	1.16	6.65	9.78	15.5	-	2.3
155	.16	1.25	6.72	3.11	.98	.58	7.83	27.4	2.2	-
156	.07	1.10	2.42	1.71	1.04	.26	6.89	11.5	-	2.6
157	.08	2.54	1.76	1.92	2.25	.29	15.91	8.6	-	7.2
158	1.15	2.50	3.46	2.34	2.23	4.20	15.66	16.7	-	4.7
159	2.8	1.87	4.40	2.46	1.70	10.2	11.71	21.0	-	2.0
160	8.4	.88	7.18	2.69	.82	30.8	5.71	23.6	5.4	-
161	10.9	.68	5.78	1.96	.57	39.8	4.26	17.1	5.3	-
162	6.7	1.04	5.98	2.70	.95	24.5	6.51	24.2	2.1	-
163	7.2	.99	5.57	2.40	.79	26.3	6.20	21.3	2.6	-
164	5.9	1.16	3.28	1.92	1.03	21.6	7.26	15.6	-	1.4
165	9.2	1.00	4.91	2.18	.84	33.6	6.26	19.8	1.8	-
166	9.9	.96	4.84	2.32	.76	36.2	6.01	20.5	1.2	-
167	5.3	1.22	6.33	3.70	1.09	19.3	7.64	29.7	-	1.2
168	5.7	.89	4.88	2.65	1.14	20.8	5.57	23.1	-	.7
169	8.3	.56	3.76	1.80	.84	30.3	3.51	16.9	.5	-
170	.38	1.33	5.50	3.01	1.24	1.39	8.33	26.0	-	.8

See footnotes at end of table.

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation--Continued

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ²	Na ³	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
171	4.7	0.98	4.85	2.55	1.18	17.0	6.14	23.0	-	0.4
172	.05	1.32	4.94	3.22	1.60	.18	8.27	23.4	-	3.4
173	.05	1.22	2.16	2.22	2.06	.18	7.64	10.4	-	6.9
174	10.1	.96	1.42	1.12	1.52	36.9	6.01	6.9	-	3.6
175	.59	1.01	6.21	3.12	1.46	2.16	6.33	29.3	-	-
176	.40	.78	5.96	3.01	1.32	1.46	4.89	27.9	0.1	-
177	.06	.94	6.39	3.06	1.24	.22	5.89	28.0	1.1	-
178	.07	.66	4.14	2.38	1.19	.26	4.13	19.6	-	1.4
179	.13	.16	4.92	2.39	.94	.48	1.00	21.8	.8	-
180	.18	.40	5.01	1.38	1.63	.66	2.51	16.8	3.9	-
181	.19	.12	3.47	1.98	1.26	.69	.75	16.6	-	1.6
182	.05	1.48	6.98	2.96	2.16	.18	9.27	30.8	1.4	-
183	.08	1.60	3.98	2.14	2.07	.29	10.02	18.8	-	2.6
184	.05	1.28	5.92	3.00	2.20	.18	8.02	28.4	-	1.4
185	.08	1.28	6.48	3.48	2.04	.29	8.02	30.6	-	1.7
186	.09	1.41	4.32	2.60	2.20	.33	8.83	20.8	-	3.6
187	.05	1.55	4.94	2.29	2.33	.18	9.71	23.9	-	1.2
188	.08	.60	9.72	4.10	1.46	.29	3.76	36.7	4.8	-
189	.10	.61	8.20	3.72	1.60	.37	3.82	34.4	2.3	-
190	.07	.46	9.03	3.92	1.60	.26	2.88	35.9	3.5	-
191	.06	.24	8.42	4.03	1.45	.22	1.50	36.2	1.8	-
192	.08	.16	8.34	3.76	1.22	.29	1.00	33.2	3.2	-
193	.11	.12	6.78	3.22	1.27	.40	.75	29.3	1.4	-
194	.15	.18	9.38	3.92	1.30	.55	1.13	34.8	5.0	-
195	.10	.16	8.72	3.46	1.02	.37	1.00	30.2	5.7	-
196	.17	.14	6.04	1.66	1.21	.62	.88	17.3	6.1	-
197	.13	.14	8.60	3.17	1.26	.48	.88	28.9	6.2	-
198	.16	.12	8.04	2.38	1.34	.58	.75	23.2	7.9	-
199	.17	.14	6.58	1.82	1.25	.62	.88	18.6	6.7	-
200	.13	.29	6.66	2.68	1.11	.48	1.82	24.6	3.6	-
201	.17	.64	4.58	2.05	1.80	.62	4.01	22.1	-	.2
202	.18	.24	5.77	2.55	1.57	.66	1.50	25.4	1.1	-
203	.16	.21	5.83	2.65	1.34	.58	1.32	25.3	1.2	-
204	.13	.26	5.16	2.26	1.18	.48	1.63	21.7	1.5	-
205	.17	.30	5.92	2.22	1.48	.62	1.88	22.6	3.0	-
206	.12	.56	4.39	2.46	1.56	.44	3.51	20.9	-	1.8
207	.12	.42	5.15	2.66	1.85	.44	2.63	24.6	-	1.3
208	.09	1.23	3.88	1.93	2.44	.33	7.70	18.9	-	2.5
209	.09	1.08	3.96	2.43	2.48	.33	6.76	19.2	-	4.3
210	.11	1.24	5.16	2.42	2.47	.40	7.77	25.0	-	1.4
211	.14	.83	8.75	3.02	2.28	.51	5.20	31.7	5.3	-
212	.14	.30	10.75	3.30	1.62	.51	1.88	31.3	10.4	-
213	.11	.14	12.84	3.99	1.33	.40	.88	35.4	13.3	-

See footnotes at end of table.

