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Compositional Variations of Organic Material From Green River Oil Shale—WOSCO EX-1 Core (Utah)

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8017

Compositional Variations of Organic Material From Green River Oil Shale–WOSCO EX-1 Core (Utah)

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COMPOSITIONAL VARIATIONS OF ORGANIC MATERIAL FROM GREEN RIVER OIL SHALE–WOSCO EX-1 CORE (UTAH)

by

W. E. Robinson[1] and G. L. Cook[2]

ABSTRACT

Differences in the composition or chemical structure of the organic material in samples of Uinta Basin (Utah) oil shale were studied relative to stratigraphic position within the Green River Formation. This involved a systematic study of the soluble organic material and the insoluble organic material (kerogen) present in the samples. Emphasis was placed upon the distribution of the alkanes (normal and isoprenoid compounds) in the soluble extracts and upon the aromaticity of the kerogen. Significant differences exist in the chemical composition of the organic material from various strata within the Uinta Basin, some of which were related to burial depth but most were related to source material variations, environmental differences, or other factors. The Uinta Basin samples differed significantly from Piceance Creek Basin and Green River Basin samples in the large amount of soluble extract they contained.

INTRODUCTION

In the continuation of the study of the organic material in various basins of the Green River Formation, an investigation was conducted on the soluble organic material and the insoluble kerogen of a Uinta Basin (Utah) core. Similar studies have been completed for cores of the Piceance Creek Basin of Colorado (_1_, _5_)[3] and the Green River Basin of Wyoming (_6_). The organic material of the three cores hopefully is characteristic of the organic material in the three major basins of the Green River Formation.

The objective of this study was to determine the nature of the total organic material in selected core samples and ascertain if observed compositional and structural differences were related to normal diagenesis. This involved studying both the soluble organic material and the insoluble kerogen in each sample. The soluble extracts were fractionated by various techniques and analyzed by gas chromatography where retention times were correlated to

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[1] Project leader.

[2] Retired.

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

those of the compound previously identified by mass spectral, NMR, and infrared data. The insoluble kerogen was compared by physical properties such as atomic hydrogen-to-carbon ratios, volatile material ratios, carbon residue ratios, oxidation rates, thermal alteration indices, and the specific gravity of the assay oil obtained from the kerogen.

It has been shown by various researchers that the organic material in sedimentary rock shows alteration due to increased static pressure and sediment temperature as the depth of burial increased. The soluble organic material and gases tend to increase in hydrogen content and the insoluble organic residue tends to become more aromatic at greater depths of burial. Most of these maturation processes occur at depth of burial much greater than that encountered in the Green River Formation; however, some structural variations of the organic material in the Green River oil shale have been found.

Robinson and coworkers (7) studied a 900-foot oil shale core of the Piceance Creek Basin and found that the amount of alkanes from the soluble extracts increased with increase in depth of burial. Recently, Robinson and Cook (5-6) studied the total organic material in a Colorado core and a Wyoming core of the Green River Formation. They found considerable compositional and structural variations of the organic material--some of which were related to burial depth. Anders and Robinson (1) made a detailed study of the soluble organic material from the Colorado No. 1 core and found significant distribution differences in the n-alkanes, the chain isoprenoid compounds, the steranes, the pentacyclic triterpanes, and perhydro-β-carotene. Some of these differences were related to burial depth, and others were related to source material, environmental conditions, or other factors.

Hunt and coworkers (4) studied the soluble organic material of the Uinta Basin (Utah) and suggested evidence of four chemically different types of organic materials. These materials are referred to as gilsonite, ozocerite, albertite, and wurtzilite, the source beds of which were believed to be particular stratigraphic units identified by field geology. They also suggested that the changes in the chemical character of these organic materials are correlative with lithologic changes due to depositional environment. They found no evidence of differences in the soluble materials attributed to metamorphism, catalytic cracking, or depth of burial.

In the present study the organic material in selected samples from WOSCO EX-1 core (Utah) was investigated by using various compositional and statistical analyses. Most of the chemical structure variations in the organic material were similar to those found for the Colorado and Wyoming cores. Similar to results found for these two cores, the results from the Utah core showed some evidence of depth-related alteration; but most of the changes were undoubtedly due to other factors. One significant difference that distinquished the Utah core from the other two cores was the large amount of soluble organic material present in the Uinta Basin.

OIL-SHALE SAMPLES

WOSCO EX-1 core was drilled by Western Oil Shale Corporation in Uintah County, Utah (sec 36, T 9 S, R 20 E), to sample Green River Formation oil shale (Eocene, 50×10^6 years) in the Uinta Basin of Utah. The location of the core site, along with analytical and stratigraphic data, is described in a report by Smith and coworkers (8).

Although the Green River Formation of Utah has been described by various researchers (2, 4, 8), specific information about the area where the EX-1 corehole was drilled has not permitted the assignment of members of the formation to stratigraphic positions. However, Smith and coworkers (8) did make the following positional assignments for the WOSCO EX-1 core: (1) Bottom of A-groove (top of Mahogany zone), 2,267.3 feet; (2) Mahogany marker, 2,289.5 to 2,289.8 feet; and (3) top of B-groove (bottom of Mahogany zone), 2,360.2 feet. A mineralized zone containing substantial quantities of nahcolite and shortite in addition to the usual oil-shale minerals was found at depths from 1,740 to 1,975 feet.

Because the core has not been assigned various formation members similar to that of the Colorado and Wyoming cores, the core is herein described by five different zones. The five zones along with the footage and the sample numbers were as follows: (1) The mineralized zone, samples 1 through 11--1,766.9 to 1,960.0 feet; (2) bottom of the mineralized zone to top of Mahogany zone, samples 12 through 32--1,980.0 to 2,261.0 feet; (3) Mahogany zone, samples 33 through 42--2,270.0 to 2,360.0 feet; (4) top one-half of core from bottom of Mahogany zone to bottom of core, samples 43 through 60--2,376.5 to 2,661.0 feet; and (5) bottom one-half of core from bottom of Mahogany zone to bottom of core, samples 61 through 75--2,680.0 to 2,963.0 feet.

The average distance between samples was about 17 feet, and the average length of core taken for one sample was 1.0 foot with maximum length of 2.0 feet and minimum length of 0.2 foot. Most of the samples of less than 1 foot in length involved bitumen-impregnated tuffs and samples immediately above and below the tuffs. Four tuffs were selected for study (samples Nos. 16, 26, 40, and 49). The section of the core taken for samples 48, 49, and 50 is pictured in figure 1.

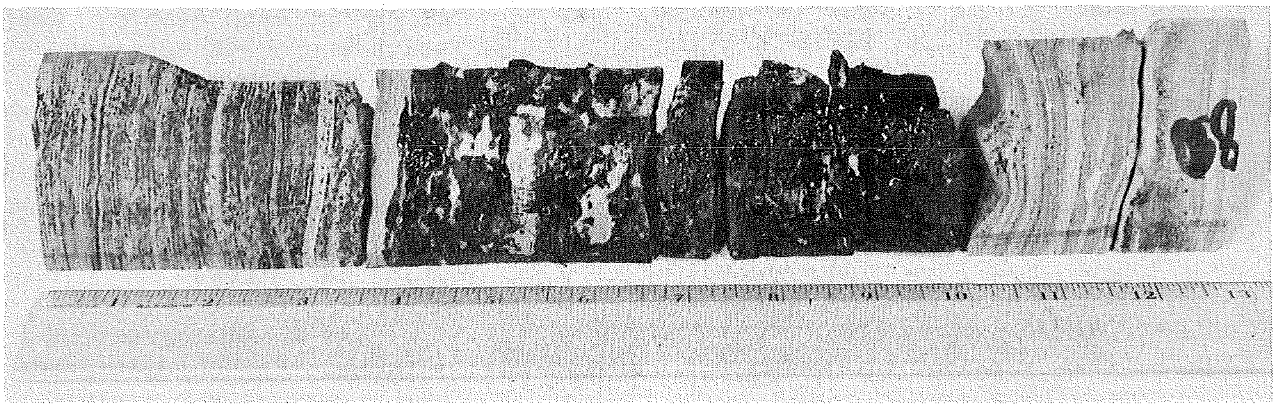

FIGURE 1. - Bitumen-impregnated section of WOSCO EX-1 core.

EXPERIMENTAL PROCEDURES

The experimental procedures used in this report are essentially the same as those used in the previous studies of the organic material in Colorado No. 1 core (1, 5) and Wyoming No. 1 core (6). Detailed descriptions of the procedures are not repeated here.

A flow diagram of the experimental operations is shown in figure 2, and brief descriptions of the illustration captions are as follows:

Lithologic sectioning of the oil-shale core (8).--Lithologic description of the entire core was made, and the core was divided into samples of similar appearance.

Assay of oil-shale core samples (8).--Each sample was crushed to pass an 8-mesh-per-inch screen and then assayed. Oil yields and specific gravities of the assay oils were determined for each sample.

Selection of 75 oil-shale samples.--Samples for the present study were selected from the unused portions of the samples prepared for assay. Samples were selected in an attempt to analyze at least one sample in each 20-foot section of the core. This was not always possible because of insufficient samples or samples of low organic carbon content.

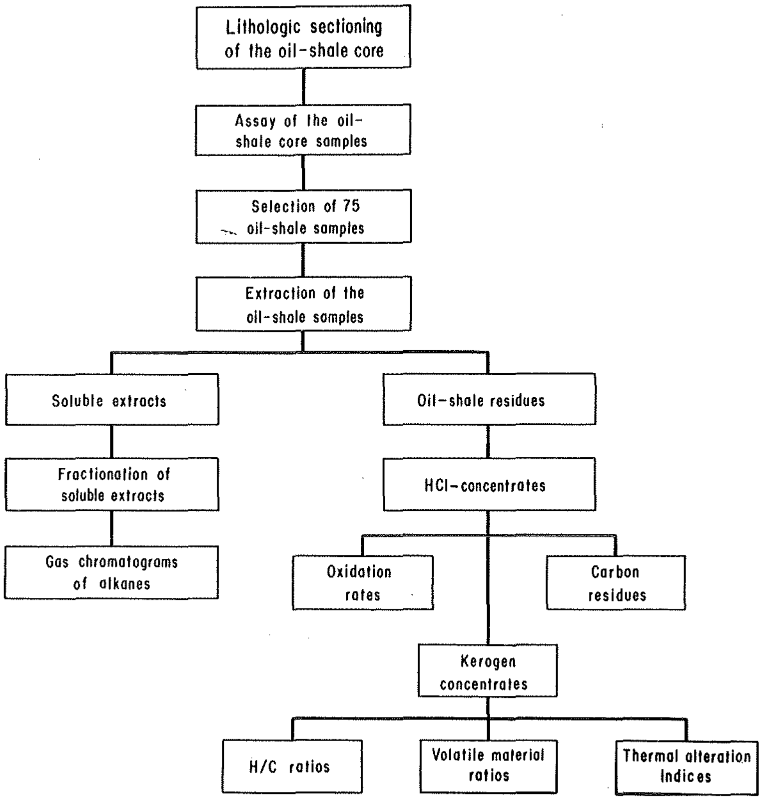

FIGURE 2. - Flow diagram of experimental operations.

Extraction of the oil-shale samples.--Each minus 8-mesh sample was crushed further to pass a 100-mesh-per-inch screen and extracted 24 hours using redistilled cyclohexane as the solvent.

Fractionation of soluble extracts.--The weight-percent of extract was determined for each sample. Each soluble extract was fractionated into n-alkanes, branched plus cyclic alkanes, aromatic oil, resins, and pentane-insoluble material by solvent treatment, elution chromatography, and molecular sieves.

Gas chromatograms of alkanes.--Gas chromatograms were obtained for n-alkane fractions and branched plus cyclic alkane fractions.

Relative quantities were determined for each n-alkane fraction and for selected branched plus cyclic alkanes from chromatographic peak areas.

HCl-concentrates.--Each extracted sample was treated with 10 percent HCl to remove mineral carbonates.

Carbon residues.--An aliquot part of each HCl-concentrate was heated at 500° C in an inert atmosphere, and the percentage of the total organic carbon remaining on the heated residue was determined. This residual carbon is called carbon residue (CR). (Highly condensed aromatic materials have carbon residue ratios greater than 50.)

Oxidation rates.--The oxidation rate (OR) of the organic material, using hot 3 percent alkaline potassium permanganate solution was determined for each HCl-concentrate. (Side chains on aromatic structures, partially unsaturated structures, and oxygen-containing groups or linkages are oxidixed easily; whereas, highly saturated hydrocarbon structures are oxidized slowly.)

Kerogen concentrates.--An aliquot part of each HCl-concentrate was treated with concentrated hydrofluoric acid at room temperature to remove most of the hydrated minerals and some silicates. The residue from each HF liquid treatment was centrifuged using bromoform as the liquid medium. This latter treatment partially removed pyrite and other heavy minerals not removed by the HF treatment.

H/C ratios.--The weight-percent of hydrogen and carbon in each kerogen concentrate was determined. (Highly aromatic materials have atomic H/C ratios less than 1.0.)

Volatile material ratios.--The ratio of the material volatilized at 500° C in an inert atmosphere to the total organic carbon in the kerogen concentrate was determined. This material is referred to as volatile material (VM). (Highly condensed aromatic materials have VM ratios less than 0.50.)

Thermal alteration indices.--The thermal alteration index (TA1) described by Staplin (<u>10</u>) was determined for each kerogen concentrate using an optical microscope and transmitted light. Thermal alteration indices provide estimates of the degree of diagenesis of sedimentary organic material and are assigned values of 1 to 5. (Unaltered, fresh-yellow organic material is given a value of 1.0; slightly altered, brownish-yellow material is given a value of 2.0; moderately altered, brown material is given a value of 3.0; strongly altered, black material is given a value of 4.0; and severely altered, black material, with additional evidence of rock metamorphism, is given a value of 5.0. Intermediate colors are given appropriate values.)

The data obtained from the study were used in several mathematical calculations to show various relationships. Extraction ratios, alkane ratios, volatile-material ratios, and various ratios for components of the soluble extract were obtained by dividing the weight-percent of the determined property by weight-percent of organic carbon. For example, the extraction ratio is as follows:

$$\text{Extraction ratio} = \frac{\text{Soluble extract, weight-percent of oil shale}}{\text{Organic carbon, weight-percent of oil shale}},$$

or the unit weight of soluble extract per unit weight of organic carbon. Carbon residue ratios were calculated as weight-percent of total organic carbon remaining on the heated sample as carbon residue. Hydrogen-to-carbon ratios were calculated on the atomic basis.

The methods used for linear regression and correlation analysis are described by Ezekiel and Fox (3). The equation used for these calculations is $Y = a + bX$, where Y represents the dependent variable and X represents the independent variable. The value a is the intercept of the Y axis, and b is the slope of the regression curve. The coefficient of determination r^2 shows the proportion of the variance in the value of the dependent variable that can be explained by variation in the value of the independent variable. These coefficients are ratios whose values are within the range of 0 to 1. The standard error of estimate $\overline{S}yx$ indicates how closely the estimated values (regression curve) agree with the observed values. When 30 or more samples are used, 68 percent of the data points should fall in an area above and below the regression line equivalent to the Y axis value of one standard error of estimate. The F-ratio is a test statistic for linear regression. If the calculated F-value exceeds the F-table value, one can say within the predetermined confidence limits that the observation was real and not due to chance.

RESULTS AND DISCUSSION

Like the previous studies (1, 5-6) of Piceance Creek Basin oil shale of Colorado and Green River Basin oil shale of Wyoming, the study of Uinta Basin oil shale of Utah was designed to show compositional similarities or differences in the organic components of the oil shale. In each case, the oil-shale organic material consists of the soluble organic material referred to as soluble material and the insoluble organic material referred to as kerogn.

Mineral and Organic Carbon Contents

Analyses of the total oil shale for organic and mineral carbon were among the various techniques used to show variations in the composition of the oil-shale samples. The results of these analyses are shown in table 1 along with the burial depth of each sample studied. The organic carbon contents averaged 5.8 weight-percent and ranged from 0.2 to 21.2 weight-percent. The mineral carbon contents averaged 5.4 weight-percent and ranged from 1.3 to 9.3 weight-percent. The four bitumen-impregnated samples were not included in this average.

