DEPARTMENT OF THE INTERIOR

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ABUNDANCES OF MAJOR ELEMENTS AND SEDIMENTARY COMPONENTS OF CUTTINGS FROM THE FOXEN MUDSTONE AND THE SISQUOC, MONTEREY, AND POINT SAL FORMATIONS IN THE UNION HOBBS 22 WELL, AND PRELIMINARY COMPARISON WITH CORES FROM THE UNION NEWLOVE 51 WELL, ORCUTT OIL FIELD, ONSHORE SANTA MARIA BASIN, CALIFORNIA

by

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ABSTRACT

Cuttings analyzed from the Union Hobbs 22 well in the Orcutt oil field include all intervals in a complete sequence of the Monterey Formation and upper part of the underlying Point Sal Formation as well as most intervals in a complete sequence of the overlying Sisquoc Formation. Also analyzed were selected intervals from the Foxen Mudstone overlying the Sisquoc Formation. Overall features of the sequence include: (1) in the lower part of the Sisquoc Formation, high detritus (av 65%), moderate silica (av 29%), low carbonate minerals (av 3%), low apatite (av 0.2%), and low organic matter (av 1.8%); (2) a sharp decrease in detritus (to av 38%), sharp increase in organic matter (to av 8.4%), and moderate increase in silica (to av 37%) and carbonate minerals (to av 16%) downward across the Monterey-Sisquoc boundary; (3) most abundant apatite (30-foot average as high as 9%) in the middle part of the Monterey Formation; (4) generally increasing abundance of carbonate minerals downward within the Monterey Formation; and (5) less abundant silica (av 16%) and organic matter (av 2.9%) together with more abundant carbonate minerals (av 41%) in the Point Sal Formation. Other specially notable features of the sequence include very high average organic matter abundance in the Foxen Mudstone (30-foot average as high as 26.1%) and a markedly higher ratio of K_2O/Al_2O_3 in the Monterey and Point Sal Formations than in the Sisquoc Formation and Foxen Mudstone.

Comparison of cuttings from the Union Hobbs 22 well with cores previously analyzed from the nearby Union Newlove 51 well confirms the usefulness and efficiency of cuttings for examining the compositional sequence of fine-grained Miocene strata in the area. The composition of cuttings in the lower part of the Sisquoc Formation are extremely close to the composition of the cores. Overall compositional differences between the Sisquoc and Monterey Formations and compositional trends within the Monterey Formation are also similar in cores and cuttings, although the numbers of core samples are inadequate to derive meaningful averages in the more heterogeneous Monterey Formation.

INTRODUCTION

The Monterey Formation in the south central coastal basins of California (Figure 1) has received considerable attention in recent years. Because of the formation's heterogeneity, however, meaningful compositional comparison of different Monterey sections has been difficult. Analysis of cuttings has proven to be an efficient approach to this problem. As summarized by Isaacs and others (1986) and Isaacs (1987), part of the testing of the cuttings method has been comparison of cuttings from the Union Hobbs 22 well with cores analyzed from the nearby Union Newlove 51 well (Isaacs and others, 1989b).

This report presents the detailed data on cuttings from the Union Hobbs 22 well, which is located in the Orcutt oil field, onshore Santa Maria basin (Figure 2). In this well, the Foxen Mudstone (as defined by the operator) extends from well depths of 260 to 800 ft, the Sisquoc Formation from 800 to 1720 ft, the Monterey Formation from 1720 to 2400 ft, and the Point Sal Formation from 2400 ft to total depth at 3135 feet (Mary Lou Thornton, written communication, 1990). Cuttings were collected by the operator throughout the well in 30-foot intervals. Within the Monterey and Point Sal Formations, all 30-foot intervals were analyzed, providing a complete compositional sequence of the Monterey Formation and upper part of the Point Sal Formation in this