TABLE A-1. - Analytical data and calculated component content for samples representing the saline section of the Green River Formation--Continued

Sample	Determined cations, weight-percent ¹					Calculated component values, weight-percent ¹				
	Na ²	Na ³	Ca	Mg	Fe	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan
214	0.08	0.08	8.78	3.27	1.09	0.29	0.50	29.0	6.5	-
215	.12	.08	10.29	3.88	1.27	.44	.50	34.3	7.4	-
216	.10	.08	6.90	2.93	1.46	.37	.50	27.9	2.6	-
217	.12	.10	8.28	3.20	1.32	.44	.63	29.4	5.1	-
218	.10	.16	10.10	3.83	1.24	.37	1.00	33.8	7.2	-
219	.14	.20	5.20	1.97	1.73	.51	1.25	21.6	1.8	-

¹All analytical and component values are based on original oil-shale sample.

²Water-soluble sodium.

³Acid-soluble sodium.

TABLE A-2. - Calculated nahcolite, dawsonite, calcite, and X-ray diffraction peak height of the minerals

Sample	Nahcolite		Dawsonite		Calcite	
	Weight-percent	Peak height	Weight-percent	Peak height	Weight-percent	Peak height
1	0.26	-	0.50	-	1.6	14
2	.29	-	.44	-	.2	8
3	.29	-	.63	-	.7	10
4	.26	-	.56	-	2.5	17
5	.29	-	.63	-	.1	22
6	.48	-	.94	-	-	-
7	.58	-	1.75	7	-	-
8	.33	-	.69	-	.5	-
9	.40	-	.88	-	-	-
10	.33	-	.56	-	-	-
11	.51	-	.56	-	-	-
12	.51	-	.56	-	.5	-
13	.73	-	.88	-	.5	-
14	.73	-	4.70	31	-	-
15	3.95	26	5.14	35	-	-
16	.66	-	4.63	31	-	-
17	2.85	20	4.63	44	.4	-
18	.48	-	5.51	51	.6	-
19	.80	-	3.76	23	.2	-
20	21.9	73	3.76	23	2.0	-
21	14.3	65	3.51	25	.9	-
22	14.6	68	4.38	38	.8	-
23	13.2	66	2.94	21	1.0	-
24	.51	-	7.26	60	2.2	-
25	3.11	20	8.64	50	.2	-
26	.73	-	4.57	40	.5	-
27	1.10	-	6.14	37	2.8	-
28	6.94	30	6.89	49	-	-
29	8.0	39	5.14	36	3.2	-
30	12.6	128	6.76	33	1.8	-

TABLE A-2. - Calculated nahcolite, dawsonite, calcite, and X-ray diffraction peak height of the minerals--Continued

Sample	Nahcolite		Dawsonite		Calcite	
	Weight-percent	Peak height	Weight-percent	Peak height	Weight-percent	Peak height
31	31.8	38	4.32	46	1.5	-
32	14.4	70	5.70	53	-	-
33	11.3	60	2.94	34	-	-
34	11.7	59	3.76	35	-	-
35	1.06	-	5.51	88	-	-
36	32.6	85	7.64	50	-	-
37	39.6	106	2.82	26	-	-
38	15.0	23	1.00	7	-	-
39	35.8	80	1.50	8	-	-
40	6.8	36	.75	-	-	-
41	32.9	130	.88	5	0.5	-
42	15.5	52	7.70	57	-	-
43	34.9	90	6.01	60	-	-
44	22.1	62	4.38	33	-	-
45	52.7	245	4.13	37	.4	-
46	7.7	49	7.01	69	-	8
47	27.4	96	7.89	67	-	-
48	3.95	15	10.27	78	-	-
49	24.5	104	5.14	51	2.3	-
50	3.07	22	9.08	71	-	-
51	2.34	18	8.52	70	.3	-
52	20.8	77	6.51	82	.1	-
53	20.5	104	5.76	59	-	-
54	35.8	158	4.63	48	1.5	25
55	42.8	235	4.63	50	1.2	-
56	53.3	255	3.63	43	.7	-
57	19.7	78	9.14	94	-	-
58	9.9	38	9.14	73	-	-
59	23.8	102	6.89	65	.2	-
60	15.0	88	7.58	88	1.6	13
61	16.8	86	9.27	98	2.4	12
62	14.1	57	9.02	88	3.2	9
63	11.6	54	9.90	88	1.1	-
64	3.18	13	9.90	84	2.2	6
65	.51	7	6.01	88	6.4	30
66	28.7	114	5.51	60	3.3	17
67	15.0	59	7.83	72	.7	-
68	16.5	62	9.96	94	-	-
69	10.3	44	11.59	88	-	-
70	9.5	32	8.77	75	-	-
71	33.3	138	5.32	67	-	-
72	13.7	45	10.15	73	-	-
73	.22	-	9.14	71	2.0	-
74	.29	-	6.26	76	-	-
75	.22	10	6.76	65	-	-
76	.26	-	13.40	110	-	-
77	.44	-	13.34	106	-	-

TABLE A-2. - Calculated nahcolite, dawsonite, calcite, and X-ray diffraction peak height of the minerals--Continued