TABLE 1. - Depth of burial from surface, organic carbon contents, and mineral carbon contents of oil-shale samples

Sample	Depth of burial, ft	Organic carbon, wt-pct	Mineral carbon, wt-pct
1	1,766.9-1,768.0	3.1	5.6
2	1,787.0-1,788.0	4.6	6.2
3	1,800.0-1,801.0	4.0	6.2
4	1,820.0-1,821.0	7.9	2.0
5	1,840.0-1,841.0	5.6	3.9
6	1,860.0-1,861.0	4.2	8.5
7	1,880.0-1,882.0	2.8	5.3
8	1,900.0-1,901.0	4.4	6.9
9	1,920.0-1,921.0	7.4	7.1
10	1,939.0-1,940.6	6.4	6.5
11	1,958.5-1,960.0	9.0	5.6
12	1,980.0-1,981.0	4.0	5.4
13	2,000.0-2,001.0	3.5	5.8
14	2,020.0-2,021.0	4.0	5.7
15	2,024.7-2,025.0	4.9	6.1
16	2,025.0-2,025.4	[1] 79.9	-
17	2,025.4-2,025.6	5.6	6.4
18	2,040.0-2,041.0	3.8	6.4
19	2,060.0-2,061.0	10.1	6.0
20	2,081.9-2,083.0	6.6	7.1
21	2,100.0-2,101.0	11.6	4.9
22	2,120.0-2,121.0	2.9	4.4
23	2,140.0-2,142.0	10.3	5.7
24	2,160.0-2,161.0	5.0	5.5
25	2,177.1-2,177.3	8.6	4.5
26	2,177.3-2,177.9	[1] 8.3	-
27	2,177.9-2,178.1	7.0	4.7
28	2,181.0-2,182.0	4.3	5.0
29	2,199.8-2,201.0	4.4	6.4
30	2,220.0-2,221.0	5.6	7.5
31	2,240.0-2,241.0	5.2	6.6
32	2,260.0-2,261.0	5.0	7.1
33	2,270.0-2,271.0	14.3	4.9
34	2,280.0-2,281.0	9.9	5.2
35	2,290.0-2,291.0	3.8	4.1
36	2,300.0-2,301.3	15.8	5.6
37	2,320.0-2,321.0	6.9	6.6
38	2,340.3-2,341.6	13.6	6.2
39	2,354.3-2,354.8	4.3	5.2
40	2,354.8-2,355.3	[1] 6.1	-
41	2,355.3-2,355.8	5.5	6.4
42	2,359.0-2,360.0	12.9	6.2
43	2,376.5-2,377.8	3.0	4.6
44	2,408.0-2,409.0	.8	1.3
45	2,422.2-2,423.0	.9	5.9

[1] Bitumen impregnated tuff.

TABLE 1. - Depth of burial from surface, organic carbon contents, and mineral carbon contents of oil-shale samples--Continued

Sample	Depth of burial, ft	Organic carbon, wt-pct	Mineral carbon, wt-pct
46	2,444.0-2,445.0	3.1	5.9
47	2,459.0-2,460.0	3.7	8.3
48	2,479.1-2,479.4	21.2	5.0
49	2,479.4-2,479.8	[1]8.4	-
50	2,479.8-2,480.0	10.4	6.4
51	2,480.0-2,481.0	9.3	6.2
52	2,500.0-2,501.0	12.1	5.6
53	2,521.0-2,522.0	7.7	6.3
54	2,536.0-2,537.0	4.0	2.8
55	2,560.0-2,561.0	1.3	4.7
56	2,573.0-2,574.0	1.4	3.6
57	2,607.0-2,608.0	3.0	3.5
58	2,618.0-2,619.0	2.2	6.3
59	2,640.0-2,641.0	5.9	2.8
60	2,660.0-2,661.0	2.6	7.4
61	2,680.0-2,681.0	3.7	7.5
62	2,706.0-2,707.0	3.2	7.5
63	2,723.0-2,724.0	5.3	6.3
64	2,746.0-2,747.0	8.5	6.1
65	2,760.0-2,761.0	8.4	6.9
66	2,780.0-2,781.0	2.9	2.3
67	2,800.0-2,801.0	3.8	3.2
68	2,820.0-2,821.0	2.3	9.1
69	2,844.0-2,845.0	.4	2.4
70	2,860.0-2,861.0	.2	1.3
71	2,880.0-2,881.0	.4	1.8
72	2,901.0-2,902.0	2.5	2.3
73	2,923.0-2,924.0	5.0	9.3
74	2,940.0-2,941.0	8.7	2.7
75	2,962.0-2,963.0	7.2	3.7

[1] Bitumen impregnated tuff.

The distribution of the organic carbon as positive or negative deviation from the average value is shown in figure 3. Generally the samples are represented equally by below and above average organic carbon contents except for samples 54 to 75 which are predominantly below average organic carbon content. Samples in the Mahogany zone between A-groove and B-groove (samples 35 through 42) are generally above average organic carbon content.

The mineral carbon distribution of the samples is shown in figure 4. Generally the upper portion of the core is above average mineral carbon content and the lower portion tends toward lower than average mineral carbon content. This is similar to the results found for the Colorado No. 1 core (5) where there was a definite trend toward lower than average mineral carbon contents with increased depth of burial.

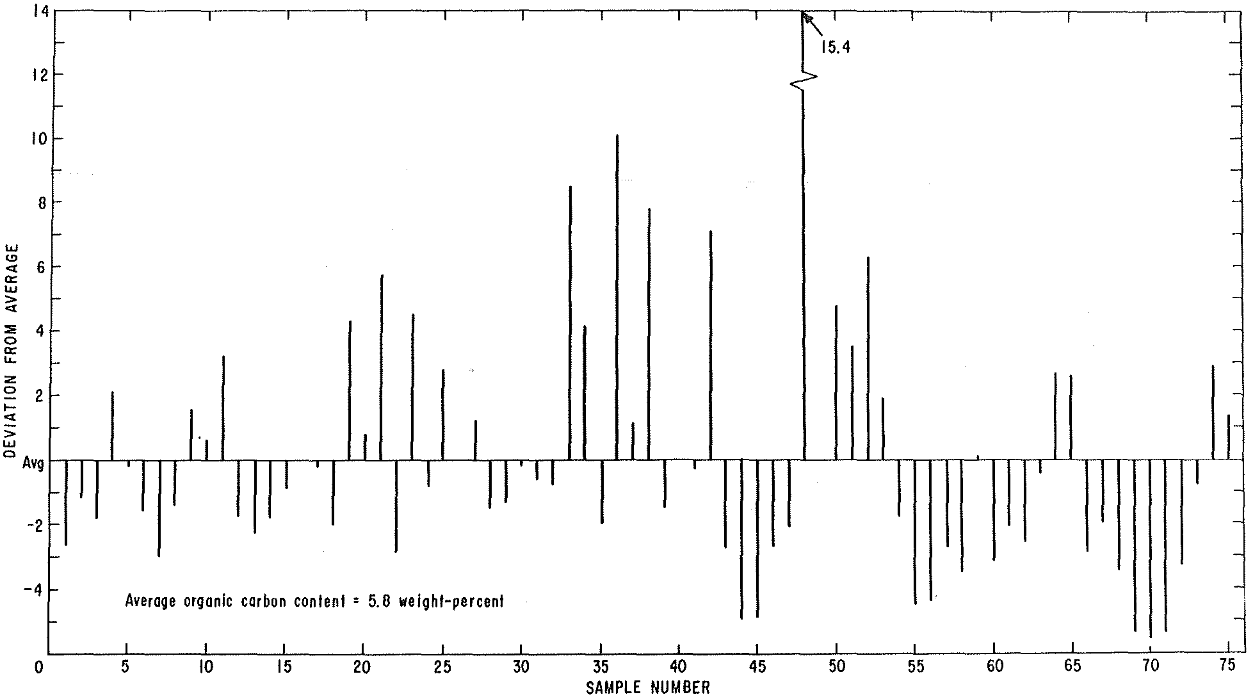

FIGURE 3. - Deviation of organic carbon contents from average.

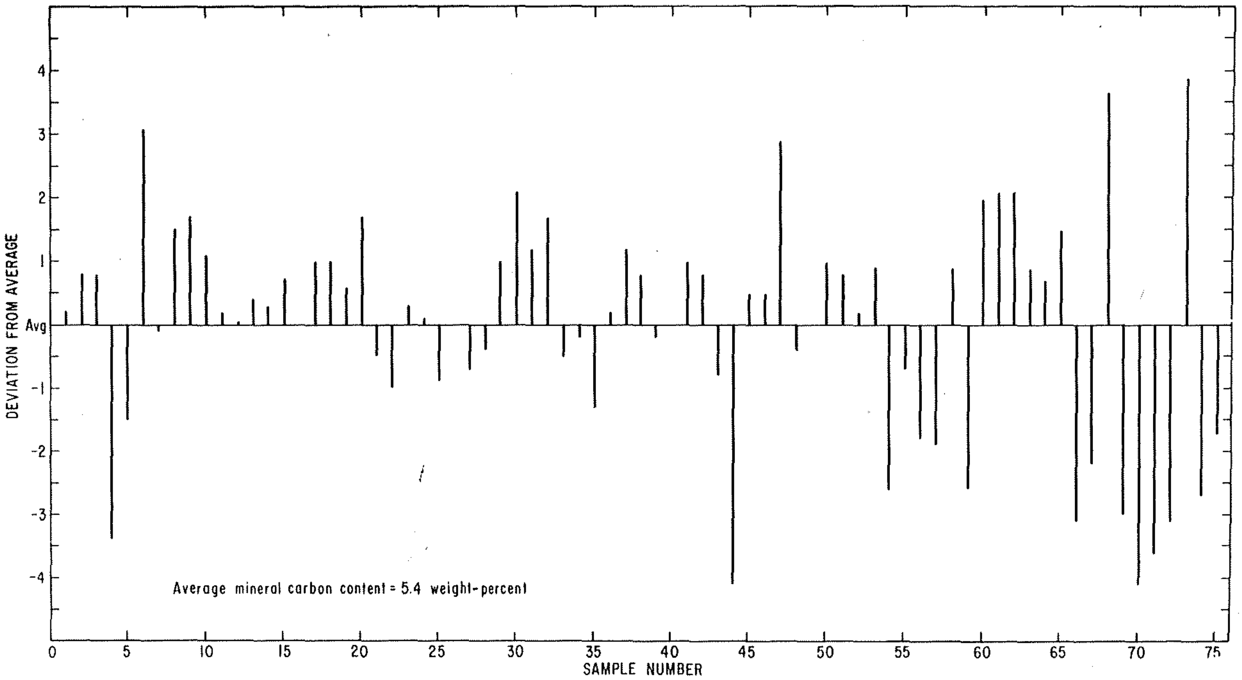

FIGURE 4. - Deviation of mineral carbon contents from average.

The relationship of mineral carbon contents as functions of organic carbon contents was examined. Data for the calculated regression curve and other pertinent information for this relationship are given in table 2. From the low coefficient of determination (r^2 = 0.02), it appears that there is no linear relationship between the organic carbon and mineral carbon contents of the 75 samples. In other words, the accumulation and preservation of the organic material was not dependent upon subsequent mineral carbon content and vice versa.

TABLE 2. - Linear correlations for mineral and organic carbon

Relationship[1]	r^2	a	b	$\bar{S}yx$	F ratio
Mineral carbon (Y).......... Organic carbon (X)..........	0.02	5.0	+0.07	1.8	[2]1.6

[1] Y = a + bX.

[2] Table value corresponding to F = 0.01 (99 percent) is 7.1.

Soluble Organic Material

Compositional Analysis

The results of the fractionation of the cyclohexane-soluble extracts obtained from the selected core samples are given in table 3. The amount of soluble extract ranged from <0.1 to 93.9 weight-percent and averaged 2.4 weight-percent. The amount of extract per 100 grams of organic carbon (extraction ratio × 10^2) ranged from 1.4 to 118.7 and averaged 22.5. The amounts of the various fractions of the soluble extracts were as follows: n-Alkanes ranged from 1.0 to 17.1 weight-percent and averaged 3.8 weight-percent; branched plus cyclic alkanes ranged from 9.4 to 51.4 weight-percent and averaged 25.7 weight-percent; aromatic oil ranged from 0.6 to 28.3 weight-percent and averaged 3.2 weight-percent; resins ranged from 3.2 to 78.6 weight-percent and averaged 55.4 weight-percent; and pentane-insoluble material ranged from <0.1 to 45.8 weight-percent and averaged 11.9 weight-percent.

Of the 75 samples, 8 samples contained more than 2 weight-percent of soluble extract. Three of these samples (Nos. 26, 40, and 49) were described earlier as bitumen-impregnated tuffs, and one of these samples (No. 16) was described as a bitumen (8). Sample No. 16 contained the highest percentage of pentane-insoluble material of any of the 75 samples; however, the amount of pentane-insoluble material did not exceed 50 percent. In most cases, the composition of the extracts taken from samples immediately above and below the bitumen and the bitumen-impregnated tuff samples (that is, samples Nos. 15 and 17 and so forth) differs from composition of the bitumen or the extract from the bitumen-impregnated tuffs. This suggests that the soluble organic material in a tuff originated in that strata and did not migrate from strata immediately above or below the tuff. Additional evidence for this observation will be given later in the discussion of the isoprenoid content of the extracts.

TABLE 3. - Compositional analyses of the soluble organic material

Sample	Soluble material, wt-pct of oil shale	Extraction ratio × 10^2	Components of soluble material, wt-pct of total				
			Normal alkanes	Branched plus cyclic alkanes	Aromatic oil	Resins	Pentane-insoluble material
1	1.2	38.8	3.1	13.7	2.3	63.1	17.8
2	1.1	22.8	3.8	12.8	1.9	72.4	9.1
3	1.1	27.6	2.2	10.0	1.4	75.0	11.4
4	3.6	45.3	1.5	9.4	.6	62.0	26.5
5	5.1	90.6	1.3	13.0	1.2	57.1	27.4
6	.6	13.5	3.0	15.4	1.7	71.8	8.1
7	1.0	34.9	2.4	14.0	2.0	70.1	11.5
8	1.0	22.0	2.9	17.0	1.7	59.8	18.6
9	1.4	18.6	2.3	10.7	1.4	64.6	21.0
10	1.9	30.4	2.4	9.7	1.1	59.6	27.2
11	1.9	21.6	3.3	10.8	1.0	68.6	16.3
12	2.1	51.1	1.8	17.9	2.1	54.8	23.4
13	1.4	39.1	1.7	16.9	2.4	62.5	16.5
14	1.8	46.0	2.2	16.6	1.9	55.2	24.1
15	.7	13.8	2.7	19.3	3.3	70.5	4.2
16	93.9	[1]117.5	1.1	12.4	1.4	39.3	45.8
17	1.3	23.5	2.1	11.0	2.4	68.4	16.1
18	1.5	39.8	1.6	18.4	1.3	63.6	15.1
19	1.6	15.5	1.0	11.0	1.0	75.8	11.2
20	2.4	36.1	1.1	17.7	2.1	59.6	19.5
21	1.5	13.2	2.1	29.3	3.2	63.5	1.9
22	.7	24.7	3.0	31.1	2.8	57.7	5.4
23	1.5	14.4	1.4	19.1	2.5	73.7	3.3
24	1.0	19.4	2.0	26.0	2.6	68.4	1.0
25	1.5	17.2	2.7	24.4	3.8	63.0	6.1
26	2.9	[1]34.8	1.0	14.7	2.7	71.0	10.6
27	1.2	17.3	2.3	22.8	3.4	64.8	6.7
28	1.2	27.7	1.3	15.6	1.6	78.6	2.9
29	1.7	39.0	1.9	20.8	2.1	67.1	8.1
30	1.2	21.5	2.1	26.2	2.8	66.7	2.2
31	1.2	23.0	2.4	22.0	2.8	71.1	1.7
32	1.3	25.0	3.7	20.3	1.7	71.2	3.1
33	.6	4.6	1.8	20.8	3.8	68.1	5.5
34	1.0	10.2	1.2	21.5	3.4	69.2	4.7
35	.3	7.4	4.5	21.4	2.5	67.3	4.3
36	1.7	10.8	1.6	15.9	2.7	70.8	9.0
37	1.1	15.8	1.7	24.5	3.8	56.9	13.1
38	1.0	7.6	1.9	15.4	1.7	76.6	4.4
39	1.2	26.5	2.9	19.4	2.5	66.0	9.2
40	7.2	[1]118.7	1.5	14.4	2.0	66.7	15.4
41	.3	5.5	4.6	27.3	6.0	48.5	13.6
42	.4	2.9	4.2	32.1	4.7	55.9	3.1
43	.1	3.7	4.0	43.8	4.7	40.1	7.4

[1] Bitumen impregnated tuff.

TABLE 3. - Compositional analyses of the soluble organic material--Continued

Sample	Soluble material, wt-pct of oil shale	Extraction ratio X 10^2	Components of soluble material, wt-pct of total				
			Normal alkanes	Branched plus cyclic alkanes	Aromatic oil	Resins	Pentane-insoluble material
44	0.5	70.7	4.5	37.3	7.2	36.4	14.6
45	.7	75.6	1.1	36.3	7.1	53.1	2.4
46	.3	8.6	5.7	38.0	2.6	51.0	2.7
47	.8	22.3	3.5	36.5	3.4	54.7	1.9
48	.6	3.0	3.8	33.3	4.9	53.4	4.6
49	7.5	[1]89.2	1.8	21.9	2.5	59.2	14.6
50	1.3	12.4	1.3	23.6	2.0	58.6	14.5
51	.8	8.4	2.2	33.6	3.0	52.0	9.2
52	.9	7.2	3.2	22.4	1.9	68.3	4.2
53	.4	5.4	6.1	35.9	6.9	48.8	2.3
54	.1	3.5	2.1	46.0	4.1	46.3	1.5
55	.1	5.4	3.5	23.8	1.8	28.2	42.7
56	.1	6.2	3.9	37.5	4.5	32.1	22.0
57	.2	5.9	3.6	47.6	3.0	41.6	4.2
58	.2	8.0	6.6	41.6	4.3	38.6	8.9
59	.2	3.7	3.4	37.4	3.4	45.3	10.5
60	.6	22.4	4.9	32.6	2.2	47.7	12.6
61	.4	10.5	5.9	39.2	3.8	42.0	9.1
62	.3	10.2	5.4	35.9	2.7	44.7	11.3
63	.3	6.4	7.9	33.9	2.7	35.4	20.1
64	.3	3.3	6.7	33.2	2.9	38.2	19.0
65	1.0	11.7	4.5	39.7	5.2	43.0	7.6
66	.2	6.8	11.2	24.6	1.9	36.3	26.0
67	.1	2.4	13.2	20.0	1.4	45.9	19.5
68	.2	9.8	9.9	33.6	1.2	37.4	17.9
69	<.1	5.1	10.8	45.4	3.0	40.8	<.1
70	<.1	5.9	17.1	51.4	28.3	3.2	<.1
71	<.1	4.8	4.6	34.2	11.4	49.8	<.1
72	.1	2.0	15.2	44.4	3.8	24.2	12.4
73	.2	4.0	6.4	40.7	4.2	45.7	3.0
74	.1	1.4	8.6	39.3	2.8	35.5	13.8
75	.5	6.8	7.2	26.5	2.7	44.7	18.9

[1] Bitumen impregnated tuff.