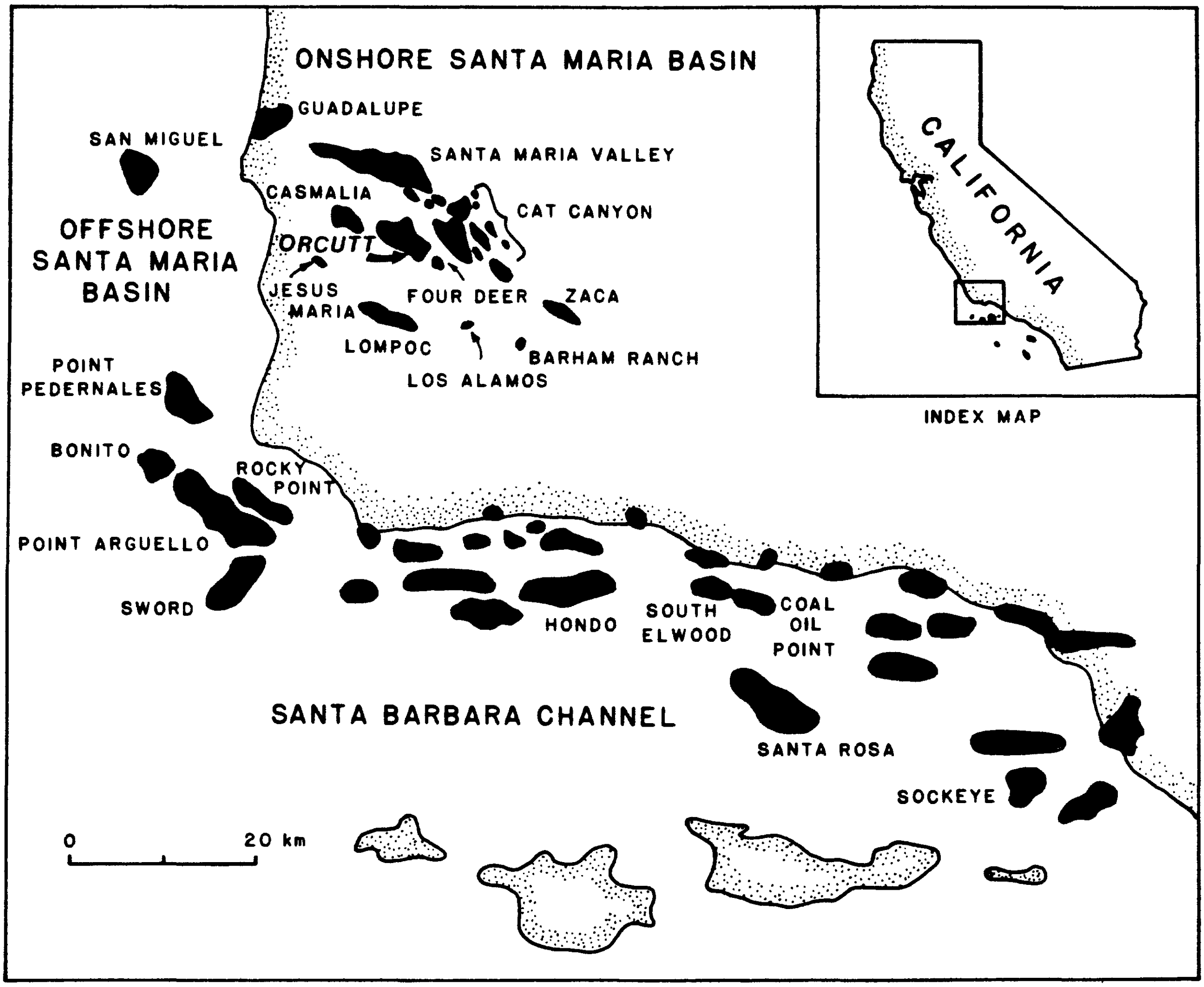

Figure 1. Location map showing position of the Orcutt oil field and other oil and gas fields in the Santa Maria and Santa Barbara-Ventura areas, California. Labeled fields have significant production or potential from Monterey Formation fractured reservoirs. Adapted from California Division of Oil and Gas (1974) and Williams (1985).

area. Cuttings from each 30-foot interval were also analyzed in overlying strata of the Sisquoc Formation up to depths of 1435 feet, as well as cuttings from selected 30-foot intervals in the Sisquoc up to depths of 800 feet and in the Foxen Mudstone at depths from 800 to 335 feet.

METHODS

Sample Preparation

Bulk cuttings were washed by personnel at Union Oil and Gas Company prior to receipt at the U.S. Geological Survey. After receipt, samples were split with a riffle splitter and submitted for grinding and analysis by the U.S.