Sample	Nahcolite		Dawsonite		Calcite	
	Weight-percent	Peak height	Weight-percent	Peak height	Weight-percent	Peak height
78	8.0	34	9.96	108	1.2	14
79	27.4	142	4.13	64	5.9	32
80	36.5	160	3.51	48	3.7	26
81	17.1	76	6.89	78	3.3	26
82	25.9	126	6.08	58	-	-
83	40.9	250	4.76	66	1.5	-
84	37.6	195	4.45	57	.3	20
85	21.9	420	3.88	53	-	-
86	36.3	150	2.57	18	-	-
87	16.8	92	5.70	52	1.5	-
88	20.5	82	7.39	68	1.8	-
89	.33	-	8.14	60	-	-
90	.22	-	7.39	71	-	-
91	.51	-	11.21	93	-	-
92	20.5	88	7.77	66	-	-
93	2.19	17	7.77	51	1.1	-
94	1.17	18	7.39	70	1.9	20
95	.18	-	8.52	94	2.9	-
96	.15	-	5.01	61	.1	-
97	.44	-	4.26	38	-	-
98	.22	-	.69	7	4.0	-
99	.44	-	.69	-	-	-
100	.40	-	.38	-	3.8	11
101	.73	-	1.57	11	4.0	20
102	.55	-	.63	-	-	-
103	.66	-	1.57	-	-	-
104	.80	-	.50	-	-	-
105	.58	-	.56	-	2.0	8
106	.58	-	.44	-	1.8	18
107	.11	-	.56	-	-	-
108	.07	-	.44	-	3.3	23
109	.07	-	.63	-	3.4	26
110	.07	-	.63	-	-	-
111	.07	-	1.38	7	.2	-
112	.07	-	.44	-	-	-
113	.04	-	.38	-	-	-
114	.04	-	.44	-	-	-
115	.11	-	.75	-	-	-
116	.07	-	.75	-	-	-
117	.07	-	.50	-	-	-
118	.07	-	.75	-	2.9	-
119	.04	-	.63	-	3.5	-
120	.07	-	1.44	11	-	-
121	.11	-	2.25	10	-	-
122	.11	-	4.38	39	-	-
123	.11	-	4.63	37	-	-
124	.15	-	6.14	52	-	-

TABLE A-2. - Calculated nahcolite, dawsonite, calcite, and X-ray diffraction peak height of the minerals--Continued

Sample	Nahcolite		Dawsonite		Calcite	
	Weight-percent	Peak height	Weight-percent	Peak height	Weight-percent	Peak height
125	4.53	-	6.64	59	1.4	-
126	.15	-	6.51	74	2.3	-
127	.15	-	4.45	30	-	-
128	.11	-	.56	-	-	-
129	.15	-	4.32	51	-	-
130	.22	-	6.14	50	-	-
131	.15	-	.63	-	-	-
132	.26	-	1.50	17	-	-
133	2.78	-	6.14	51	1.4	-
134	.18	-	9.27	74	-	-
135	.15	-	5.89	48	-	-
136	.18	-	11.65	72	-	-
137	.18	-	7.89	71	-	-
138	.18	-	7.45	78	-	-
139	5.70	27	4.63	51	-	-
140	5.48	25	8.27	81	1.4	-
141	.18	-	6.76	81	1.3	-
142	11.0	48	8.14	79	-	-
143	.18	-	11.27	88	-	-
144	.15	-	9.21	80	.3	-
145	3.54	20	9.71	106	1.8	-
146	18.6	94	7.01	90	.7	-
147	.22	-	9.58	94	6.8	35
148	4.28	13	7.39	53	2.1	-
149	3.22	21	9.02	67	.8	-
150	6.80	26	9.14	72	-	-
151	.26	-	11.84	122	-	-
152	2.70	15	9.27	91	-	-
153	6.03	30	7.89	82	-	-
154	6.65	62	9.78	74	-	-
155	.58	-	7.83	76	2.2	-
156	.26	-	6.89	72	-	-
157	.29	-	15.91	134	-	-
158	4.20	26	15.66	123	-	-
159	10.2	44	11.71	110	-	-
160	30.8	126	5.51	60	5.4	35
161	39.8	190	4.26	40	5.3	45
162	24.5	94	6.51	65	2.1	19
163	26.3	114	6.20	88	2.6	17
164	21.6	90	7.26	51	-	-
165	33.6	136	6.26	72	1.8	-
166	36.2	150	6.01	83	1.2	-
167	19.3	83	7.64	60	-	-
168	20.8	84	5.57	72	-	-
169	30.3	152	3.51	57	.5	-
170	1.39	11	8.33	80	-	-
171	17.0	80	6.14	72	-	-

TABLE A-2. - Calculated nahcolite, dawsonite, calcite, and X-ray diffraction peak height of the minerals--Continued

Sample	Nahcolite		Dawsonite		Calcite	
	Weight-percent	Peak height	Weight-percent	Peak height	Weight-percent	Peak height
172	0.18	11	8.27	65	-	-
173	.18	-	7.64	94	-	-
174	36.9	205	6.01	58	-	-
175	2.16	20	6.33	65	-	-
176	1.46	-	4.89	44	0.1	-
177	.22	-	5.89	66	1.1	-
178	.26	-	4.13	43	-	-
179	.48	-	1.00	-	.8	-
180	.66	-	2.51	13	3.9	22
181	.69	-	.75	-	-	-
182	.18	-	9.27	43	1.4	-
183	.29	-	10.02	55	-	-
184	.18	-	8.02	40	-	-
185	.29	-	8.02	40	-	-
186	.33	-	8.83	51	-	-
187	.18	-	9.71	48	-	-
188	.29	-	3.76	19	4.8	-
189	.36	-	3.82	23	2.3	-
190	.26	-	2.88	23	3.5	-
191	.22	-	1.50	5	1.8	-
192	.29	-	1.00	7	3.2	-
193	.40	-	.75	-	1.4	-
194	.55	-	1.13	7	5.0	-
195	.36	-	1.00	-	5.7	18
196	.62	-	.88	-	6.1	25
197	.48	-	.88	-	6.2	14
198	.58	-	.75	-	7.9	33
199	.62	-	.88	-	6.7	22
200	.48	-	1.82	8	3.6	44
201	.62	-	4.01	23	-	-
202	.66	-	1.50	8	1.1	-
203	.58	-	1.32	8	1.2	-
204	.48	-	1.63	11	1.5	-
205	.62	-	1.88	11	3.0	13
206	.44	-	3.51	35	-	-
207	.44	-	2.63	22	-	-
208	.33	-	7.70	51	-	-
209	.33	-	6.76	48	-	-
210	.40	-	7.77	49	-	-
211	.51	-	5.20	42	5.3	16
212	.51	-	1.88	9	10.4	28
213	.40	-	.88	-	13.3	39
214	.29	-	.50	-	6.5	18
215	.44	-	.50	-	7.4	21
216	.36	-	.50	-	2.6	-
217	.44	-	.63	-	5.1	15
218	.37	-	1.00	8	7.2	17
219	.51	-	1.25	7	1.8	15