Fractions of the soluble extract (as weight-percent of extract) are plotted as deviations from average values in figure 5. The hydrocarbon portion of the extracts--namely the n-alkanes, the branched plus cyclic alkanes, and the aromatic oil--show trends toward greater-than-average amounts at the bottom of the core. This suggests that the extracts tend to become more hydrocarbonlike at the greatest depth of burial. This tendency is further verified by a comparable below average value for the resin content of samples at the greatest depth of burial. This suggests that the resin portion of the extract may have been converted to hydrocarbons at the greatest depths of burial. The pentane-insoluble material, which is the highest-molecular-weight

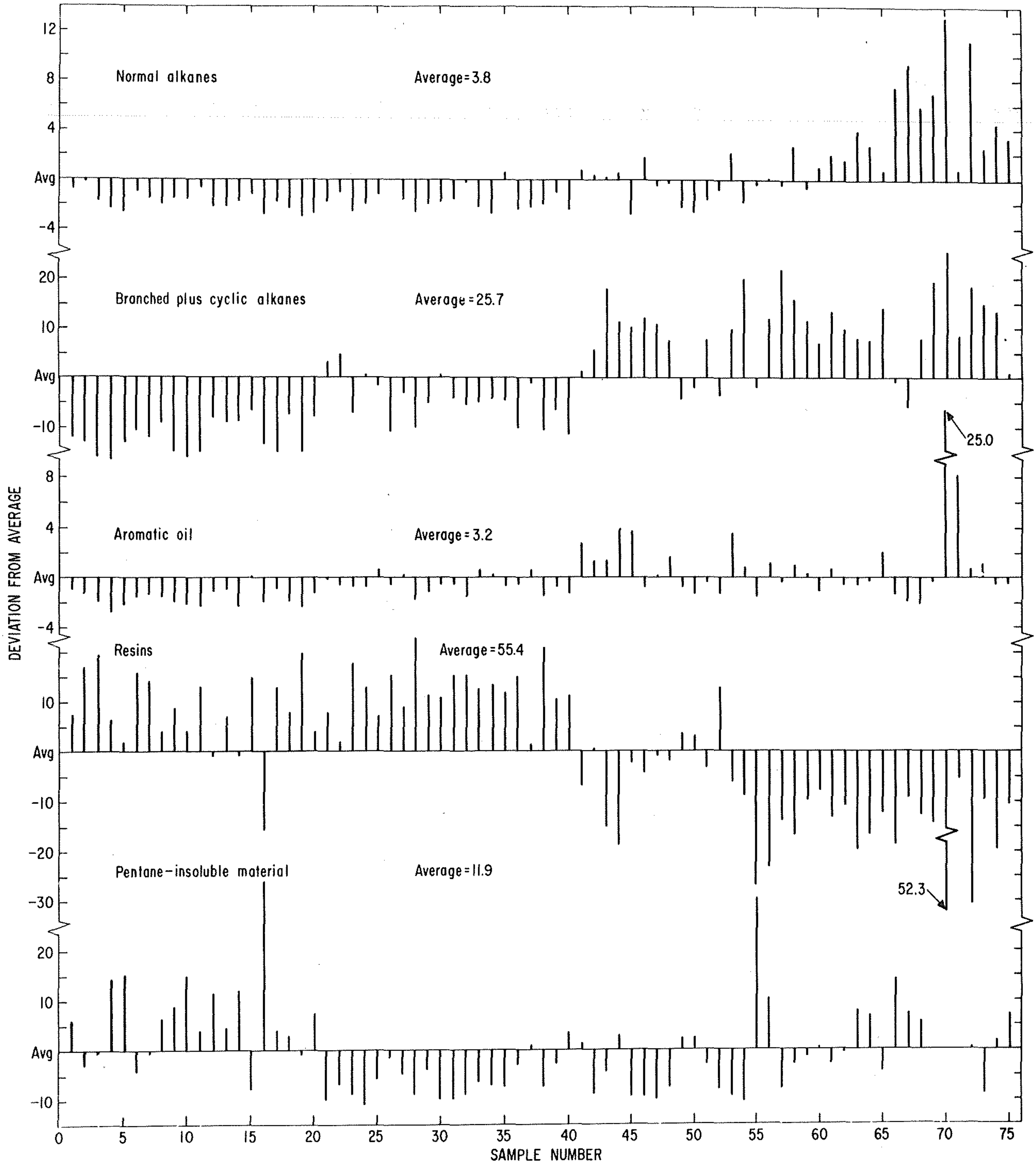

FIGURE 5. - Relative distribution of fractions of the soluble extracts.

portion of the extracts, does not show a similar decrease at the greatest depths of burial.

Although the extracts show evidence of maturation or becoming more hydrocarbonlike at the greatest depths of burial, there is no increase in the extraction ratios with increased depth of burial. This is verified by figure 6 where the extraction ratios are plotted as deviation from average values for the 75 samples. These data, like those for the Colorado No. 1 core and

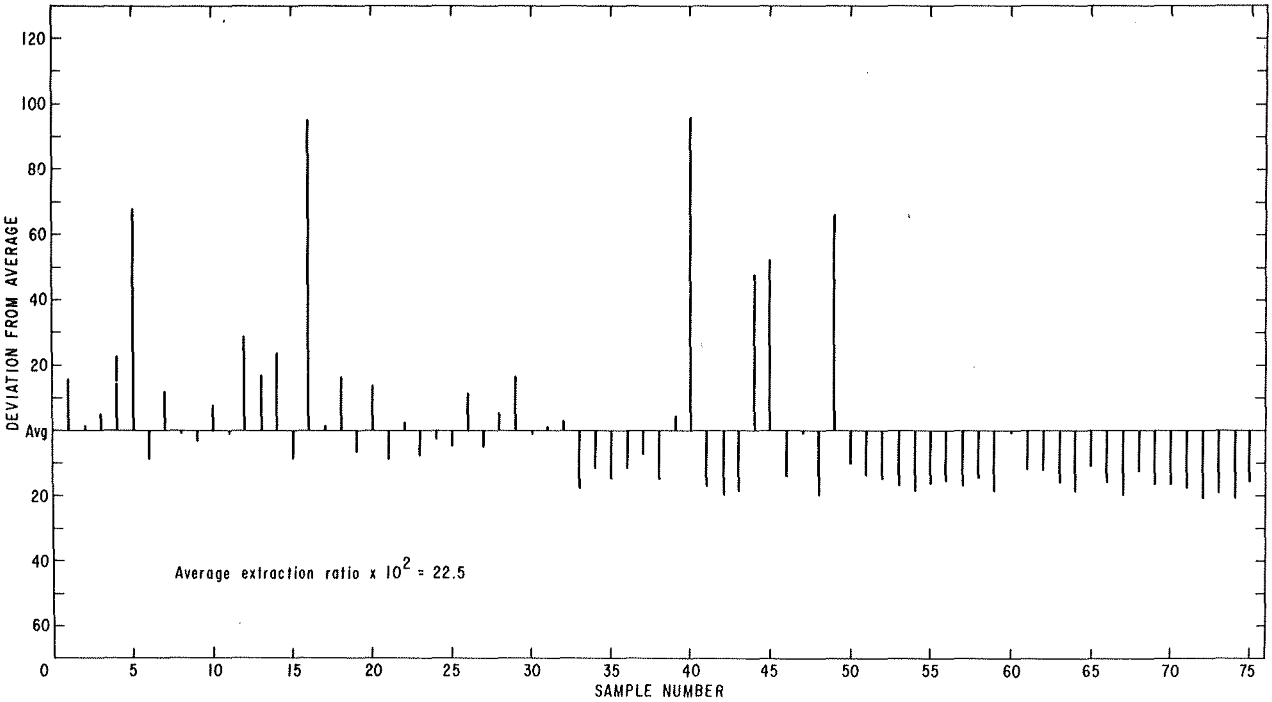

FIGURE 6. - Deviation of extraction ratios from average.

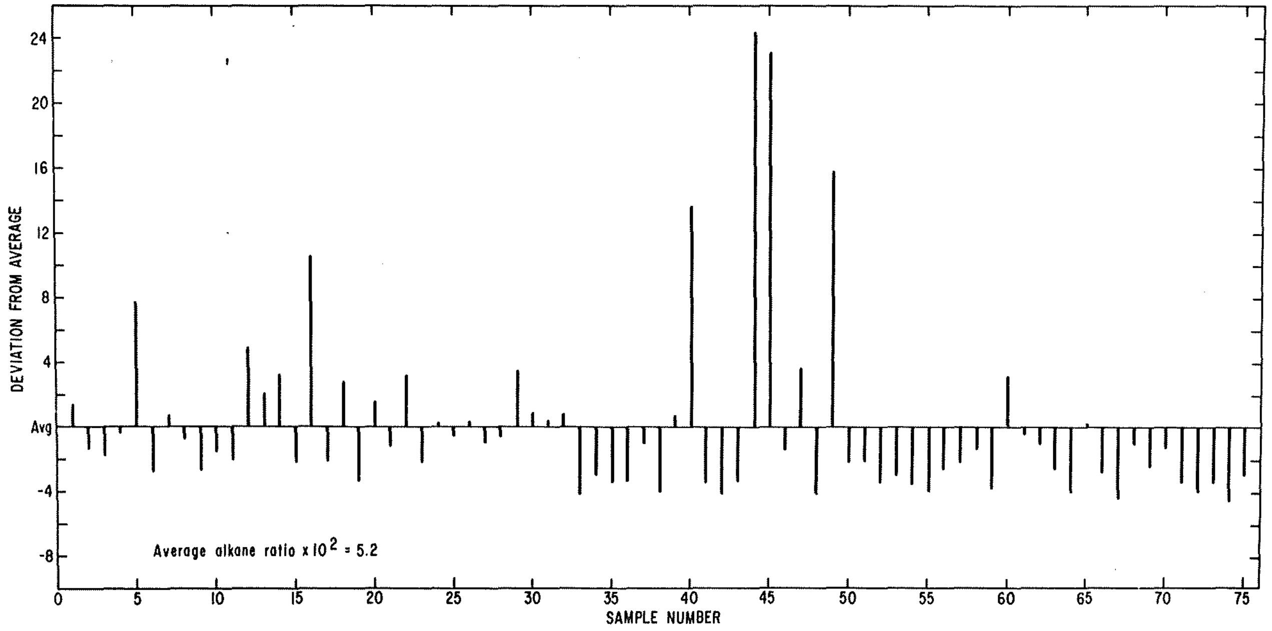

FIGURE 7. - Deviation of total alkane ratios from average.

the Wyoming No. 1 core, show that the soluble organic material was not derived from the insoluble kerogen during geologic time. If, however, the soluble organic material and the kerogen originated from the same precursors and differed only by molecular weight, the extraction ratios would be expected to be nearly the same. As there are considerable deviations from the average values, these variations shown in figure 6 probably resulted from other factors or combinations of several factors. The extremely high average extraction ratio for the WOSCO EX-1 core (22.5) relative to the Colorado No. 1 core (10.9) and the Wyoming No. 1 core (6.9) adds importance to the question of why the Uinta Basin contains more soluble organic material per unit of organic carbon than the other two basins. This study does not answer this question, but the data plotted in figure 6 shows very vividly the very high concentration of extract in some samples and the much lower concentration of extract in samples at the bottom of the formation.

The alkane ratios (fig. 7) show deviations from the average similar to that of the extraction ratios and are not depth related. However, the percentages of the soluble extracts (weight-percent) represented by total alkanes (fig. 8) for samples 41 to 75 generally exceeds the average value. This suggests that position in the formation has a significant influence upon the alkane content of the soluble extracts and that the extracts from the bottom of the formation have been subjected to mild diagenetic alteration. This characteristic was also displayed in the soluble material from Colorado No. 1 core and Wyoming No. 1 core. Because of the significant difference in depths of burial of the three cores, factors other than increased pressure and temperature due to increased depths of burial may have been controlling factors in the high alkane content of the soluble extracts taken from the bottom portions of the Green River Formation.

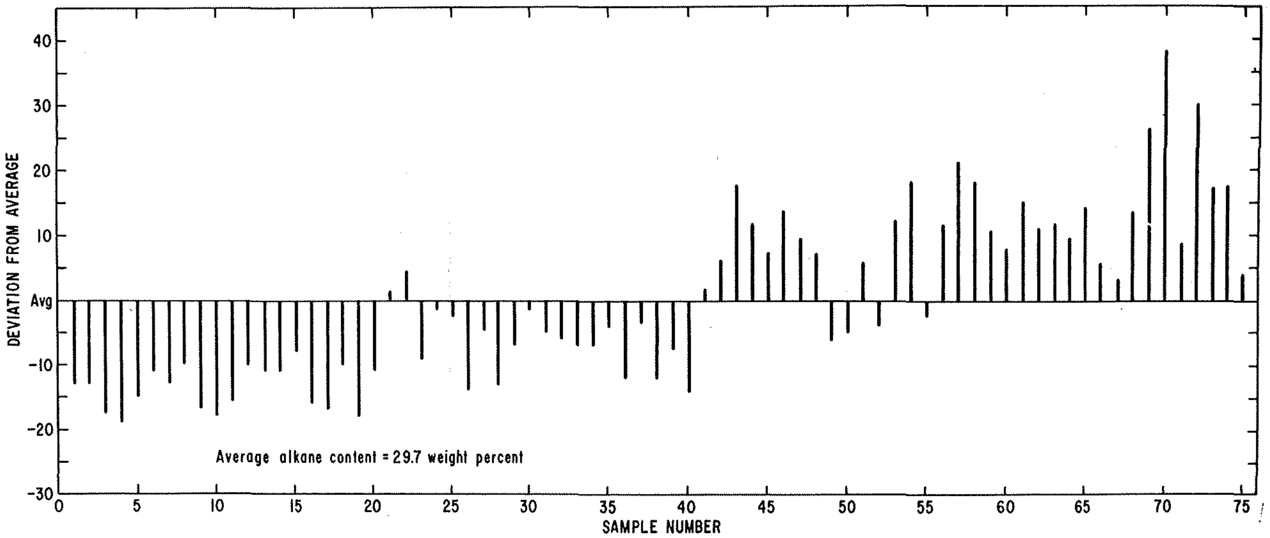

FIGURE 8. - Deviation of total alkane contents from average.

n-Alkane Compounds

The distribution of the n-alkanes by carbon number for each of the 75 samples of soluble extract is given in table 4. Seven of the first eleven samples have little or no n-alkanes in the C_{20} to C_{29} range. This distribution of n-alkanes is different than that for most samples of Green River oil-shale extract, and it occurs in a section of the core that has been described as a highly mineralized zone (8). This suggests that environmental conditions of the lake basin during this period of the deposition had a significant effect upon the composition of the precursors of the n-alkanes. Apparently the conditions of deposition differed for samples 4, 5, and 6 from those of the other eight samples, as their n-alkane distributions were significantly different. Samples 1 through 17 contained extremely high concentrations of the C_{17} n-alkane, and in five samples the C_{17} n-alkane amounted to more than 80 percent of the fraction. Of the selected Colorado No. 1 and Wyoming No. 1 core samples, only samples Nos. 6 and 7 of the Colorado No. 1 core showed similar high yields of the C_{17} n-alkane. Generally, the content of the C_{22} n-alkane was much lower than previously found in Green River samples, and in only 11 samples did the amount of C_{22} n-alkane predominate over adjacent carbon numbers. However, the odd-to-even carbon number predominance for n-alkanes in the C_{25} to $_{31}$ range was very high for this core relative to Colorado No. 1 core and Wyoming No. 1 core. This was due to the absence or near absence of even carbon-numbered n-alkanes in the C_{25} to C_{31} range for samples 1 through 11. These extreme differences in the n-alkane content of samples from the upper portion of the core suggest that differences in environmental conditions had a significant effect upon the carbon-number distribution of the n-alkanes.