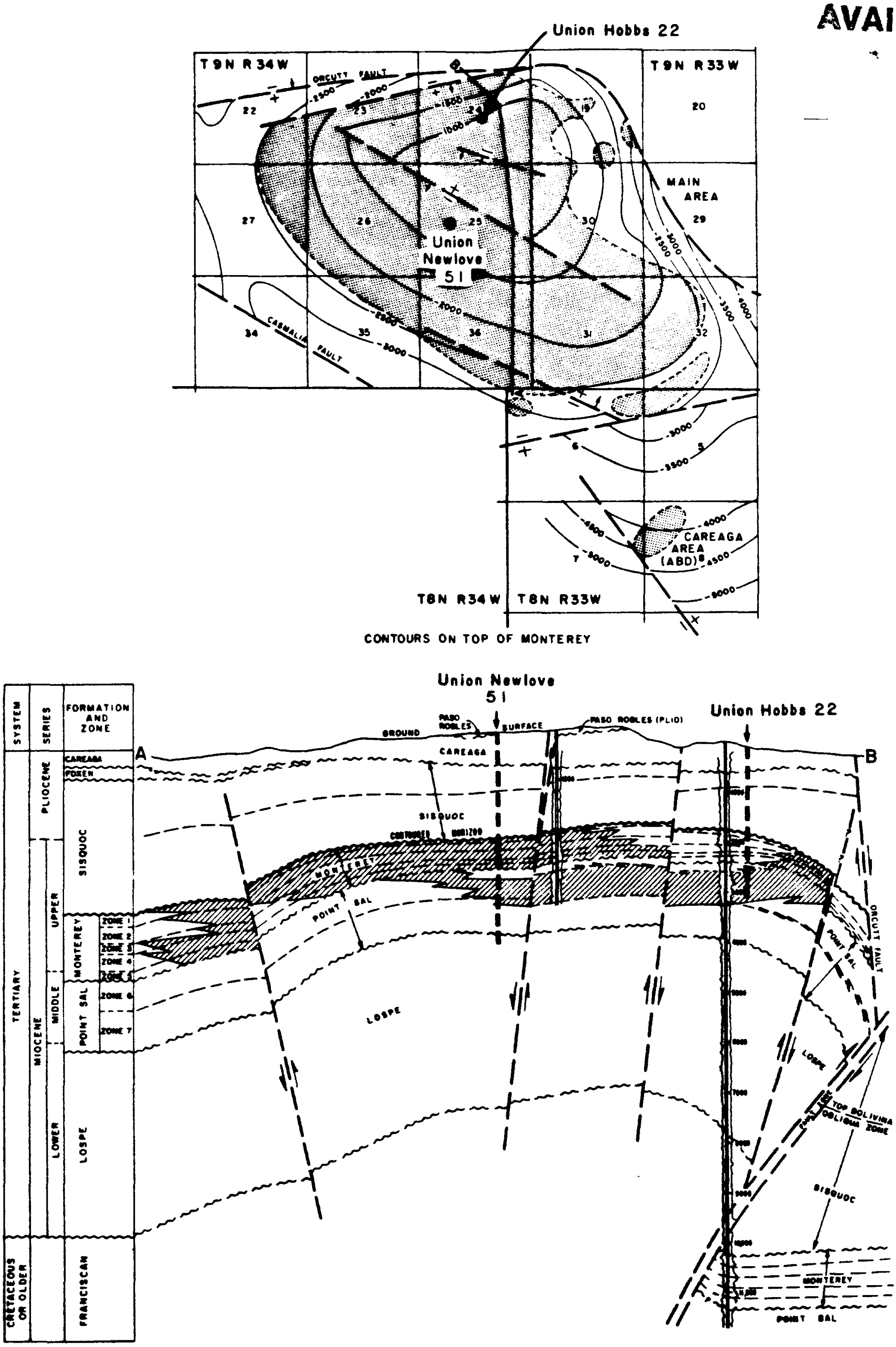

Figure 2. Map and cross-section of the Orcutt oil field, showing location of the Union Hobbs 22 and Union Newlove 51 wells. Shaded areas show extent of oil reservoir. Modified after California Division of Oil and Gas (1974).

Geological Survey Branch of Geochemistry. Samples were not dried prior to analysis, and in contrast to most results previously reported (Isaacs and others, 1989a, b), fractions analyzed for major oxides and carbon both included H_2O^- (adsorbed water). Amounts of H_2O^- probably range from about 1 wt% to as much as 5 wt% in clay-rich samples (Isaacs, 1980, appendix A).

Analytical Techniques - Major Elements

Samples were analyzed for major elements by X-ray fluorescence spectroscopy, using methods described by Taggart and Wahlberg (1980a, b) and Taggart and others (1981, 1987). Identical methods were used on samples reported by Isaacs and others (1989a, b). For this analysis, 0.8 g of sample (ground to <100 mesh) was weighed into a tared platinum-gold (95:5) crucible and ignited for 45 minutes at 920°C, after which it was reweighed to determine loss on ignition (LOI). An 8 g charge (dry basis) of lithium tetraborate was then added to the crucible, physically mixed with the sample, and then fused at 1130°C for 40 minutes (Taggart and Wahlberg, 1980a) after which it was cast in a platinum-gold mold (Taggart and Wahlberg, 1980b) and allowed to cool. The disc was then presented to a Phillips PW1600 simultaneous X-ray spectrometer using an on-line Digital Equipment Corporation PDP 11/04 computer to perform a de Jongh matrix correction program (Taggart and others, 1981, 1987).