TABLE A-3. - Calculated dolomite, ferroan, and X-ray diffraction peak heights of the minerals

Sample	Calculated dolomite, weight-percent	Dolomite peak height	Nahcolite peak height	Quartz peak height	Calculated ferroan, weight-percent	Ferroan peak height	Secondary dawsonite peak height
1	27.8	88	-	39	-	-	-
2	17.7	65	-	81	-	-	-
3	25.5	78	-	45	-	-	-
4	30.6	84	-	49	-	-	-
5	30.4	92	-	54	-	5	-
6	25.0	82	-	54	2.6	9	-
7	21.7	70	-	45	1.9	11	-
8	28.9	82	-	17	-	9	-
9	20.0	58	-	25	3.8	13	-
10	31.7	94	-	80	-	9	-
11	32.0	98	-	55	1.4	8	-
12	32.9	108	-	98	-	11	-
13	31.0	106	-	78	1.7	16	-
14	24.6	77	-	110	2.7	16	12
15	20.0	67	26	104	2.0	19	18
16	24.3	82	-	120	2.1	18	15
17	26.7	98	20	106	-	10	14
18	27.7	90	-	118	-	17	16
19	32.3	102	-	108	-	14	10
20	25.9	114	73	100	-	8	11
21	25.9	104	65	94	-	12	12
22	23.8	94	68	85	-	17	18
23	22.2	88	66	73	-	7	11
24	24.7	79	-	102	-	21	21
25	26.4	90	20	118	-	-	19
26	26.4	82	-	94	-	21	18
27	27.2	94	-	132	-	-	17
28	24.4	86	30	108	.6	-	21
29	28.9	98	39	106	-	13	15
30	26.4	102	128	104	-	9	18
31	21.4	112	38	136	-	-	20
32	24.8	88	70	104	.1	18	16
33	23.9	86	60	82	1.9	12	5
34	17.1	71	59	108	2.7	17	12
35	10.2	39	-	128	5.1	28	28
36	11.4	52	85	124	2.9	25	27
37	17.9	85	106	81	2.2	15	-
38	5.9	21	23	14	.4	-	-
39	8.7	37	80	29	1.3	-	-
40	20.5	67	36	54	2.4	10	-
41	21.5	98	130	47	-	9	-
42	21.0	68	52	116	.8	-	36
43	22.0	90	90	118	1.3	12	15
44	21.1	86	62	122	-	12	12

TABLE A-3. - Calculated dolomite, ferroan, and X-ray diffraction peak heights of the mineral--Continued

Sample	Calculated dolomite, weight-percent	Dolomite peak height	Nahcolite peak height	Quartz peak height	Calculated ferroan, weight-percent	Ferroan peak height	Secondary dawsonite peak height
45	11.5	80	245	85	-	-	27
46	23.2	84	49	116	2.3	20	12
47	18.8	82	96	130	1.8	22	23
48	23.2	86	15	148	2.7	32	33
49	27.5	114	104	108	-	14	14
50	27.3	102	22	142	1.7	23	25
51	29.5	120	18	132	-	19	19
52	27.8	142	77	152	-	12	17
53	22.3	112	104	144	.9	20	18
54	22.4	128	158	122	-	-	20
55	18.2	128	235	122	-	-	18
56	14.9	110	255	90	-	-	14
57	17.1	78	78	158	1.6	25	23
58	20.2	82	38	140	2.4	24	27
59	24.1	120	102	160	-	13	18
60	22.2	108	88	142	-	-	23
61	16.1	84	86	172	-	-	38
62	17.9	88	57	136	-	-	24
63	21.2	86	54	148	-	-	27
64	19.1	64	13	154	-	-	20
65	8.6	29	7	205	-	-	15
66	11.5	69	114	92	-	-	15
67	24.6	96	59	128	-	5	21
68	17.5	68	62	124	1.2	20	21
69	22.4	90	44	148	.7	-	34
70	19.5	78	32	140	2.3	20	16
71	15.3	90	138	112	.3	14	25
72	17.5	75	45	122	.6	-	24
73	24.2	75	-	128	-	19	20
74	19.2	63	-	152	.6	16	18
75	13.7	47	10	132	4.4	20	-
76	10.3	40	-	166	6.5	44	40
77	24.6	84	-	170	2.2	27	28
78	25.1	92	34	148	-	-	27
79	25.3	138	142	106	-	-	11
80	18.7	118	160	100	-	-	15
81	21.8	106	76	134	-	-	19
82	15.4	88	126	124	1.1	24	26
83	17.2	120	250	115	-	-	23
84	19.9	126	195	122	-	13	15
85	22.7	106	120	92	.4	10	10
86	14.8	88	150	68	1.5	11	7
87	23.7	122	92	120	-	-	21
88	17.1	88	82	120	-	-	21

TABLE A-3. - Calculated dolomite, ferroan, and X-ray diffraction peak heights of the mineral--Continued