The odd-even predominance (9) for the C_{17} and C_{29} n-alkanes is shown in figure 9. For both alkanes, the odd-even predominance (OEP) is extremely high for the upper portion of the core and diminishes to a low value for the bottom one-third of the core. The last 25 samples have odd-even predominances of 2 or less for the normal C_{17}, and the last 15 samples have odd-even predominance of 2 or less for the normal C_{29}. The decrease in OEP with depth of burial is similar to that found for Colorado No. 1 core and Wyoming No. 1 core; however, the magnitude of the OEP value for both carbon numbers at the top of the core is much greater for the Utah core. This is due to the high content of n-C_{17} and the nearly complete absence of even carbon-numbered n-alkanes in the C_{25} to C_{31} range in samples from the upper portion of the Utah core.

TABLE 4. - Distribution of n-alkanes

Sample	Normal alkanes, pct of fraction																						
	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}
1	-	-	4.9	4.2	71.9	1.5	1.3	-	-	-	-	-	-	-	2.0	-	5.0	-	7.0	-	2.2	-	-
2	-	-	4.9	4.8	86.5	2.0	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	2.4	3.9	86.3	-	-	-	-	-	-	-	-	-	-	-	3.7	-	3.7	-	-	-	-
4	-	-	2.3	5.3	65.0	3.1	3.9	2.1	2.4	2.8	2.1	1.2	1.6	-	2.0	-	3.1	-	3.1	-	-	-	-
5	-	-	-	8.6	49.5	2.1	2.5	1.6	1.6	2.0	1.8	.7	2.0	0.8	3.6	1.2	8.2	1.3	8.6	1.1	2.8	-	-
6	-	-	3.6	13.4	63.9	2.3	2.4	1.0	1.3	1.1	.9	-	.7	-	1.2	2.8	2.5	-	2.9	-	-	-	-
7	-	-	2.5	7.6	81.6	3.2	3.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	2.0	3.6	48.6	1.2	1.1	-	-	-	-	-	-	-	3.2	1.7	12.5	2.1	15.9	1.9	6.2	-	-
9	-	-	2.3	5.3	79.5	2.2	2.3	-	-	-	-	-	-	-	-	-	4.1	-	4.3	-	-	-	-
10	-	-	1.4	3.1	86.6	-	-	-	-	-	-	-	-	-	-	-	3.2	-	4.4	-	1.3	-	-
11	-	-	2.9	3.0	84.0	-	1.5	-	-	-	-	-	-	-	-	-	3.6	-	3.9	-	1.1	-	-
12	-	-	-	2.4	65.5	2.7	3.4	1.4	1.5	1.5	1.8	1.0	1.9	1.2	3.4	1.3	5.1	1.0	3.9	-	1.0	-	-
13	-	-	-	2.0	61.0	2.0	2.6	-	1.3	1.4	1.3	-	1.4	1.0	3.3	1.2	7.8	1.4	9.5	-	2.8	-	-
14	-	-	1.1	2.2	49.5	1.9	2.2	.9	1.1	1.1	1.2	.6	1.7	1.0	4.6	1.9	10.6	1.6	12.7	.9	3.2	-	-
15	-	-	2.7	3.2	58.0	2.3	2.4	-	1.1	1.1	1.1	-	1.5	.9	3.4	1.5	7.8	1.3	8.7	.9	2.1	-	-
16	-	-	-	-	41.1	3.0	4.5	3.1	2.9	3.8	3.4	2.4	3.9	2.5	6.2	2.6	10.2	1.7	6.8	.7	1.2	-	-
17	-	-	2.7	3.7	61.0	2.2	2.9	1.2	1.3	1.3	1.3	.9	1.7	1.1	3.5	1.7	6.0	1.1	5.2	-	1.2	-	-
18	-	-	-	1.0	22.2	1.6	2.0	1.1	1.3	1.6	1.7	1.3	3.1	2.2	7.5	3.5	17.0	3.4	19.3	2.5	6.5	0.6	0.6
19	-	-	-	-	6.3	2.1	4.4	3.2	3.9	4.8	4.5	3.0	5.0	3.1	9.4	3.7	17.2	3.3	18.0	2.0	5.1	.5	.5
20	-	-	-	-	7.6	1.9	3.8	2.7	3.5	4.4	4.7	3.1	5.4	3.3	10.2	3.9	17.7	3.1	16.6	2.2	5.0	.5	.4
21	-	-	-	1.0	7.6	1.1	1.3	1.0	1.3	1.4	1.9	1.1	2.7	2.4	10.1	4.7	24.0	4.4	23.1	2.7	6.8	.8	.6
22	-	-	.3	1.3	12.5	2.4	3.5	2.0	2.5	2.8	3.1	1.9	3.2	2.2	6.8	3.1	15.5	3.8	19.7	2.9	7.7	1.3	1.5
23	-	-	.3	1.8	19.8	3.1	4.1	2.1	3.2	3.0	3.3	1.9	3.5	2.0	6.5	2.9	15.4	3.0	16.9	1.7	4.7	.4	.4
24	-	-	-	.6	17.4	2.6	3.8	2.2	3.3	3.2	3.7	2.0	4.2	2.4	6.7	2.8	15.4	3.1	18.0	1.9	5.4	.5	.8
25	0.7	1.6	3.7	3.9	27.2	3.0	3.7	2.5	3.5	3.0	3.7	2.3	4.6	3.2	7.3	3.4	10.9	2.1	7.4	.9	1.4	-	-
26	-	-	.4	.7	1.9	.5	.7	.8	1.0	1.0	1.9	1.5	3.7	3.6	9.8	6.8	22.1	7.1	20.7	4.5	8.3	1.6	1.4
27	-	-	.9	1.2	12.0	1.3	1.7	1.3	2.2	2.1	3.9	2.6	5.4	4.1	10.4	5.3	17.5	3.9	16.6	2.2	4.4	.6	.4
28	-	-	-	.6	23.4	3.4	7.5	3.0	4.4	3.9	4.6	2.4	4.4	2.4	6.0	2.6	12.0	2.5	14.1	1.6	3.5	.4	.3
29	-	-	.5	1.8	18.4	2.0	2.8	1.7	3.0	2.5	3.9	2.0	4.1	2.3	6.8	3.0	13.7	3.4	18.2	2.1	6.4	.6	.8
30	-	-	-	.9	14.9	1.9	2.6	1.7	3.2	2.5	4.2	2.3	5.0	2.8	9.0	3.2	14.0	3.4	18.6	2.3	6.0	.7	.8
31	-	-	-	-	3.2	.6	1.1	.8	1.9	1.8	3.4	2.0	5.6	3.3	12.4	3.8	19.0	4.1	24.7	2.6	8.1	.8	.8
32	-	-	-	.6	12.7	1.7	3.0	1.8	3.9	3.0	4.9	2.4	5.6	3.3	11.1	3.9	14.2	3.1	16.1	1.9	5.7	.6	.5
33	-	-	-	-	2.3	1.6	4.1	3.3	6.4	5.3	7.0	3.6	6.4	4.1	9.8	4.5	16.5	3.6	13.4	2.2	4.6	.7	.6
34	-	-	.8	2.5	15.9	3.7	5.7	3.6	5.4	4.0	5.2	2.9	4.7	3.1	7.1	4.1	13.6	3.3	8.4	1.9	2.9	.7	.5
35	-	-	-	.5	11.6	4.5	8.9	5.1	9.1	5.9	7.6	3.7	5.9	3.5	7.0	3.3	10.4	2.5	6.6	1.3	1.8	.5	.3
36	-	-	-	-	-	-	1.8	2.3	4.8	4.4	5.7	3.5	5.9	4.5	9.5	5.5	18.9	5.2	16.7	3.2	5.9	1.3	.9
37	-	-	-	-	.5	1.1	2.6	2.6	4.8	3.8	5.7	3.4	5.9	4.4	9.3	5.5	18.7	5.5	16.5	2.9	5.6	1.0	.9
38	-	-	-	.9	10.6	5.7	10.0	7.9	8.8	6.7	6.4	3.8	5.0	3.5	5.4	3.2	7.8	2.7	6.9	1.5	2.3	.5	.4

TABLE 4. - Distribution of n-alkanes--Continued

Sample	Normal alkanes, pct of fraction																					
	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}
39	-	-	0.7	0.9	9.2	1.0	1.8	1.1	1.5	2.2	3.1	2.3	5.5	4.2	12.3	5.7	18.0	3.9	15.7	2.4	7.3	0.6	0.6
40	-	0.2	.6	.8	6.5	.7	1.3	.7	1.2	1.8	2.4	1.8	4.5	4.1	11.7	5.6	19.5	4.5	20.0	2.7	8.0	.6	.7
41	-	.5	1.9	3.1	16.9	2.5	3.3	2.3	2.9	3.5	4.1	2.7	5.1	3.8	9.1	4.0	12.0	3.4	11.9	1.8	4.5	.4	.3
42	-	-	-	.2	9.3	1.5	2.8	1.6	2.2	2.4	2.7	1.6	3.2	2.2	6.9	3.7	13.4	4.2	24.6	3.4	12.1	1.1	.9
43	-	-	-	-	-	-	1.0	2.8	5.4	6.6	6.1	4.6	5.5	4.8	7.9	5.4	14.4	5.2	14.7	3.9	7.4	2.4	1.9
44	-	-	-	-	1.1	1.8	3.8	4.8	6.6	7.1	8.5	7.9	9.2	8.4	9.8	8.0	9.7	4.9	4.6	1.7	1.3	.5	.3
45	-	-	-	-	-	-	.3	1.3	1.6	2.8	4.6	5.7	8.3	8.7	11.7	9.8	13.5	8.7	9.9	5.1	4.2	2.2	1.6
46	-	-	-	.8	6.2	2.6	4.0	3.2	4.8	4.7	6.3	3.1	5.9	3.2	8.3	3.6	17.0	3.1	15.1	2.0	5.2	.5	.4
47	-	-	.5	1.6	7.6	3.3	4.1	3.4	4.8	4.5	5.9	3.5	5.7	4.0	8.1	4.6	15.4	3.8	13.0	1.8	3.6	.5	.3
48	0.6	1.9	4.0	4.8	10.3	4.5	5.5	4.0	5.6	4.3	5.5	3.4	5.0	3.7	6.8	3.9	10.7	3.2	7.8	1.5	2.3	.4	.3
49	.5	.9	1.7	2.3	13.5	2.0	2.4	1.7	2.4	2.4	3.2	2.1	4.0	2.9	6.6	3.9	13.8	4.5	17.2	3.3	6.2	1.3	1.2
50	-	-	1.1	2.5	6.6	3.0	4.1	3.4	4.3	3.8	4.8	3.2	4.8	3.8	7.6	4.9	15.2	4.9	12.9	2.8	4.6	.9	.8
51	-	-	.5	3.1	6.9	3.8	5.0	4.1	5.8	4.8	6.2	4.1	6.3	5.0	8.6	5.0	12.8	3.7	8.6	1.9	2.8	.6	.4
52	-	-	-	2.3	.6	1.3	4.0	4.6	7.1	6.2	6.8	5.0	6.3	5.1	8.5	5.2	13.3	3.9	11.2	2.5	4.4	.8	.9
53	-	-	.5	4.0	4.9	4.4	5.2	5.4	6.4	6.0	6.6	5.8	6.9	6.1	6.5	5.2	7.8	3.7	7.4	2.1	3.4	.9	.8
54	-	-	-	10.6	7.1	6.7	7.7	6.7	7.1	6.0	5.7	3.8	4.4	3.3	4.4	3.3	7.7	2.9	5.9	2.2	2.5	1.1	.9
55	-	-	.5	4.0	3.7	6.6	6.3	8.4	5.2	5.7	4.4	4.1	4.0	4.0	5.7	5.1	9.3	5.1	7.1	3.2	3.1	2.0	2.5
56	-	-	.2	5.9	3.9	3.0	3.0	3.7	4.2	4.3	4.8	4.9	6.4	6.9	9.6	7.2	13.3	5.0	6.8	2.5	2.6	1.0	.8
57	-	-	-	4.1	7.5	6.9	7.6	7.3	7.8	6.1	5.7	4.0	4.7	3.8	5.8	3.5	8.1	2.7	7.6	1.9	3.1	.9	.9
58	-	-	-	1.3	2.7	1.3	2.4	2.4	6.1	3.7	8.2	4.9	8.8	6.6	12.6	5.6	15.1	3.0	9.3	1.4	3.9	.4	.3
59	-	0.5	.6	2.1	6.3	6.7	8.6	7.4	7.2	6.0	6.8	6.0	7.6	5.1	9.9	3.7	7.3	2.0	3.0	1.1	.9	.7	.5
60	0.2	1.1	4.2	2.3	4.6	3.4	4.9	4.6	5.7	5.2	7.0	6.7	8.9	6.1	13.6	4.1	10.2	2.0	4.0	.7	.5	-	-
61	-	-	-	.7	2.5	2.4	4.1	4.1	4.8	5.7	5.8	5.9	7.3	7.1	10.0	7.2	10.9	5.3	8.6	2.5	3.6	.8	.7
62	-	-	-	1.1	2.8	2.0	3.5	2.5	3.1	3.5	4.0	4.4	5.9	6.8	9.3	7.8	14.7	6.9	11.9	3.0	5.2	.9	.7
63	-	-	.5	2.6	4.7	4.1	5.1	5.1	4.6	6.2	6.5	6.5	7.3	7.5	7.9	7.2	8.0	5.0	4.8	2.2	1.9	.8	.5
64	-	-	-	3.6	10.4	7.6	10.0	8.2	8.5	8.0	7.1	6.3	6.2	5.7	5.5	4.1	4.0	1.3	1.3	.9	.9	.4	-
65	-	-	.3	2.6	6.0	4.7	6.7	8.1	5.5	6.0	6.3	4.7	5.8	3.8	6.4	6.4	8.9	4.5	5.9	3.1	2.8	.9	.6
66	-	-	-	1.2	3.8	3.4	5.1	5.7	6.9	8.1	8.5	7.8	8.2	8.5	8.7	6.7	6.7	3.6	3.4	1.5	1.3	.5	.4
67	-	-	-	4.0	16.5	8.6	7.6	7.5	6.8	7.4	6.6	6.1	5.7	5.3	5.0	4.0	3.5	2.0	1.7	.8	.6	.3	-
68	-	-	-	1.0	1.6	2.6	3.8	4.6	6.0	6.9	7.7	7.6	8.8	9.1	10.4	8.5	8.3	4.9	4.2	1.8	1.4	.5	.3
69	-	-	-	.2	.5	1.5	2.4	4.7	6.3	7.6	7.7	8.4	9.1	9.4	11.1	8.3	8.7	4.9	4.1	2.0	1.6	.8	.7
70	-	-	-	-	2.9	4.9	4.9	9.4	4.7	7.3	5.3	6.2	5.6	5.5	6.7	5.9	8.4	4.6	7.1	3.6	3.7	2.0	1.3
71	-	-	-	-	-	.7	2.2	3.6	4.2	5.3	5.8	6.1	7.8	8.2	11.6	8.3	11.1	6.1	8.2	3.6	3.9	1.8	1.5
72	-	-	-	-	1.7	2.3	3.0	3.8	4.6	5.1	6.1	6.4	8.7	9.3	13.3	9.0	11.2	5.5	5.7	2.0	1.7	.6	-
73	-	-	.3	2.0	5.1	4.0	4.7	5.5	6.4	8.0	6.1	5.4	6.2	4.8	6.6	5.0	8.0	3.9	9.3	2.4	4.5	1.0	.8
74	-	-	-	.9	2.9	4.6	7.1	7.9	9.6	10.9	8.2	6.8	7.2	6.0	7.3	5.0	6.0	2.8	3.9	1.2	1.2	.3	.2
75	-	-	.1	.8	1.6	1.9	3.4	3.1	4.4	5.3	6.1	7.0	9.4	9.9	12.2	8.2	10.2	4.9	6.1	1.8	2.6	.6	.4

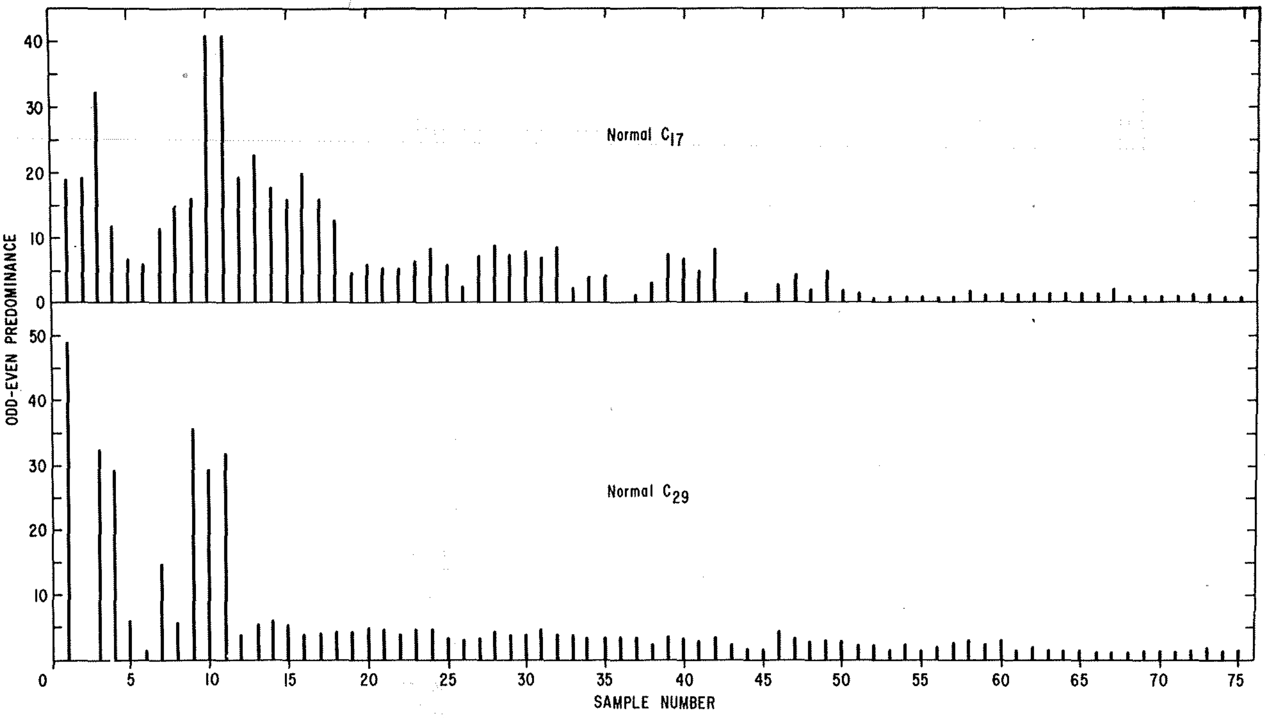

FIGURE 9. - Odd-even predominance of selected n-alkanes.

Isoprenoid Compounds

The distribution of the 11 major isoprenoid compounds isolated from the soluble extracts is shown in table 5. Unlike the n-alkanes, the distribution of the isoprenoid compounds in the extracts from the highly mineralized portion of the core was not significantly different than the remainder of the samples. There were major differences, however, in the distribution of the isoprenoid compounds for the entire core. For example, the amounts of the C_{20} isoprenoid compound (phytane) ranged from 0.7 to 31.7 percent, and the amounts of the C_{40} isoprenoid compound (perhydro-β-carotene) ranged from 0.8 to 28.0 percent. These are significant differences, most of which probably are explained by source material differences. The total amount of the branched plus cyclic alkane fraction represented by the 11 isoprenoid compounds ranged from 27.5 to 82.0 percent with a tendency for the lower values to be represented by samples from the bottom portion of the formation.

TABLE 5. - Distribution of 11 major isoprenoid compounds

Sample	Selected alkanes, weight-percent of branched plus cyclic alkanes											
	Chain isoprenoids					5α Steranes			Pentacyclic triterpanes		Perhydro-β-carotene	Total
	C_{15}	C_{16}	C_{18}	C_{19}	C_{20}	C_{27}	C_{28}	C_{29}	$C_{30\text{-A}}$	$C_{30\text{-C}}$	C_{40}	
1	2.1	7.8	5.1	17.0	17.4	0.4	6.4	3.3	6.4	2.8	4.5	73.2
2	1.5	5.9	3.9	13.0	13.4	.2	7.2	3.3	5.6	3.0	4.9	61.9
3	1.4	5.2	3.7	13.1	13.8	.2	7.0	3.3	4.6	2.8	3.5	58.6
4	1.0	3.4	2.2	7.5	12.3	.3	5.0	3.5	5.7	3.3	14.3	58.5
5	-	-	2.6	8.8	22.2	.1	4.7	2.8	4.9	2.6	13.1	61.8
6	-	3.2	5.9	15.8	31.7	.1	6.4	4.7	6.2	3.8	4.2	82.0
7	-	1.3	2.4	8.4	11.6	.8	4.4	3.4	5.5	3.3	10.3	51.4
8	-	2.8	2.7	9.4	10.3	.6	4.4	3.8	5.8	3.1	11.3	54.2
9	-	4.8	3.6	13.9	12.8	.5	4.9	2.6	6.6	3.3	5.8	58.8
10	-	2.0	2.1	8.4	9.5	.5	4.2	1.9	6.5	3.5	15.8	54.4
11	-	2.4	2.4	7.3	8.6	.6	5.6	3.9	6.8	3.8	11.5	52.9
12	-	-	2.7	9.2	10.4	2.0	5.6	3.2	9.9	5.2	25.8	74.0
13	-	1.1	2.3	8.0	7.7	1.3	4.8	3.7	6.5	4.0	21.5	60.9
14	-	1.4	2.1	8.6	8.5	1.5	3.8	4.2	7.7	4.1	16.8	58.7
15	1.2	4.6	2.7	8.4	7.1	1.5	4.8	4.4	6.5	2.7	14.5	58.4
16	-	-	1.2	4.4	3.9	2.9	3.9	2.6	6.6	4.4	20.3	50.2
17	.6	4.0	3.5	10.6	8.8	2.0	3.9	3.1	6.2	3.4	5.6	51.7
18	-	1.1	1.9	8.3	8.6	1.8	3.9	2.9	5.7	3.0	12.1	49.3
19	-	-	1.8	7.3	7.3	1.4	4.0	4.3	8.3	5.2	18.2	57.8
20	-	1.2	2.1	9.7	10.5	1.8	3.5	3.9	5.7	2.6	16.5	57.5
21	-	1.0	1.3	5.0	6.0	.9	4.1	5.8	6.0	3.2	25.1	58.4
22	-	.2	1.2	4.8	5.4	1.2	3.7	5.9	4.8	2.4	30.5	60.1
23	-	-	1.3	5.0	5.5	1.6	4.3	4.5	6.4	3.5	20.0	52.1
24	-	.4	1.5	5.3	5.7	.9	2.3	2.5	4.5	2.4	14.7	40.2
25	1.7	5.2	4.2	10.5	8.5	1.0	2.6	2.8	6.2	3.8	13.3	59.8
26	-	.8	1.1	2.6	2.9	2.7	7.0	9.1	4.9	14.4	11.7	57.2
27	.9	3.4	3.3	8.0	6.5	1.3	2.2	2.2	6.3	3.5	24.3	61.9
28	-	.3	1.1	4.3	4.1	2.3	5.6	3.7	7.6	3.3	10.2	42.5
29	-	.3	1.2	4.9	4.8	1.1	2.9	4.6	5.9	3.6	28.0	57.3
30	-	1.9	3.0	10.5	9.7	1.3	2.8	3.7	7.0	3.2	17.0	60.1
31	-	.6	1.8	8.1	8.6	1.4	3.4	4.9	5.7	3.3	22.9	60.7
32	-	-	1.6	7.0	9.8	1.7	6.4	5.9	5.4	5.0	10.7	53.5
33	-	.5	3.3	9.9	10.4	3.0	6.9	8.4	5.2	4.1	2.1	53.8
34	-	.4	1.0	2.9	2.8	2.4	4.6	6.0	5.9	4.7	12.4	43.1
35	-	-	.8	4.8	9.4	1.8	3.2	6.2	5.6	3.7	7.5	43.0
36	-	.3	.9	3.3	4.2	2.3	3.8	7.6	8.8	5.9	10.0	47.1
37	-	-	.5	2.0	2.9	2.3	4.5	6.4	8.4	5.4	16.0	48.4
38	-	-	.7	2.4	2.9	2.3	4.1	5.4	7.3	6.6	8.9	40.6
39	.6	2.7	2.3	9.1	9.6	2.3	4.8	6.3	6.1	4.0	9.0	56.8
40	.9	4.0	3.1	12.3	13.1	2.8	4.3	5.8	5.3	3.0	4.2	58.8
41	-	2.8	3.6	14.1	13.7	2.4	5.3	8.2	6.8	3.8	9.3	70.0
42	-	-	1.7	4.1	5.4	1.9	4.8	5.2	4.2	4.2	9.5	40.0
43	-	-	.7	2.3	2.4	2.3	4.0	5.3	4.4	4.4	15.0	40.8

TABLE 5. - Distribution of 11 major isoprenoid compounds--Continued

Sample	Selected alkanes, weight-percent of branch plus cyclic alkanes											Total
	Chain isoprenoids					5α Steranes			Pentacyclic triterpanes		Perhydro-β-carotene	
	C_{15}	C_{16}	C_{18}	C_{19}	C_{20}	C_{27}	C_{28}	C_{29}	$C_{30\text{-A}}$	$C_{30\text{-C}}$	C_{40}	
44	-	-	0.3	1.1	2.1	2.1	3.2	6.7	4.7	5.7	6.9	32.8
45	-	-	-	.4	.8	2.2	2.2	5.1	5.1	6.5	8.3	30.6
46	-	-	1.8	6.1	7.0	1.5	5.6	5.4	4.7	5.3	9.7	47.1
47	-	-	2.5	5.0	5.4	1.8	6.1	6.0	3.3	3.5	15.4	49.0
48	0.6	2.2	2.0	7.0	7.1	2.2	9.0	11.7	4.6	3.5	6.2	56.1
49	.9	2.4	2.2	5.6	4.5	1.0	2.3	3.2	4.6	2.9	22.3	51.9
50	-	.7	1.7	3.4	3.9	1.6	8.4	11.9	5.1	3.8	13.2	53.7
51	-	-	1.1	2.8	3.6	3.2	7.4	11.3	4.8	4.1	13.0	51.3
52	-	-	1.6	5.6	7.8	3.3	5.2	8.9	6.1	5.4	10.8	54.7
53	-	-	1.6	3.6	3.3	2.5	4.2	7.5	6.3	5.7	6.2	40.9
54	-	-	.5	2.1	2.2	2.6	3.6	8.7	7.1	5.6	6.6	39.0
55	-	-	-	.1	.7	4.3	4.1	7.9	5.9	4.6	3.6	31.2
56	-	-	.5	1.6	3.0	2.6	3.3	4.5	3.2	3.2	8.7	30.6
57	-	-	.3	1.2	2.0	2.5	3.2	5.0	4.6	3.8	21.7	44.3
58	-	-	1.0	4.4	5.1	2.6	4.3	6.9	4.7	4.2	10.1	43.3
59	-	-	.5	1.6	2.9	2.2	3.2	7.7	5.6	4.6	10.6	38.9
60	-	.3	2.0	3.7	4.6	4.7	6.6	9.2	4.7	3.2	11.4	50.4
61	-	-	1.2	2.3	4.8	3.3	5.0	7.4	4.7	3.5	12.5	44.7
62	-	-	1.5	2.5	6.9	4.8	8.4	10.0	4.2	2.8	8.5	49.6
63	-	-	1.2	1.9	4.1	3.1	4.7	5.8	5.0	4.7	7.4	37.9
64	-	-	2.0	3.7	5.4	3.2	5.5	10.4	6.6	5.6	10.2	52.6
65	-	-	1.6	4.3	7.6	3.9	4.8	6.8	4.3	5.0	3.5	41.8
66	-	-	.1	1.4	4.6	3.4	4.0	4.3	4.5	5.4	4.6	32.3
67	-	-	.6	3.3	7.4	3.0	2.9	3.1	3.0	3.4	.8	27.5
68	-	-	.3	1.4	3.4	5.0	5.8	8.0	6.7	7.4	4.5	42.5
69	-	-	.1	.6	1.4	3.7	5.7	6.8	4.8	3.9	3.8	30.8
70	-	-	-	.5	3.1	5.2	5.2	3.5	4.8	4.2	2.1	28.6
71	-	-	.4	3.7	9.9	1.8	2.3	2.5	3.7	2.3	1.0	27.6
72	-	-	-	.2	1.7	6.8	7.3	10.1	7.7	7.1	4.6	45.5
73	-	-	2.9	7.8	7.0	3.1	4.1	6.4	5.8	3.7	1.8	42.6
74	-	-	1.5	5.2	8.7	3.3	5.0	4.8	4.9	4.3	2.8	40.5
75	-	.8	3.9	6.2	7.3	5.9	5.6	5.5	4.5	3.0	2.1	44.8

The distribution of the four isoprenoid compound types relative to individual samples is shown in figure 10. Samples 5, 40, and 49 contain the most chain isoprenoid compounds; samples 40, 44, and 45 contain the most steranes; samples 16, 44, and 45 contain the most pentacyclic triterpanes; and samples 16, 22, and 49 contain the most perhydro-β-carotene. It is of interest to note that six of these seven samples (5, 16, 40, 44, 45, and 49) have the six highest extraction ratios of the 75 samples. This suggests a relationship of some nature between the amount of isoprenoid compounds present in the soluble extract and the extraction ratios. It is also of interest to note that the amount of chain isoprenoid compounds in sample 40 contains about 6 percent of the total organic carbon and that the perhydro-β-carotene in

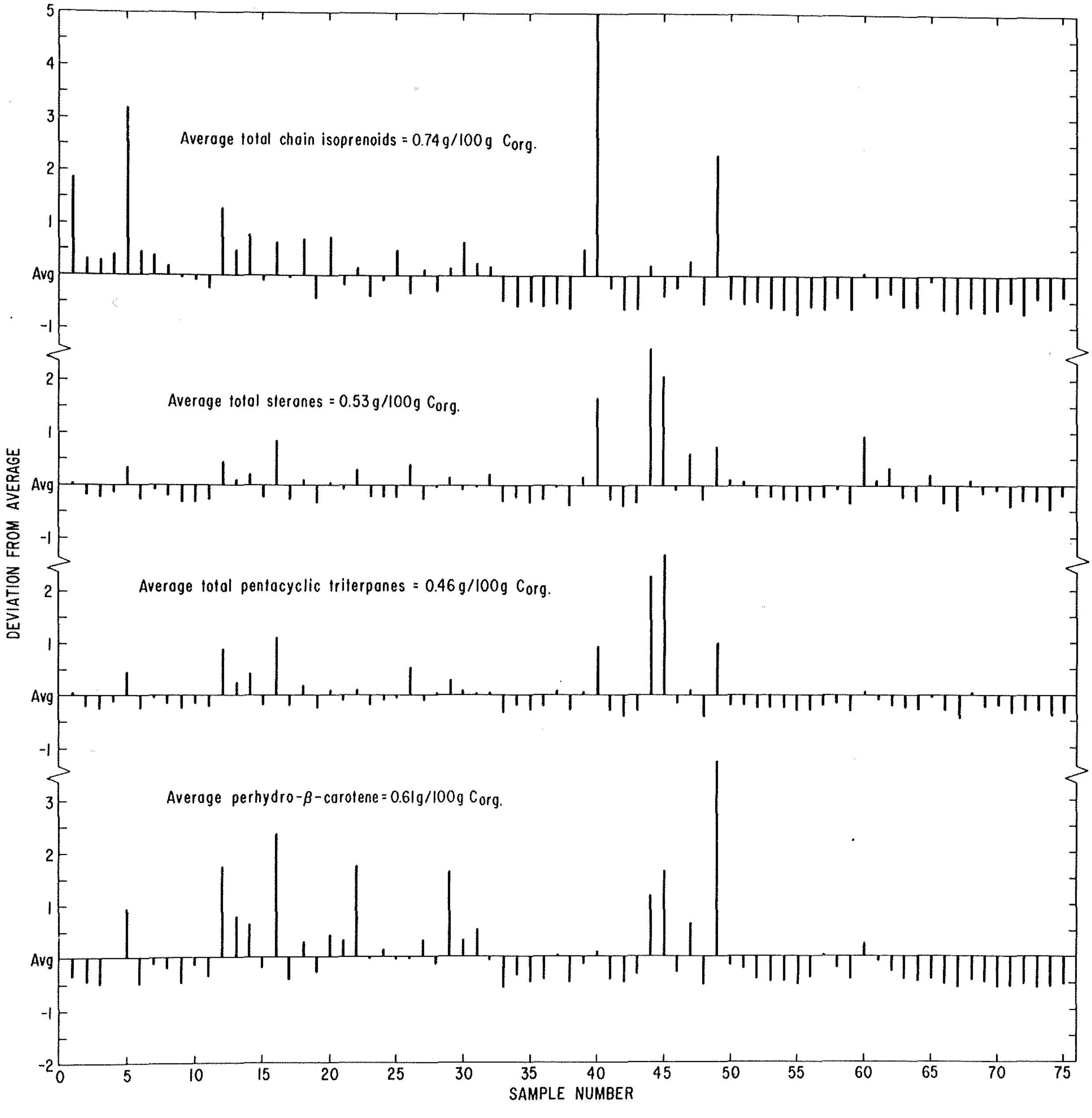

FIGURE 10. - Deviation of major branched and cyclic-alkane types from average.

sample 49 contains about 4 percent of the total organic carbon. This represents a significantly large amount of the total organic carbon in the oil-shale samples. Figure 10 also illustrates the nearly consistent below average amounts of the 11 isoprenoid compounds in samples 50 through 75.

It is evident that there are major differences in the isoprenoid contents of samples 16, 26, 40, and 49 relative to the samples immediately above or below these bitumen-impregnated samples. These compositional differences suggest little upward or downward post-depositional migration of the soluble organic material from strata to strata in this particular location of the formation.

Linear Regression Analysis

Linear regression analysis was used to investigate significant relationships in the data collected for the soluble extracts. Data for the calculated regression curve and other pertinent information for these relationships are shown in table 6.