Sample	Calculated dolomite, weight-percent	Dolomite peak height	Nahcolite peak height	Quartz peak height	Calculated ferroan, weight-percent	Ferroan peak height	Secondary dawsonite peak height
89	23.0	82	-	130	0.6	18	17
90	23.5	83	-	112	3.8	21	15
91	12.5	45	-	136	5.1	30	30
92	18.0	84	88	102	1.5	28	28
93	28.3	98	17	120	-	17	18
94	26.4	108	18	108	-	-	21
95	28.0	96	-	122	-	-	21
96	24.0	77	-	146	-	6	9
97	17.0	61	-	150	2.6	23	21
98	28.6	112	-	102	-	4	4
99	20.6	70	-	180	.8	5	-
100	23.6	73	-	120	-	6	-
101	20.0	52	-	120	-	12	5
102	20.5	76	-	152	.3	6	-
103	13.8	43	-	178	.5	9	-
104	21.8	69	-	116	.5	11	-
105	22.7	78	-	136	-	4	-
106	13.1	41	-	200	-	5	-
107	25.4	77	-	40	.5	6	-
108	30.2	98	-	45	-	5	-
109	29.8	88	-	36	-	4	-
110	24.0	90	-	42	2.2	9	-
111	23.9	76	-	25	-	8	-
112	32.3	104	-	50	1.1	7	-
113	29.7	104	-	50	.1	-	-
114	28.5	104	-	62	2.4	5	-
115	22.8	79	-	70	4.0	22	-
116	25.3	88	-	88	1.4	11	-
117	24.3	86	-	100	.5	12	-
118	31.1	94	-	88	-	9	-
119	31.3	84	-	74	-	8	-
120	29.0	79	-	71	.6	9	-
121	23.4	71	-	72	.1	10	4
122	21.7	61	-	84	.7	13	10
123	25.9	55	-	88	.1	12	9
124	24.7	58	-	79	.3	14	16
125	28.0	81	-	96	-	-	14
126	29.6	79	-	92	-	10	13
127	19.7	56	-	84	.9	16	18
128	22.1	64	-	66	.4	9	-
129	17.0	46	-	88	4.0	21	11
130	20.3	65	-	114	2.4	14	22
131	27.0	75	-	67	.8	12	-
132	26.9	84	-	50	1.9	8	8

TABLE A-3. - Calculated dolomite, ferroan, and X-ray diffraction
peak heights of the mineral--Continued

Sample	Calculated dolomite, weight-percent	Dolomite peak height	Nahcolite peak height	Quartz peak height	Calculated ferroan, weight-percent	Ferroan peak height	Secondary dawsonite peak height
133	21.7	76	-	102	-	13	15
134	22.2	62	-	130	2.6	16	21
135	17.0	62	-	108	3.9	18	18
136	22.4	70	-	126	3.6	36	38
137	27.4	94	-	116	2.7	21	15
138	30.2	88	-	112	1.0	16	18
139	25.7	106	27	112	1.1	13	13
140	28.4	108	25	152	-	-	18
141	30.0	110	-	126	-	8	17
142	18.6	88	48	132	2.2	22	22
143	23.2	86	-	150	3.0	21	27
144	29.4	100	-	138	-	-	21
145	20.7	82	20	170	-	-	23
146	12.9	92	94	130	-	-	24
147	13.0	46	-	166	-	-	24
148	17.5	64	13	138	-	4	19
149	24.1	94	21	182	-	-	23
150	22.7	90	26	132	.9	-	23
151	24.8	96	-	156	2.0	18	27
152	20.0	73	15	156	3.0	25	23
153	16.9	76	30	138	1.6	16	23
154	15.5	73	62	134	2.3	-	27
155	27.4	96	-	134	-	8	16
156	11.5	44	-	180	2.6	9	19
157	8.6	32	-	160	7.2	43	46
158	16.7	67	26	178	4.7	39	35
159	21.0	83	44	136	2.0	-	31
160	23.6	120	126	122	-	-	14
161	17.1	98	190	96	-	-	16
162	24.2	110	94	120	-	-	17
163	21.3	104	114	116	-	-	20
164	15.6	80	90	122	1.4	-	27
165	19.8	110	136	138	-	-	27
166	20.5	128	150	120	-	-	19
167	29.7	144	83	134	1.2	-	17
168	23.1	114	84	116	.7	11	21
169	16.9	112	152	122	-	12	16
170	26.0	114	11	144	.8	9	21
171	23.0	98	80	104	.4	-	20
172	23.4	96	11	136	3.4	24	19
173	10.4	47	-	195	6.9	31	27
174	6.9	66	205	118	3.6	27	23
175	29.3	130	20	148	-	10	22
176	27.9	132	-	130	-	6	13

TABLE A-3. - Calculated dolomite, ferroan, and X-ray diffraction
peak heights of the mineral--Continued

Sample	Calculated dolomite, weight- percent	Dolomite peak height	Nahcolite peak height	Quartz peak height	Calculated ferroan, weight- percent	Ferroan peak height	Secondary dawsonite peak height
177	28.0	118	-	144	-	-	23
178	19.6	80	-	215	1.4	18	23
179	21.8	70	-	146	-	6	-
180	16.8	37	-	114	-	7	11
181	16.6	49	-	164	1.6	8	-
182	30.8	90	-	190	-	-	13
183	18.8	67	-	150	2.6	-	25
184	28.4	84	-	160	1.4	15	17
185	30.6	98	-	146	1.6	18	13
186	20.8	77	-	178	3.6	24	21
187	23.9	82	-	180	1.2	-	25
188	36.7	116	-	92	-	-	10
189	34.4	102	-	126	-	-	4
190	35.9	106	-	94	-	-	8
191	36.2	102	-	84	-	4	3
192	33.2	102	-	94	-	-	6
193	29.3	92	-	104	-	7	-
194	34.8	108	-	108	-	3	5
195	30.2	92	-	108	-	5	-
196	17.3	66	-	114	-	11	-
197	28.9	90	-	100	-	-	-
198	23.2	63	-	118	-	7	-
199	18.6	61	-	124	-	8	-
200	24.6	84	-	124	-	5	7
201	22.1	74	-	118	.2	9	12
202	25.4	84	-	122	-	6	-
203	25.3	80	-	122	-	-	-
204	21.7	84	-	118	-	-	6
205	22.6	74	-	112	-	4	10
206	20.9	72	-	170	1.8	8	14
207	24.6	90	-	116	1.3	-	10
208	18.9	75	-	136	2.5	-	26
209	19.2	72	-	114	4.3	25	24
210	25.0	88	-	118	1.4	8	21
211	31.7	100	-	102	-	-	8
212	31.3	96	-	72	-	-	-
213	35.4	104	-	77	-	-	-
214	29.0	118	-	60	-	-	-
215	34.3	120	-	92	-	-	-
216	27.9	114	-	104	-	3	-
217	29.4	100	-	114	-	4	-
218	33.8	110	-	106	-	3	6
219	21.6	68	-	104	-	-	7