TABLE 6. - Linear correlations for the soluble organic material

No.	Relationship (Y = a + bX)	r^2	a	b	$\bar{S}yx$	F-ratio[1]
1	Soluble extract[2] (Y); organic carbon[2] (X)..	0.04	0.69	+0.07	1.02	3.3
2	Extraction ratio[3] (Y); depth[4] (X)..........	.18	.97	-.32	.22	15.8
3	Alkane ratio[3] (Y); depth[4] (X)..............	.03	.12	-.03	.05	2.2
4	C_{20}/C_{19} ratio[3] (Y); depth[4] (X).............	.18	-2.31	+1.67	1.16	16.2
5	C_{19} isoprenoid ratio[3] (Y); C_{20} isoprenoid ratio[3] (X).	.80	.04	+.70	.14	293.0
6	C_{18} isoprenoid ratio[3] (Y); C_{20} isoprenoid ratio[3] (X).	.73	.02	+.19	.05	188.2
7	C_{28} sterane ratio[3] (Y); C_{29} sterane ratio[3] (X).	.72	.07	+.52	.09	186.3
8	C_{27} sterane ratio[3] (Y); C_{29} sterane ratio[3] (X).	.80	<.01	+.37	.05	284.9
9	$C_{30\text{-C}}$ pentacyclic ratio[3] (Y); $C_{30\text{-A}}$ pentacyclic ratio[3] (X).	.77	-.04	+.91	.13	251.4
10	Total sterane ratio[3] (Y); total chain isoprenoid ratio[3] (X).	.22	.33	+.27	.47	20.3
11	Total pentacyclic ratio[3] (Y); total chain isoprenoid ratio[3] (X).	.19	.27	+.25	.48	16.8
12	Total C_{40} carotene ratio[3] (Y); total chain isoprenoid ratio[3] (X).	.23	.30	+.41	.68	22.0
13	Total pentacyclic ratio[3] (Y); total sterane ratio[3] (X).	.84	-.02	+.90	.21	388.8
14	Total C_{40} carotene ratio[3] (Y); total sterane ratio[3] (X).	.38	.14	+.89	.61	43.9
15	Total C_{40} carotene ratio[3] (Y); total pentacyclic ratio[3] (X).	.52	.12	+1.07	.54	80.7

[1] Table value corresponding to F = 0.01 (99 percent) is 7.1 for 75 samples.
[2] Weight-percent of oil shale.
[3] Based on grams of component per 100 grams of organic carbon.
[4] In thousands of feet.

There appears to be no linear relationship between the amount of soluble extract (weight-percent) and the organic carbon content (weight-percent) of the shale. This differs from results found for Colorado No. 1 core and Wyoming No. 1 core where positive relationships were found for these properties. A positive relationship between these two properties shows that for each increase in organic carbon content of the oil shale there is a corresponding increase in soluble extract. A negative linear relationship, where the soluble extract increases as the carbon content decreases, suggests degradation of organic carbon into soluble extract. No relationship between the two properties may imply loss of soluble extract relative to total organic carbon, possibly by migration. This possibility may be illustrated further by the relationship between extraction ratio and depth of burial where a negative linear relationship (r^2 = 0.18) was found for the Utah core. A positive relationship for these properties would suggest degradation of carbon to soluble extract or an inflow of soluble extract with increase in depth of burial; no relationship would suggest a constant ratio of extract to carbon irrespective of depth burial; and a negative relationship would suggest a decrease in extract relative to carbon by migration, decomposition, or decreased amounts of precursor material for the soluble extract with increased depth of burial. The negative relationship found may imply lateral migration of some of the soluble organic material sometime during its history into fissures, veins, crystal cavities, or sandstone pores accounting for some of the bitumen-filled veins of the Uinta Basin (4). Below average amounts of soluble extract were found for samples from the bottom portion of the core (table 3). As would be expected from the above relationships, the alkane ratios do not show a correlation with depth of burial.

A positive linear relationship (r^2 = 0.18) was found for the C_{20}/C_{19} isoprenoid ratio with depth of burial. This differs from what would be expected if the C_{19} isoprenoid compound were derived from the C_{20} isoprenoid compound by depth-related factors. Significantly high r^2 values (0.80 and 0.73) were found for the relationships between the C_{19} and C_{20} isoprenoid compounds and the C_{18} and C_{20} isoprenoid compounds. Because both relationships were positive, it can be concluded that neither the C_{18} nor the C_{19} compounds were degraded from the C_{20} compound after deposition. However, it does suggest that all three of the chain isoprenoid compounds had common precursors. Likewise, the C_{27}, C_{28}, and C_{29} steranes as well as the C_{30}-A and the C_{30}-C pentacyclic triterpane compounds all showed positive relationships with r^2 values ranging from 0.72 to 0.80. This suggested also that the three steranes had common precursors as did the two C_{30} pentacyclic triterpanes.

The total steranes, total pentacyclic triterpanes, and the total C_{40} carotenes were correlated with the total chain isoprenoid compounds. Positive relationships were found with r^2 values ranging from 0.19 to 0.23. This suggests that the three different types of isoprenoid compounds may have had some common precursors with the chain isoprenoid compounds. More significant positive relationships were found between the total steranes, total pentacyclic triterpanes, and the total C_{40} carotenes where positive relationships with r^2 values ranging from 0.38 to 0.84 were obtained. The results suggest that these three isoprenoid-type compounds may have had common origins and common precursors.

Kerogen

Differences in the kerogen from the selected samples were determined by the use of various structure-related properties. These properties are as follows: Atomic hydrogen-to-carbon ratio (H/C); volatile material ratio (VM); carbon residue ratio (CR); oxidation rate (OR); and specific gravity of the

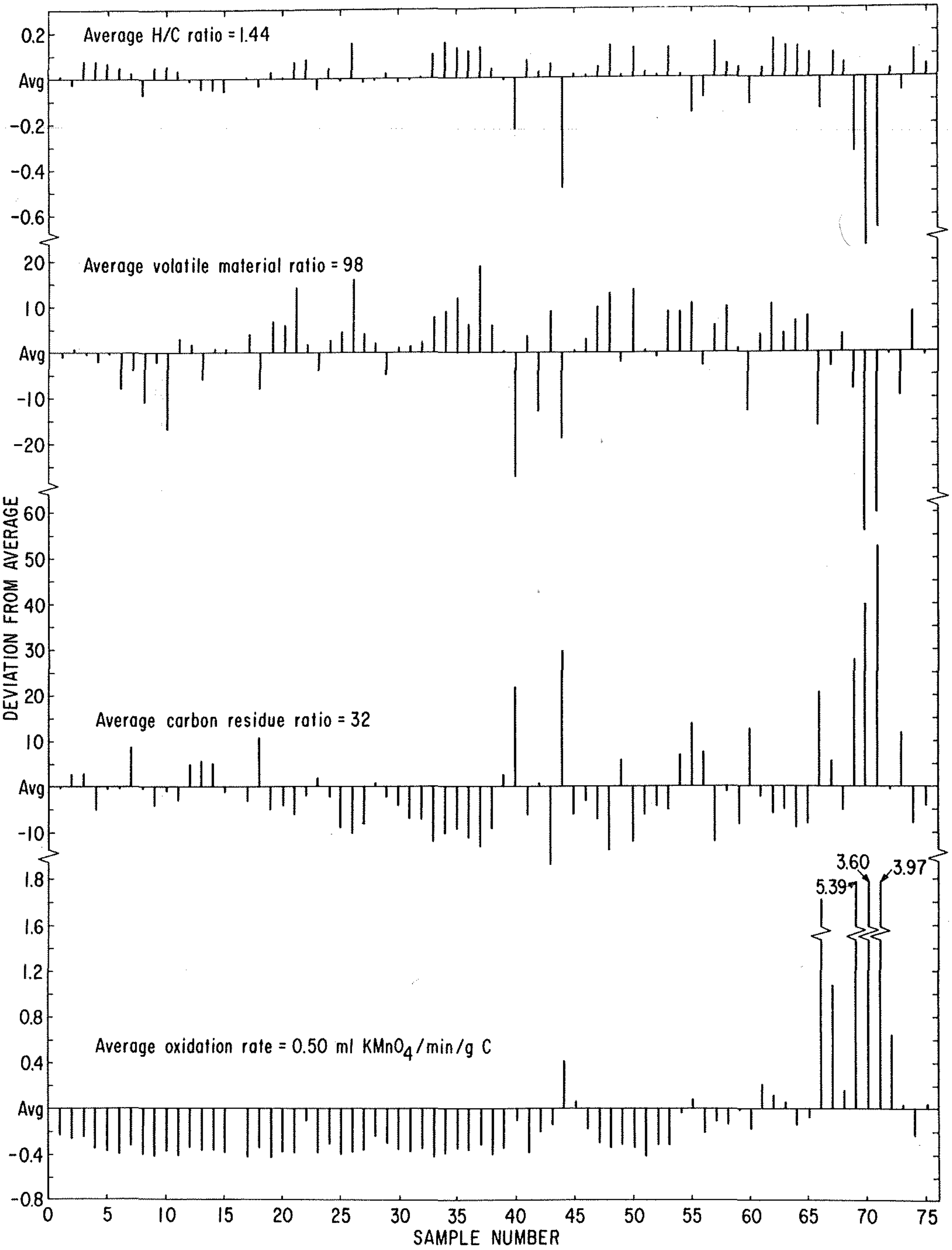

FIGURE 11. - Deviation of H/C ratios, volatile material ratios, carbon residue ratios, and oxidation rates from average.

assay oil. The first four properties indicate differences in aromatic content of the kerogen, and the last property shows differences in the oil-producing portion of the kerogen. The thermal alteration index (TAl) or the degree of kerogen alteration during geologic time was estimated by optical microscopic observation.

The test results are shown in table 7. The H/C ratios range from 0.70 to 1.61; the VM ratios range from 59 to 117; the CR ratios range from 15 to 85; the oxidation rates range from 0.08 to 5.89; the TAl's range from 1.6 to 3.8; and the specific gravities of the assay oils range from 0.898 to 0.938. These results show that there are significant differences in the kerogen structure and in the specific gravity of the oil produced from the kerogen by assay.

A plot of the first four properties as positive or negative deviation from the average for each sample is shown in figure 11. In general, the results show that higher than average aromatic content of the kerogen occurs in samples from the bottom portion of the core. This is evidenced by below-average H/C ratios, below-average volatile material ratios, above-average carbon residue ratios, and above-average oxidation rates for samples in this section of the core. There are some exceptions to this generalization; for example, the below-average values for the volatile material ratio at the top of the core and the nearly consistent deviation of samples 40 and 44. These two samples are among those pointed out earlier as having the highest extraction ratios, suggesting that for these two samples there may be some relationship between aromaticity of the kerogen and the extraction ratios. The evidence for the above-average aromatic content of the kerogen of the Utah core is similar to results obtained for Colorado No. 1 core and Wyoming No. 1 core where an increase in aromaticity of the kerogen was found also for samples taken from the bottom of the formation.

Somewhat like Colorado No. 1 core, the specific gravities of the assay oils from the Utah core samples show (fig. 12) a general decrease with burial depth. Whereas the Colorado samples showed a fairly consistent decrease in specific gravity of the assay oil with increase in sample number (depth related), the decrease in specific gravity for the Utah core is much more variable.

Linear regression analysis was used to correlate properties of the kerogen from each of the selected samples. The values for the regression curves, the coefficient of determination, the standard error of estimate, and the F-ratio are shown in table 8. In each instance, the values for the five properties of the kerogen are related successively to depth of burial, alkane ratio of the soluble extracts, and organic carbon contents of the original oil-shale sample.

Apparently there is no linear relationship between increased aromatization of the kerogen and depth of burial as there was no linear relationship between H/C ratio, VM ratio, CR ratio, and depth of burial. However, there was some indication of a positive relationship between oxidation rate and depth of burial (r^2 = 0.23). There was also some evidence of a negative correlation (r^2 = 0.30) between specific gravity of the assay oil and depth of burial. As discussed previously, this general trend is seen in figure 12.

TABLE 7. - Properties relating differences in the kerogen

Sample	Atomic hydrogen to carbon ratio	Volatile material ratio[1]	Carbon residue ratio[2]	Oxidation rate[3]	Thermal alteration index	Specific gravity of assay oil
1	1.45	97	32	0.27	3.6	0.938
2	1.41	99	35	.24	3.0	.934
3	1.52	98	35	.26	2.9	.926
4	1.52	96	28	.15	2.8	.911
5	1.52	98	32	.13	3.1	.901
6	1.49	90	32	.10	2.8	.932
7	1.47	94	41	.18	3.7	.921
8	1.37	87	32	.11	2.9	.928
9	1.49	96	28	.08	2.3	.927
10	1.50	81	31	.12	2.9	.927
11	1.47	101	29	.08	2.9	.928
12	1.43	100	37	.16	3.7	.925
13	1.39	92	38	.15	3.5	.923
14	1.39	99	37	.14	3.5	.926
15	1.38	99	31	.12	2.6	-
16	-	-	-	-	-	-
17	1.44	102	29	.09	2.2	-
18	1.41	90	43	.17	3.3	.930
19	1.47	105	27	.08	2.1	.925
20	1.44	104	28	.13	2.8	.921
21	1.51	112	26	.12	3.2	.905
22	1.52	100	30	.41	3.6	.914
23	1.39	94	34	.12	3.1	.927
24	1.48	101	30	.20	2.9	.917
25	1.43	103	23	.11	2.9	-
26	1.59	114	22	.12	3.4	-
27	1.42	102	24	.15	2.8	-
28	1.43	100	33	.26	3.1	.921
29	1.46	93	30	.21	3.0	.922
30	1.42	99	28	.14	3.2	.923
31	1.43	99	25	.15	3.2	.918
32	1.44	100	25	.16	1.9	.924
33	1.55	106	20	.09	1.9	.908
34	1.60	107	22	.10	2.4	.900
35	1.57	110	23	.17	2.8	.921
36	1.56	104	21	.15	2.9	.900
37	1.58	117	19	.18	3.1	.913
38	1.48	104	23	.10	1.6	.914
39	1.43	98	35	.17	2.9	-
40	1.21	71	54	.41	3.8	-
41	1.52	102	26	.13	2.0	-
42	1.47	85	33	.31	2.7	.931
43	1.50	107	15	.37	2.1	.923

See footnotes at end of table.

TABLE 7. - Properties relating differences in the kerogen--Continued

Sample	Atomic hydrogen to carbon ratio	Volatile material ratio[1]	Carbon residue ratio[2]	Oxidation rate[3]	Thermal alteration index	Specific gravity of assay oil
44	0.95	79	62	0.91	3.8	-
45	1.45	98	26	.56	2.8	-
46	1.45	101	29	.32	2.9	0.922
47	1.49	108	25	.20	3.4	.908
48	1.58	111	18	.16	2.9	-
49	1.45	96	38	.18	3.4	-
50	1.57	112	20	.17	2.9	-
51	1.46	98	26	.09	2.9	.910
52	1.44	97	28	.18	2.8	.917
53	1.57	107	27	.19	2.5	.919
54	1.45	107	39	.46	3.4	.924
55	1.28	109	46	.58	3.8	-
56	1.35	95	40	.28	3.6	-
57	1.59	104	20	.40	1.8	.927
58	1.50	108	31	.36	3.5	.917
59	1.48	99	24	.50	2.8	.913
60	1.32	85	45	.32	3.7	.904
61	1.48	102	30	.72	3.0	.925
62	1.61	109	26	.62	2.9	.903
63	1.58	102	27	.56	2.9	.899
64	1.58	105	23	.36	2.8	.898
65	1.55	106	24	.42	2.8	.900
66	1.30	82	53	2.32	3.7	.912
67	1.55	95	38	1.58	3.3	.901
68	1.51	102	27	.66	2.8	.909
69	1.11	90	60	5.89	3.8	-
70	.70	59	72	4.10	3.8	-
71	.78	63	85	4.47	3.8	-
72	1.48	98	32	1.16	1.7	-
73	1.38	89	44	.53	3.3	.918
74	1.56	107	24	.27	2.8	.907
75	1.50	98	28	.53	3.2	.911

[1] $\frac{\text{Wt-pct VM}}{\text{Wt-pct organic carbon}} \times 10^2$.

[2] $\frac{\text{Wt CR}}{\text{Wt organic carbon}} \times 10^2$.

[3] Milliliters of permanganate solution per minute per gram organic carbon.