TABLE A-4. - Calculated and measured carbon dioxide content
for oil-shale samples

Sample	Carbon dioxide, weight-percent, calculated from cation values						Deter- mined	Difference
	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan	Total		
1	0.1	0.2	13.1	0.7	-	14.1	14.1	0.0
2	.2	.1	8.3	.1	-	8.7	8.6	.1
3	.2	.2	12.0	.3	-	12.7	12.6	.1
4	.1	.2	14.4	1.1	-	15.8	15.9	-.1
5	.2	.2	14.3	-	-	14.7	14.3	.4
6	.3	.3	11.5	-	1.3	13.4	13.0	.4
7	.3	.5	9.9	-	.9	11.6	11.3	.3
8	.2	.2	13.3	.2	-	13.9	13.7	.2
9	.2	.3	9.3	-	1.9	11.7	11.1	.6
10	.2	.2	14.9	-	-	15.3	15.5	-.2
11	.3	.2	15.1	-	.7	16.3	16.0	.3
12	.3	.2	15.5	.2	-	16.2	15.6	.6
13	.4	.3	14.6	-	.9	16.2	16.0	.2
14	.4	1.4	11.6	-	1.4	14.8	14.7	.1
15	2.1	1.6	9.3	-	.9	13.9	14.0	-.1
16	.3	1.4	11.2	-	1.0	13.9	14.4	-.5
17	1.5	1.4	12.4	.2	-	15.5	15.2	.3
18	.3	1.7	12.8	.3	-	15.1	14.7	.4
19	.4	1.1	15.0	.1	-	16.6	16.6	.0
20	11.5	1.1	12.1	.9	-	25.6	25.2	.4
21	7.5	1.1	12.0	.4	-	21.0	21.3	-.3
22	7.6	1.3	11.0	.4	-	20.3	20.5	-.2
23	6.9	.9	10.3	.4	-	18.5	19.1	-.6
24	.3	2.2	11.4	1.0	-	14.9	14.8	.1
25	1.6	2.6	12.2	.1	-	16.5	15.9	.6
26	.4	1.4	12.3	.2	-	14.3	14.3	.0
27	.6	1.9	12.6	1.2	-	16.3	16.3	.0
28	3.6	2.1	11.2	-	.3	17.2	17.6	-.4
29	4.2	1.6	13.4	1.4	-	20.6	20.7	-.1
30	6.6	2.1	12.3	.8	-	21.8	22.4	-.6
31	16.7	1.3	10.0	.7	-	28.7	28.7	.0
32	7.5	1.7	11.5	-	-	20.7	20.8	-.1
33	5.9	.9	11.1	-	.9	18.8	19.2	-.4
34	6.1	1.1	7.9	-	1.3	16.4	16.5	-.1
35	.6	1.7	4.6	-	2.4	9.3	9.4	-.1
36	17.1	2.3	5.2	-	1.4	26.0	26.0	.0
37	20.7	.9	8.3	-	1.1	31.0	30.8	.2
38	7.9	.3	2.7	-	.2	11.1	10.9	.2
39	18.8	.5	4.0	-	.6	23.9	24.0	-.1
40	3.6	.2	9.6	-	1.2	14.6	14.0	.6
41	17.2	.3	10.1	.2	-	27.8	27.5	.3
42	8.1	2.4	9.7	-	.4	20.6	20.8	-.2
43	18.3	1.8	10.2	-	.6	30.9	30.8	.1
44	11.6	1.3	9.8	-	-	22.7	22.7	.0
45	27.6	1.3	5.3	.2	-	34.4	34.1	.3

TABLE A-4. - Calculated and measured carbon dioxide content
for oil-shale samples--Continued

Sample	Carbon dioxide, weight-percent, calculated from cation values						Deter- mined	Difference
	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan	Total		
46	4.0	2.1	10.7	-	1.1	17.9	18.4	-0.5
47	14.4	2.4	8.7	-	.9	26.4	25.9	.5
48	2.1	3.1	10.6	-	1.3	17.1	17.6	-.5
49	12.8	1.6	12.8	1.0	-	28.2	27.8	.4
50	1.6	2.8	12.7	-	.8	17.9	18.4	-.5
51	1.2	2.6	13.7	.1	-	17.6	18.0	-.4
52	10.9	2.0	13.0	-	-	25.9	26.0	-.1
53	10.7	1.8	10.4	-	.4	23.3	23.4	-.1
54	18.8	1.4	10.5	.7	-	31.4	31.5	-.1
55	22.4	1.4	8.5	.5	-	32.8	33.0	-.2
56	27.9	1.1	7.0	.3	-	36.3	36.2	.1
57	10.3	2.8	7.9	-	.8	21.8	22.2	-.4
58	5.2	2.8	9.4	-	1.2	18.6	18.9	-.3
59	12.5	2.1	11.2	.1	-	25.9	26.0	-.1
60	7.9	2.3	10.3	.7	-	21.2	21.8	-.6
61	8.8	2.8	7.5	1.1	-	20.2	20.6	-.4
62	7.4	2.8	8.3	1.4	-	19.9	20.4	-.5
63	6.1	3.0	9.3	.5	-	19.4	20.2	-.8
64	1.7	3.0	8.8	1.0	-	14.5	15.0	-.5
65	.3	1.8	3.9	2.8	-	8.8	9.2	-.4
66	15.0	1.7	5.4	1.5	-	23.6	23.8	-.2
67	7.9	2.4	11.5	.3	-	22.1	22.6	-.5
68	8.6	3.0	8.0	-	.6	20.2	20.3	-.1
69	5.4	3.5	10.3	-	.3	19.5	19.7	-.2
70	5.0	2.7	9.0	-	1.1	17.8	18.1	-.3
71	17.4	1.6	7.1	-	.1	26.2	26.9	-.7
72	7.2	3.1	8.1	-	.3	18.7	18.6	.1
73	.1	2.8	11.2	.9	-	15.0	15.0	.0
74	.2	1.9	8.9	-	.3	11.3	11.2	.1
75	.1	2.1	6.2	-	2.1	10.5	10.9	-.4
76	.1	4.1	4.7	-	3.0	11.9	12.5	-.6
77	.2	4.1	11.3	-	1.1	16.7	16.9	-.2
78	4.2	3.0	11.6	.5	-	19.3	19.7	-.4
79	14.4	1.3	11.9	2.6	-	30.2	30.3	-.1
80	19.1	1.1	8.8	1.6	-	30.6	31.7	-1.1
81	9.0	2.1	10.2	1.5	-	22.8	22.7	.1
82	13.6	1.9	7.1	-	.5	23.1	23.4	-.3
83	21.4	1.5	8.0	.7	-	31.6	32.3	-.7
84	19.7	1.4	9.3	.1	-	30.5	30.7	-.2
85	11.5	1.2	10.6	-	.2	23.5	23.7	-.2
86	19.0	.8	6.9	-	.7	27.4	27.2	.2
87	8.8	1.7	11.0	.7	-	22.2	22.3	-.1
88	10.7	2.3	7.9	.8	-	21.7	22.3	-.6
89	.2	2.5	10.6	-	.3	13.6	13.9	-.3
90	.1	2.3	10.8	-	1.8	15.0	15.3	-.3