TABLE 8. - Linear correlations for the kerogen

No.	Relationship[1]	r^2	a	b	$\bar{S}yx$	F-ratio[2]
1	H/C ratio (Y); depth (X).............	0.04	1.66	-0.09	0.15	2.8
2	VM ratio (Y); depth (X)..............	.01	104.6	-2.67	10.3	.5
3	CR ratio (Y); depth (X)..............	.05	13.3	+8.06	11.7	3.7
4	Oxidation rate (Y); depth (X).........	.23	-2.84	+1.42	.84	22.0
5	Sp. gr. assay oil (Y); depth (X)......	.30	.955	-.016	.009	22.4
6	H/C ratio (Y); alkane ratio (X).......	.07	1.48	-.01	.15	5.4
7	VM ratio (Y); alkane ratio (X)........	.07	100.9	-.5	10.0	5.2
8	CR ratio (Y); alkane ratio (X)........	.06	29.4	+.5	11.6	4.6
9	Oxidation rate (Y); alkane ratio (X)..	.01	.56	-.01	.96	.3
10	Sp. gr. assay oil (Y); alkane ratio (X).	.01	.916	+.001	.010	.6
11	H/C ratio (Y); organic carbon[3] (X)....	.20	1.33	+.02	.14	17.6
12	VM ratio (Y); organic carbon[3] (X).....	.13	92.5	+1.0	9.6	11.2
13	CR ratio (Y); organic carbon[3] (X).....	.27	41.8	-1.6	10.2	26.7
14	Oxidation rate (Y); organic carbon[3] (X).	.16	1.09	-.10	.88	13.4
15	Sp. gr. assay oil (Y); organic carbon[3] (X).	.07	.922	-.001	.010	3.8

[1] $Y = a + bX$.
[2] Table value corresponding to F = 0.01 (99 percent) is 7.1 for 75 samples.
[3] Weight-percent of oil shale.

None of the five properties of the kerogen showed linear relationships to the alkane ratios of the soluble extracts. This suggests that the changes which occurred to the kerogen and to the soluble extract during or after deposition are not related to each other. Specifically, a tendency for aromatization of kerogen was not associated with a corresponding increase in alkane contents of the soluble extracts.

There appears to be a slight tendency for the aromatic content of the kerogen to be related to the organic carbon content of the oil-shale samples. For example, there was some evidence ($r^2 = 0.20$) that the H/C ratio was

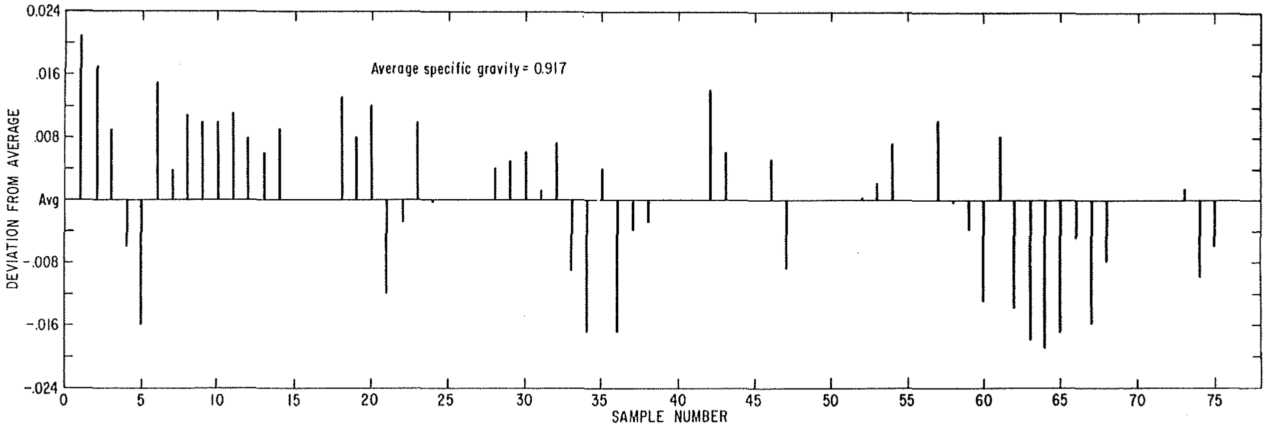

FIGURE 12. - Deviation of specific gravities of assay oils from average.

positively related to organic carbon content, the VM ratio was positively related (r^2 = 0.13) to organic carbon content, the CR ratio was negatively related (r^2 = 0.27) to organic carbon content, and the oxidation rate was negatively related (r^2 = 0.16) to organic carbon content. These relationships would all be expected if the kerogens of lowest aromatic content were from the samples with the highest organic carbon content and vice versa.

Relationships Within Sections of the Core

For comparative purposes, relationships within sections of the core were studied. The core was sectioned for this purpose as described in the section on oil shale samples. Various analytical data, based on averages for the samples representing the five sections of the core, are given in table 9.

TABLE 9. - Average property values for sections of the formation

Sample	Average value									
	Organic carbon, wt-pct	Mineral carbon, wt-pct	Extraction ratio[1]	Alkane ratio[1]	H/C ratio	Volatile material ratio[1]	Carbon residue ratio[1]	Oxidation rate	Alteration index	Specific gravity of assay oil
1 to 11	5.4	5.8	33.3	4.9	1.47	94	32	0.16	3.0	0.925
12 to 32	6.0	5.9	31.4	6.3	1.44	100	30	.16	3.0	.921
33 to 42	9.3	5.6	21.0	4.0	1.50	100	28	.18	2.6	.912
43 to 60	5.6	5.1	20.1	7.1	1.44	101	31	.35	3.1	.917
61 to 75	4.2	4.8	6.1	2.7	1.38	94	40	1.61	3.1	.908
Complete core...	5.8	5.4	22.5	5.2	1.44	98	32	.50	3.0	.917

[1] Ratio multiplied by 10^2.

The average organic carbon content of the sections ranged from 4.2 to 9.3 percent. The Mahogany zone section had the highest average organic carbon content with sections above and below this section having decreasing amounts of organic carbon content with the lowest average values occurring at the top and bottom sections of the formation. Mineral carbon contents tended to show a decrease with increase in burial depth.

The amount of soluble extract per unit of organic carbon decreased with increase in depth of burial. This is shown by a decrease from 33.3 to 6.1 for the extraction ratio. It is evident from these data that soluble extract was not formed from the kerogen by depth-related factors. It is possible that some of the soluble extract migrated from the lowest elevations sometime during the lifespan of the formation. Relative to the Colorado and Wyoming cores, the average extraction ratio of 22.5 is very high as the average value for these cores was 10.9 and 6.9, respectively. The average alkane ratios appeared to follow no general trend.

The five properties of the kerogen used to show differences in the structure of the kerogen suggest that the most aliphatic kerogen occurs in the Mahogany zone of the formation, and the most aromatic kerogen occurs in the bottom section of the formation. The specific gravities of the assay oil from the kerogen tended to decrease with increase in depth of burial. This is in agreement with general trends found for Green River oil shale.

Average n-alkane distribution for the various sections of the formation are shown in figure 13. The composition of the n-alkanes from the top of the core,

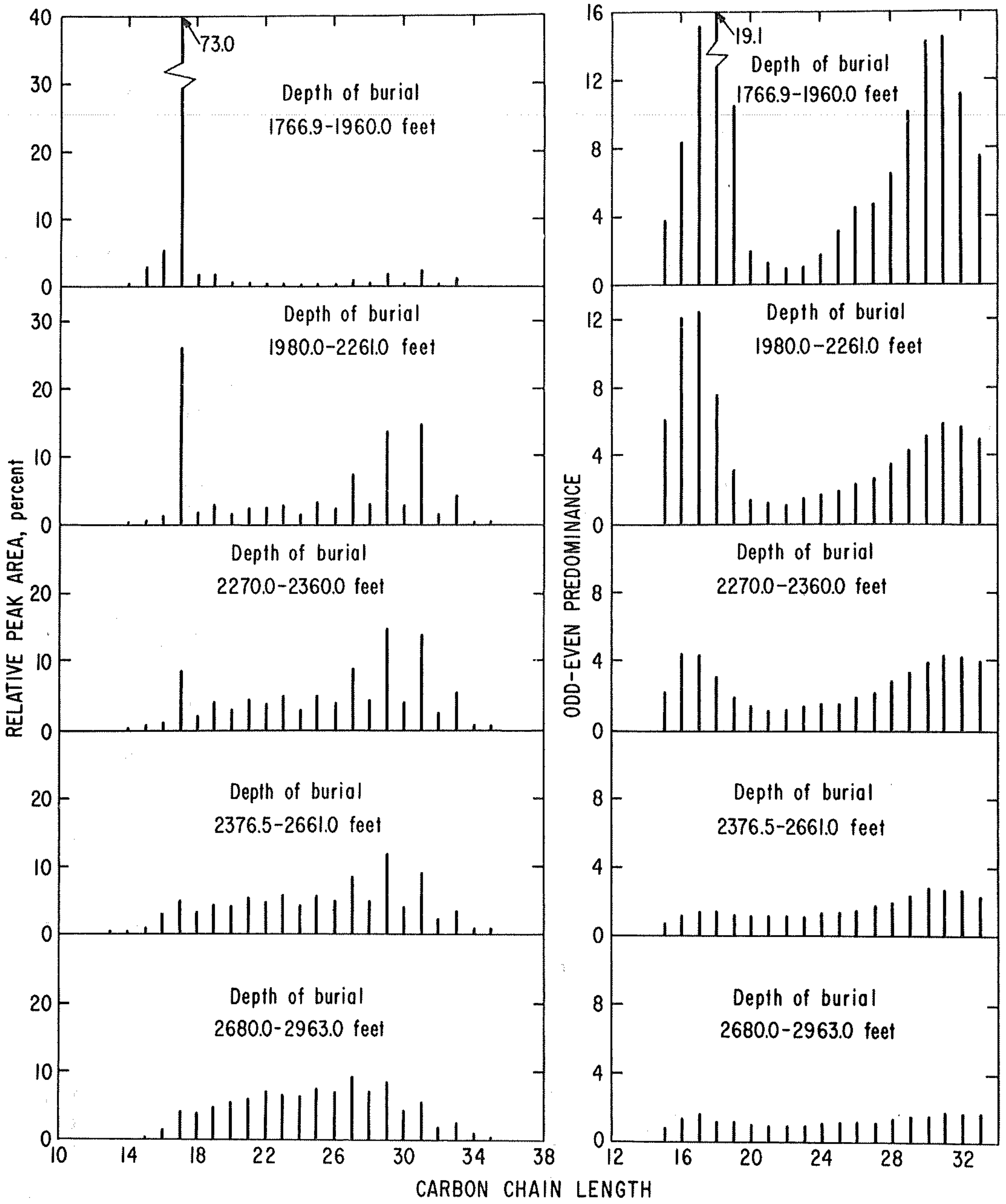

FIGURE 13. - Average n-alkane distribution for various sections of the formation.

representing the first 11 samples (depth of burial 1,766.9-1,960.0 feet), is unique and differs from that found for most Green River oil-shale samples. The unusual feature is the fact that these n-alkanes are composed of a predominance of one component, namely the C_{17} n-alkane. Immediately this unusual distribution of n-alkanes is associated with the environment of the lake which resulted in the deposition of the mineralized zone. However, a comparable n-alkane distribution to that of the Utah core was not found for the Colorado core in a highly mineralized section of that core which occurred 650 to 1,450 feet below the Mahogany marker. Regardless of the cause, it appears that the contribution of n-alkanes from precursor materials was mainly in the range of C_{17}, perhaps from algae, and there was little contribution of n-alkanes in the C_{25} to C_{33} range, perhaps from terrestrial sources, during this period of deposition. Because this mineralized zone does not occur in cores taken from the formation 15 to 20 miles east of WOSCO EX-1 core (8), this unusual feature of the n-alkanes may not be evident in all Uinta Basin oil shale.

The distribution of the n-alkanes in the remaining samples appears to be similar to that found for other Green River Formation samples. Samples from the 2,270- to 2,360-foot level are characteristic of Mahogany zone samples where the C_{17} is predominant over adjacent carbon numbers and an OEP of 3 to 4 is exemplified in the C_{25} to C_{33} range. However, the C_{22} n-alkane is not predominant over adjacent carbon numbers in the Mahogany zone samples, representing a deviation from data found for oil shale of the other basins. At the bottom of the core, the n-alkane distribution assumes the characteristic envelope of altered n-alkanes with OEP values ranging from 1 to 2, similar to that found for Colorado No. 1 core.

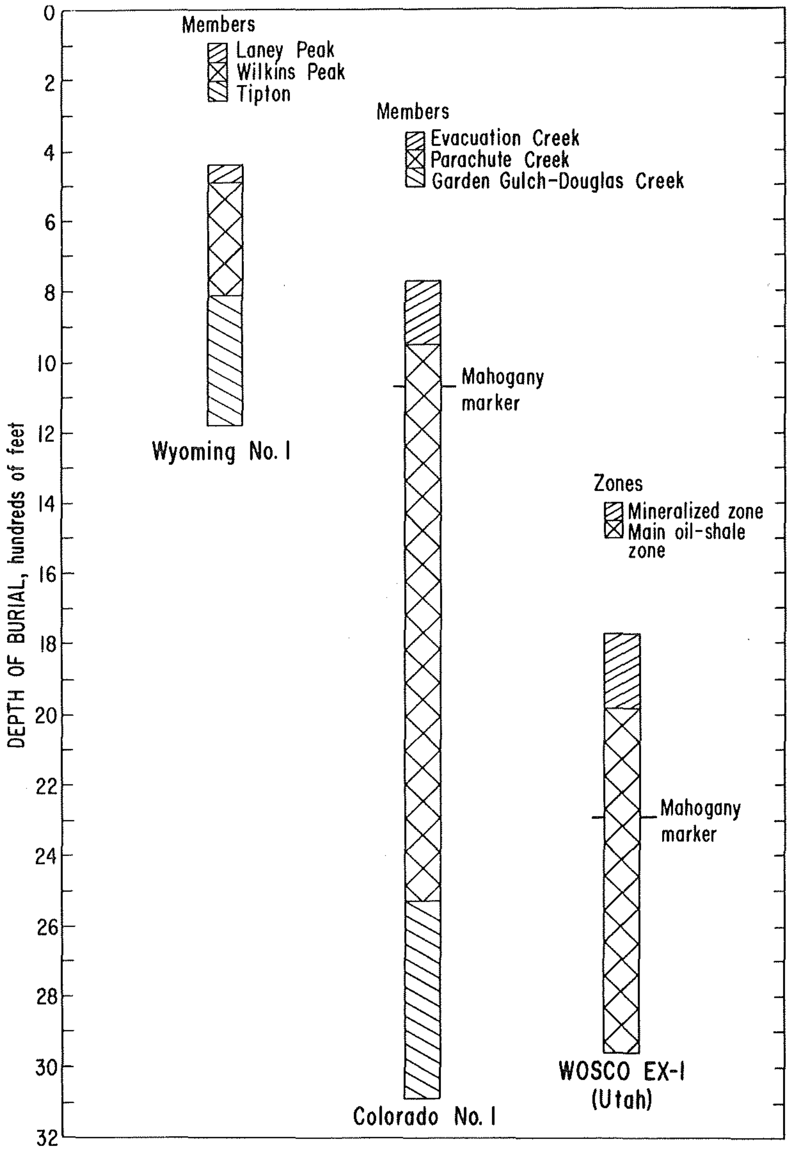

FIGURE 14. - Relative depth of burial of the three cores.

Comparisons of Three Green River Oil-Shale Cores

To aid in the understanding of the differences found for the organic material in the cores taken from the three basins, it is desirable to compare the stratigraphy of the three cores. Figure 14 shows the depth of burial, the position of the Mahogany marker, where identifiable, and the positions of the various members or zones of the formation.

Of the three cores, the Green River Formation represented in the Wyoming No. 1 core is the least extensive, and the top of the core is nearest to the surface. The Colorado No. 1 core is next in order in distance from the top of the core to the surface, but it is also the most extensive. This core represents about 2,300 feet of sedimentation compared to 1,200 feet for the Utah core and 750 feet for the Wyoming core. The Mahogany marker was not identifiable in the Wyoming core but occurs at the 1,070-foot level in the Colorado core and at the 2,289-foot level in the Utah core. Members of the formation are descriptive of each basin but are not interrelated. In some cases the descriptive members of the Piceance Creek Basin are discernible in the Uinta Basin but in this particular core they were not easily recognized.

The amounts and compositions of the soluble extracts taken from the three cores are shown in table 10. The average amount of extract per unit of organic carbon (extraction ratio) is significantly different. The least amount of extract was found in the Wyoming core, whereas the Colorado core contained on an average over one and one-half times the amount of the Wyoming core and the Utah core contained over three times the amount of the Wyoming core. The extremely high amount of soluble extract in the Uinta Basin suggests that about one-fourth of the total organic material is available for processing by solvent extraction techniques. This operation would be especially attractive in the upper 700 feet of the formation (see fig. 6).