TABLE A-4. - Calculated and measured carbon dioxide content
for oil-shale samples--Continued

Sample	Carbon dioxide, weight-percent, calculated from cation values						Deter- mined	Difference
	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan	Total		
91	0.3	3.4	5.7	-	2.4	11.8	11.9	-0.1
92	10.7	2.4	8.3	-	.7	22.1	22.5	-.4
93	1.1	2.4	13.1	0.5	-	17.1	17.7	-.6
94	.6	2.3	12.3	.8	-	16.0	16.3	-.3
95	.1	2.6	13.0	1.3	-	17.0	17.5	-.5
96	.1	1.5	11.2	-	-	12.8	13.0	-.2
97	.2	1.3	7.8	-	1.2	10.5	10.9	-.4
98	.1	.2	13.5	1.8	-	15.6	15.4	.2
99	.2	.2	9.6	-	.4	10.4	10.5	-.1
100	.2	.1	11.1	1.7	-	13.1	12.9	.2
101	.4	.5	9.1	1.8	-	11.8	11.6	.2
102	.3	.2	9.4	-	.1	10.0	9.7	.3
103	.3	.5	6.3	-	.2	7.3	6.8	.5
104	.4	.2	10.0	-	.2	10.8	10.5	.3
105	.3	.2	10.6	.9	-	12.0	11.6	.4
106	.3	.1	6.1	1.5	-	8.0	8.1	-.1
107	.1	.2	12.0	-	.3	12.6	12.0	.6
108	-	.1	14.3	1.5	-	15.9	16.4	-.5
109	-	.2	14.1	1.5	-	15.8	16.2	-.4
110	-	.2	11.3	-	1.1	12.6	12.8	-.2
111	-	.4	11.2	.1	-	11.7	11.3	.4
112	-	.1	15.3	-	.6	16.0	16.2	-.2
113	-	.1	14.1	-	.1	14.3	14.6	-.3
114	-	.1	13.4	-	1.2	14.7	15.3	-.6
115	.1	.2	10.6	-	2.0	12.9	12.9	.0
116	-	.2	11.7	-	.7	12.6	12.6	.0
117	-	.2	11.3	-	.2	11.7	11.7	.0
118	-	.2	14.5	1.3	-	16.0	15.8	.2
119	-	.2	14.6	1.5	-	16.3	16.3	.0
120	-	.4	13.5	-	.3	14.2	14.2	.0
121	.1	.7	10.8	-	-	11.6	12.0	-.4
122	.1	1.3	10.0	-	.3	11.7	12.2	-.5
123	.1	1.4	12.0	-	-	13.5	13.2	.3
124	.1	1.9	11.4	-	.1	13.5	13.7	-.2
125	2.4	2.0	13.1	.6	-	18.1	18.2	-.1
126	.1	2.0	13.9	1.0	-	17.0	17.5	-.5
127	.1	1.4	9.1	-	0.4	11.0	11.5	-.5
128	.1	.2	10.3	-	.2	10.8	10.9	-.1
129	.1	1.3	7.8	-	1.9	11.1	11.2	-.1
130	.1	1.9	9.4	-	1.2	12.6	12.3	.3
131	.1	.2	12.6	-	.4	13.3	12.8	.5
132	.1	.5	12.5	-	.9	14.0	14.0	.0
133	1.5	1.9	10.1	.6	-	14.1	13.6	.5
134	.1	2.8	10.3	-	1.3	14.5	13.3	1.2
135	.1	1.8	7.8	-	1.9	11.6	12.1	-.5

TABLE A-4. - Calculated and measured carbon dioxide content
for oil-shale samples--Continued

Sample	Carbon dioxide, weight-percent, calculated from cation values						Deter- mined	Difference
	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan	Total		
136	0.1	3.6	10.3	-	1.7	15.7	15.7	0.0
137	.1	2.4	12.7	-	1.3	16.5	16.6	-.1
138	.1	2.3	14.1	-	.5	17.0	17.3	-.3
139	3.0	1.4	12.0	-	.5	16.9	17.4	-.5
140	2.9	2.5	13.3	.6	-	19.3	19.9	-.6
141	.1	2.1	14.1	.6	-	16.9	17.0	-.1
142	5.8	2.5	8.6	-	1.1	18.0	17.8	.2
143	.1	3.4	10.8	-	1.5	15.8	15.7	.1
144	.1	2.8	13.7	.1	-	16.7	16.7	.0
145	1.9	3.0	9.7	.8	-	15.4	15.0	.4
146	9.7	2.1	8.3	.3	-	20.4	20.7	-.3
147	.1	2.9	5.9	3.0	-	11.9	11.9	.0
148	2.2	2.3	8.1	.9	-	13.5	13.0	.5
149	1.7	2.8	11.2	.4	-	16.1	16.5	-.4
150	3.6	2.8	10.6	-	.4	17.4	17.0	.4
151	.1	3.6	11.5	-	1.0	16.2	16.0	.2
152	1.4	2.8	9.2	-	1.5	14.9	15.2	-.3
153	3.2	2.4	7.8	-	.8	14.2	15.2	-1.0
154	3.5	3.0	7.2	-	1.1	14.8	14.9	-.1
155	.3	2.4	12.8	1.0	-	16.5	16.3	.2
156	.1	2.1	5.3	-	1.3	8.8	8.9	-.1
157	.2	4.9	3.9	-	3.3	12.3	12.4	-.1
158	2.2	4.8	7.6	-	2.2	16.8	17.1	-.3
159	5.3	3.6	9.6	-	1.0	19.5	19.2	.3
160	16.1	1.7	11.0	2.4	-	31.2	31.2	.0
161	20.9	1.3	8.0	2.3	-	32.5	33.4	-.9
162	12.8	2.0	11.3	.9	-	27.0	26.4	.6
163	13.8	1.9	10.0	1.1	-	26.8	26.8	.0
164	11.3	2.2	7.2	-	.7	21.4	21.6	-.2
165	17.6	1.9	9.2	.8	-	29.5	29.2	.3
166	19.0	1.8	9.6	.5	-	30.9	31.1	-.2
167	10.1	2.3	13.6	-	.6	26.9	27.0	-.1
168	10.9	1.7	10.7	-	.3	23.6	24.2	-.6
169	15.9	1.1	7.8	.2	-	25.0	25.2	-.2
170	.7	2.5	12.1	-	.4	15.7	15.6	.1
171	8.9	1.9	10.7	-	.2	21.7	21.6	.1
172	.1	2.5	10.8	-	1.7	15.1	15.2	-.1
173	.1	2.3	4.7	-	3.3	10.4	11.0	-.6
174	19.3	1.8	3.1	-	1.6	25.8	25.6	.2
175	1.1	1.9	13.6	-	-	16.6	16.8	-.2
176	.8	1.5	13.0	-	-	15.3	15.0	.3
177	.1	1.8	13.0	.5	-	15.4	15.7	-.3
178	.1	1.3	9.1	-	.7	11.2	11.1	.1
179	.3	.3	10.2	.4	-	11.2	10.5	.7
180	.3	.8	7.6	1.7	-	10.4	9.9	.5

TABLE A-4. - Calculated and measured carbon dioxide content
for oil-shale samples--Continued

Sample	Carbon dioxide, weight-percent, calculated from cation values						Deter- mined	Difference
	Nahcolite	Dawsonite	Dolomite	Calcite	Ferroan	Total		
181	0.4	0.2	7.6	-	0.8	9.0	8.4	0.6
182	.1	2.8	14.1	.6	-	17.6	17.4	.2
183	.2	3.1	8.5	-	1.2	13.0	13.4	-.4
184	.1	2.5	13.0	-	.7	16.3	15.9	.4
185	.2	2.5	14.1	-	.8	17.6	17.3	.3
186	.2	2.7	9.5	-	1.7	14.1	14.7	-.6
187	.1	3.0	10.8	-	.6	14.5	14.3	.2
188	.2	1.1	17.1	2.1	-	20.5	20.7	-.2
189	.2	1.2	16.0	1.0	-	18.4	18.4	.0
190	.1	.9	16.7	1.5	-	19.2	19.2	.0
191	.1	.5	16.9	.8	-	18.3	18.3	.0
192	.2	.3	15.5	1.4	-	17.4	17.3	.1
193	.2	.2	13.6	.6	-	14.6	14.5	.1
194	.3	.3	16.3	2.2	-	19.1	18.8	.3
195	.2	.3	14.1	2.5	-	17.1	16.8	.3
196	.3	.3	7.9	2.7	-	11.2	10.9	.3
197	.3	.3	13.5	2.7	-	16.8	16.7	.1
198	.3	.2	10.7	3.5	-	14.7	14.6	.1
199	.3	.3	8.5	2.9	-	12.0	11.9	.1
200	.3	.6	11.4	1.6	-	13.9	14.3	-.4
201	.3	1.2	10.1	-	.1	11.7	11.6	.1
202	.3	.5	11.7	.5	-	13.0	12.9	.1
203	.3	.4	11.7	.5	-	12.9	12.8	.1
204	.3	.5	10.0	.7	-	11.5	11.5	.0
205	.3	.6	10.4	1.3	-	12.6	12.7	-.1
206	.2	1.1	9.6	-	.9	11.8	11.7	.1
207	.2	.8	11.3	-	.6	12.9	12.9	.0
208	.2	2.4	8.5	-	1.2	12.3	12.6	-.3
209	.2	2.1	8.7	-	2.0	13.0	13.3	-.3
210	.2	2.4	11.3	-	.7	14.6	14.4	.2
211	.3	1.6	14.5	2.3	-	18.7	19.1	-.4
212	.3	.6	14.5	4.6	-	20.0	19.6	.4
213	.2	.3	16.5	5.8	-	22.8	22.8	.0
214	.2	.2	13.5	2.9	-	16.8	16.6	.2
215	.2	.2	16.0	3.3	-	19.7	19.7	.0
216	.2	.2	12.9	1.1	-	14.4	14.4	.0
217	.2	.2	13.7	2.2	-	16.3	16.2	.1
218	.2	.3	15.8	3.2	-	19.5	19.0	.5
219	.3	.4	9.8	.8	-	11.3	12.0	-.7

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