TABLE 10. - Average composition of the soluble extracts from the three cores

	Average value					
	Extraction ratio × 10^2	Normal alkanes	Branched plus cyclic alkanes	Aromatics	Resins	Pentane-insoluble material
Colorado core (No. 1).	10.9	3.4	30.3	2.9	54.4	9.0
Wyoming core (No. 1)..	6.9	3.8	23.6	2.7	57.4	12.5
Utah core (WOSCO EX-1)	22.5	3.9	25.8	3.3	55.5	11.5

The average compositions of the soluble extracts (table 10) taken from the three cores are fairly uniform. This is shown by the small variations in the average amounts of n-alkanes, branched plus cyclic alkanes, aromatics, resins, and pentane-insoluble material. However, plots of the compositions of the individual extracts show (fig. 15) much variation. The C_{12} to C_{40} hydrocarbons represent the sum of the n-alkanes, branched plus cyclic alkanes, and aromatics. This value, plotted against the resins and pentane-insoluble material in a triaxial diagram, shows that the extracts from the Colorado core had more samples represented in the hydrocarbon quarter section of the diagram than the Wyoming or Utah cores (23, 5, and 13 percent, respectively). This suggests that the extracts from the Colorado core have experienced the most diagenetic change and have become the most hydrocarbonlike in composition. However, the extract with the largest amount of hydrocarbons was found in a sample from the Utah core where about 97 percent of the extract consisted of hydrocarbons. Not one of the extracts appeared in the pentane-insoluble

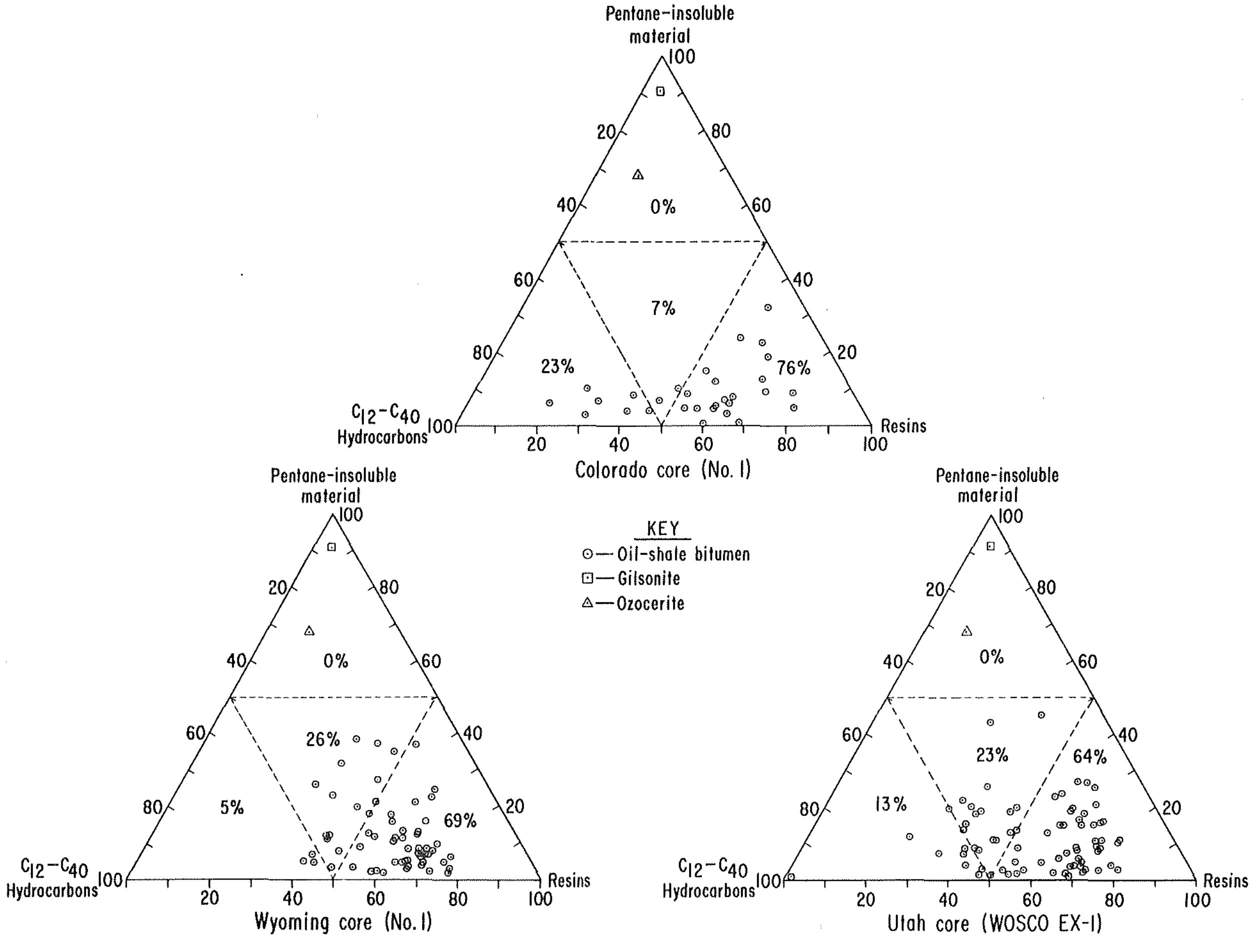

FIGURE 15. - Comparative compositions of the soluble extracts from the three cores.

material quarter section of the diagram, indicating the absence of significant amounts of high-molecular-weight materials similar to that present in gilsonite or ozocerite, two soluble materials that occur in or below the Green River Formation in the Uinta Basin. This suggests that the gilsonite and ozocerite have been subjected to more drastic change than the oil-shale extracts. For gilsonite this alteration may have occurred during the migration process which took place after this material left the source bed. Ozocerite may represent the most resistant organic residue from the more severe environment of the Wasatch deposition. Analysis of the alkanes present in the gilsonite and ozocerite show numerous characteristics of alkanes from the soluble extract. For example, the branched plus cyclic alkanes from both the gilsonite and ozocerite contain large amounts of the steranes, pentacyclic triterpanes, and perhydro-β-carotenes but are deficient in chain isoprenoid compounds relative to the oil-shale extracts. The n-alkanes from the gilsonite show properties similar to those of n-alkanes from the soluble oil-shale extracts; however, the carbon-number distribution for the n-alkanes from the ozocerite resemble a highly altered thermal product.

Significant differences were found in the alkane constituents taken from the three Green River oil-shale cores. Some of these differences are found in table 11. For example, the maximum amount of the C_{17} n-alkane relative to the other n-alkanes was 87 percent for the Utah core, 65 percent for the Colorado core, and 26 percent for the Wyoming core. A similar distribution of the C_{17} n-alkane for the three cores was found when the amounts were calculated on an average basis. These data show that the C_{17} n-alkane was much more prevalent relative to the other n-alkanes in the Uinta Basin than the other two basins. Also, the characteristic dominance of the C_{22} n-alkane was less evident in the Utah core than in the other two cores. These differences are suggestive of source material variations and shows that the precursors for the C_{17} and C_{22} n-alkanes were not uniform during the life history of the three basins. Maximum average values for the C_{31} n-alkane were also found for the Utah core.

TABLE 11. - Relative distribution of alkane compounds for the three cores

	Percentage of component[1]		
	Colorado core (No. 1)	Wyoming core (No. 1)	Utah core (WOSCO EX-1)
C_{17} n-alkane (maximum value).......	65	26	87
C_{17} n-alkane (average).............	11	8	21
C_{22} n-alkane (dominance)...........	60	70	15
C_{31} n-alkane (maximum value).......	17	19	25
Chain isoprenoids (average)........	33	43	30
Steranes (average)................	31	40	27
Pentacyclic triterpanes (average)..	25	9	21
Perhydro-β-carotene (average)......	11	8	22

[1] Percentage of n-alkanes, of dominance of C_{22} over adjacent carbon numbers, or of the 11 major isoprenoid compounds.

Similar comparisons for the isoprenoid alkanes show that the distribution of these compounds in the three cores differs. In particular, the chain isoprenoid and sterane averages for the Wyoming core are greater than the other two cores, and the pentacyclic triterpanes are less. The perhydro-β-carotene average for the Utah core was greater than the other two cores. These differences are also suggestive of source material variations.

Comparisons of the properties of the kerogen from the three cores are shown in table 12. In general, the average values for the four properties of the kerogen and the specific gravities of the assay oils of the selected samples of the three cores are very similar. This shows that on an average basis, the kerogen of the three basins is remarkably uniform. However, as shown earlier, each core contained some kerogen which had compositions significantly different from that of the average.

The results of linear regression analysis of data obtained from the three cores are shown in table 13. For this comparison only those correlations having a coefficient of determination (r^2) greater than 0.25 were considered to be significant.

TABLE 12. - Comparison of properties of the kerogen from the three cores

	Average values for samples studied				
	Atomic hydrogen to carbon ratio	Volatile material ratio	Carbon residue ratio	Oxidation rate	Specific gravity of assay oil
Colorado core (No. 1)	1.48	96	29	0.18	0.905
Wyoming core (No. 1)	1.49	102	29	.57	.914
Utah core (WOSCO EX-1)	1.44	98	32	.50	.917

TABLE 13. - Comparison of regression analyses for the three cores

No.	Relationship[1]	Significant correlation[2]		
		Colorado core	Wyoming core	Utah core
1	Mineral carbon (Y); organic carbon (X)	No	No	No
2	Soluble extract (Y); organic carbon (X)	Yes (+)	Yes (+)	No
3	Extraction ratio (Y); depth (X)	No	No	No
4	Alkane ratio (Y); depth (X)	Yes (+)	No	No
5	Alkanes, wt pct (Y); depth (X)	Yes (+)	Yes (+)	Yes (+)
6	C_{20}/C_{19} ratio (Y); depth (X)	No	No	No
7	C_{19} isoprenoid ratio (Y); C_{20} isoprenoid ratio (X)	Yes (+)	Yes (+)	Yes (+)
8	C_{18} isoprenoid ratio (Y); C_{20} isoprenoid ratio (X)	Yes (+)	Yes (+)	Yes (+)
9	C_{28} sterane ratio (Y); C_{29} sterane ratio (X)	Yes (+)	Yes (+)	Yes (+)
10	C_{27} sterane ratio (Y); C_{29} sterane ratio (X)	Yes (+)	Yes (+)	Yes (+)
11	$C_{30\text{-C}}$ pentacyclic ratio (Y); $C_{30\text{-A}}$ pentacyclic ratio (X).	Yes (+)	Yes (+)	Yes (+)
12	Total sterane ratio (Y); total chain isoprenoid ratio (X).	No	Yes (+)	No
13	Total pentacyclic ratio (Y); total chain isoprenoid ratio (X).	No	No	No
14	Total C_{40} carotene ratio (Y); total chain isoprenoid ratio (X).	No	No	No
15	Total pentacyclic ratio (Y); total sterane ratio (X).	Yes (+)	No	Yes (+)
16	Total C_{40} carotene ratio (Y); total sterane ratio (X)	No	Yes (+)	Yes (+)
17	Total C_{40} carotene ratio (Y); total pentacyclic ratio (X).	No	No	Yes (+)
18	H/C ratio (Y); depth (X)	-	No	No
19	VM ratio (Y); depth (X)	-	No	No
20	CR ratio (Y); depth (X)	-	No	No
21	Oxidation rate (Y); depth (X)	-	No	No
22	Specific gravity assay oil (Y); depth (X)	Yes (-)	No	Yes (-)
23	H/C ratio (Y); alkane ratio (X)	No	No	No
24	VM ratio (Y); alkane ratio (X)	No	No	No
25	CR ratio (Y); alkane ratio (X)	No	No	No
26	Oxidation rate (Y); alkane ratio (X)	No	No	No
27	Specific gravity assay oil (Y); alkane ratio (X)	-	No	No
28	H/C ratio (Y); organic carbon (X)	-	No	No
29	VM ratio (Y); organic carbon (X)	-	No	No
30	CR ratio (Y); organic carbon (X)	-	Yes (-)	Yes (-)
31	Oxidation rate (Y); organic carbon (X)	-	Yes (-)	No
32	Specific gravity assay oil (Y); organic carbon (X)	-	No	No

[1] Y = a + bX.

[2] The (+) or (-) sign designates slope of the regression line.

There was no linear relationship between mineral carbon content and organic carbon content of the oil shale from any of the three cores. This suggests that the deposition of mineral carbonates was not related to the deposition of organic debris from the growth of organisms. In two of the cores the amount of soluble extract was positively related to the organic carbon content. This suggests that rather uniform amounts of soluble extract were present for each unit of organic carbon and that the soluble extracts were not degraded from kerogen. Perhaps the reason the Utah core did not show a linear relationship for this property was migration of significant amounts of the soluble material from the source beds. The absence of linear relationships between extraction ratios and depths of burial also shows that the soluble extract was not degraded from the kerogen by depth-related factors. The alkane ratio for the Colorado core was related positively to depth of burial suggesting that some form of diagenesis of the alkanes did take place in the Piceance Creek Basin. On a weight-percent basis, the extracts from all three basins showed evidence of increased alkane content with depth of burial showing the effects of diagenetic or other forms of change.

The ratio of the C_{20} to C_{19} chain isoprenoid compounds was not linearly related to depth of burial for any of the cores, suggesting that the C_{19} compound was not degraded from the C_{20} compound by depth-related factors. However, the slopes of the regression curves for plots of the relationships of the three chain isoprenoid compounds, the three sterane compounds, and the two pentacyclic triterpane compounds for all three cores were positive. This suggests that the constituents of each compound type were related and probably had common precursors. Relating the chain isoprenoids to the steranes, to the pentacyclic triterpanes, and to the carotene in all possible combinations showed no conclusive evidence of linear relationships between any of the compound types. This suggests that the source material for these compound types were not interrelated and may have not been the same for each basin. However, the exceptions to this generalization may be indicative of important differences in source material.

It is evident that there was no linear relationship between the aromaticity of the kerogen and the two properties, depth of burial and alkane ratio of the soluble extracts. This shows that the differences observed in the kerogen structure were not due to depth-related factors nor were the changes observed in the kerogen structure related to changes observed in the alkane content of the soluble extract. There was some evidence that the aromaticity of the kerogen was related to organic carbon content, whereby the samples of highest carbon content contained kerogen of the lowest aromatic content and vice versa. Also, the specific gravity of the assay oils from samples of the Colorado and Utah cores decreased with increase in depth of burial, suggesting an influence on depth of burial upon the composition of the oil-forming constituents of the kerogen. Depth of burial of the Wyoming core was insufficient to cause comparable alterations.

CONCLUSIONS

This study of Green River Formation organic matter from the Uinta Basin (Utah) core, like the study of the Piceance Creek Basin (Colorado) and the

Green River Basin (Wyoming) cores, shows numerous compositional differences in the kerogen and in the soluble organic material. Some of these compositional differences were related to depth of burial, but most of the differences were probably related to source material and environmental variations.

The amount of soluble material in the Utah core is much greater than that of the other two cores. On an average basis, the extraction ratio (amount of extract per unit of organic carbon) for the Utah core was 2.1 times greater than the Colorado core and 3.3 times greater than the Wyoming core. No explanation was found for the abundance of soluble material in the Utah core; however, it did suggest that about one-fourth of the total organic material in the Uinta Basin might be commercially processed by solvent extraction techniques.

The amounts of extract per unit of oil-shale organic carbon in the Utah core, like that of the other two cores, did not increase with increase in depth of burial. This unanimity of the results of this determined property of the oil shale suggests strongly that the soluble extract did not come from the kerogen as a result of depth-related factors. It also adds credibility to another postulate concerning the source of the soluble extract in which it is believed that the soluble and insoluble organic material represent products of different degrees of polymerization of the source material.

Similar to the other two cores, the amount of soluble alkanes on a weight-percent basis increased significantly above average values in the bottom one-half of the Utah core. This suggests that portions of the soluble extract were altered to hydrocarbons due to depth-related factors. Examination of the data showed that the resin portion of the soluble extract decreased below the average values in the same samples which showed a corresponding increase in alkane content. This suggests that the polar constituents of the resin fractions were altered to hydrocarbons by factors related to burial depth. This same trend for the alkanes did not exist when they were considered on the basis of alkane ratio (amount of alkanes per unit of organic carbon) as the alkane ratios were not depth related. Only the organic material in the Colorado core showed a relationship between the alkane ratios and depth of burial; however, the extracts from the bottom portions of all three cores showed more than average amounts of alkanes on a weight-percent of extract basis.

There appeared to be no linear relationship between the weight-percent of extract and organic carbon content of the oil shale for the Uinta Basin samples. This differed from results found for the other two cores where a significant correlation for these properties was found. These results suggest that some of the organic material in the Utah core may have migrated from its original source bed. This supposition seems to be verified by the low extraction ratios for the bottom portion of the core and the extremely high concentration of soluble material in certain sections of the core. However, no correlation of properties of the extracts taken from the impregnated tuffs and the extracts taken immediately below or above the tuffs was found, suggesting that this material had not migrated vertically to any significant extent.

The distribution of the n-alkanes, isolated from the extracts of the first 11 samples of the Utah core, differed significantly from that of the remainder of the core and from the n-alkane distribution generally found for Green River oil-shale extracts. Most of the n-alkanes in the first 11 samples were in the C_{15} to C_{19} range with the C_{17} n-alkane very predominant, ranging from 49 to 87 percent of the total n-alkanes. Generally the C_{22} predominates over adjacent carbon numbers in Green River extracts, but in the Utah extract the C_{22} was predominant in only 15 percent of the samples.

There appeared to be some tendency for higher than average concentrations of isoprenoid compounds in the extracts from samples having the largest amount of extract per unit of organic carbon. In one sample the chain isoprenoid compounds represented about 6 percent of the total organic carbon, and in another sample perhydro-β-carotene represented about 4 percent of the total organic carbon.

There was no general trend toward increased aromaticity of the kerogen with depth of burial; however, the kerogen in samples below the 2,780-foot level (sample No. 66) generally had above-average aromatic content. Also, there was no linear relationship between aromaticity of the kerogen and the amount of alkanes in the soluble extract per unit of organic carbon.

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