Analytical Techniques - Carbon

Carbon was measured by methods described by Jackson and others (1987). Identical methods were used on samples reported in Isaacs and others (1989a). Total carbon abundance was measured by dry combustion with a LECO CR12 automated carbon analyzer (Jackson and others, 1987). Carbonate carbon was measured by automated coulometric titration of perchloric acid-evolved Co_2

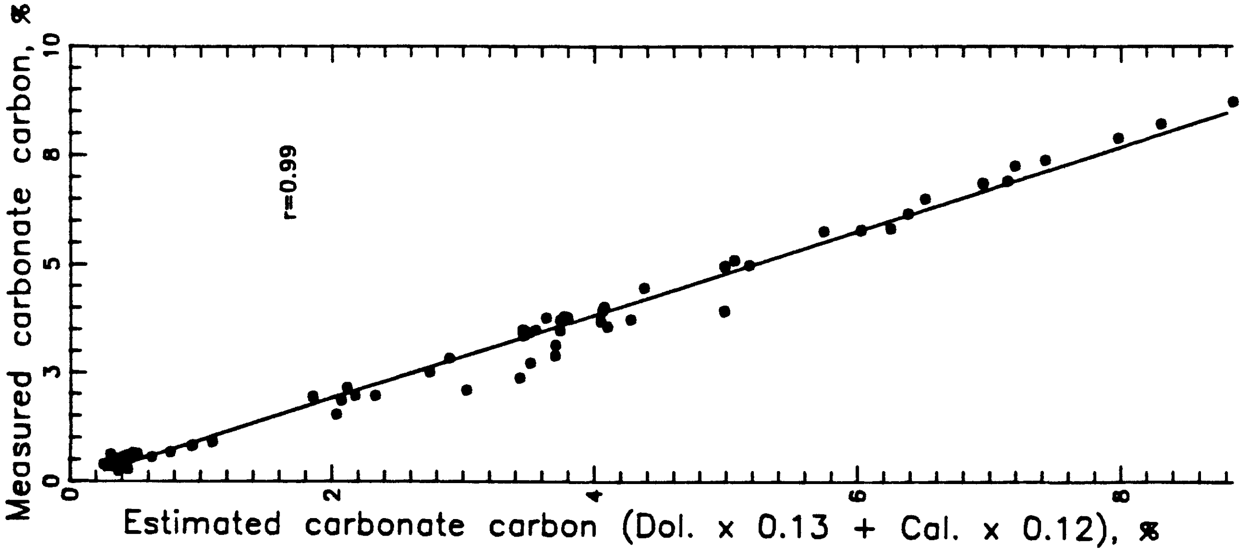

Figure 3. Measured values of carbonate carbon versus values estimated from oxide analyses in the Union Hobbs 22 well. The correlation was calculated by least-squares linear regression; "r" is the correlation coefficient.

(Huffman, 1977; Engleman and others, 1985; Jackson and others, 1987). Organic carbon was then determined by difference between total carbon and carbonate carbon.

Determination of Sedimentary Components

The major sedimentary components in the Monterey Formation are termed silica (representing both biogenic and diagenetic silica, including opal-A, opal-CT, and diagenetic quartz), detritus (detrital quartz and aluminosilicate minerals, mainly consisting of mixed layer illite-smectite clay along with minor feldspar and quartz), carbonate minerals (calcite and dolomite), apatite, and organic matter. Abundances of silica and detritus were estimated from elemental abundances of SiO_2 and Al_2O_3 by constants developed for the Monterey Formation in adjacent onshore areas (Table 1). Resulting values are for the most part reliable for Monterey strata but probably underestimate the amount of aluminosilicate material where mica or chlorite is abundant; values also may underestimate detrital quartz (and thus overestimate biogenous and diagenetic silica) in highly terrigenous samples. Abundances of silica and detritus for non-Monterey strata should thus be regarded as approximations.

Abundances of calcite, dolomite, and apatite were estimated from abundances of CaO, MgO, and P_2O_5 after adjustment of these values for average abundances in the aluminosilicate fraction (Table 1). Because abundance values were not confirmed by X-ray diffraction analysis, they are preliminary estimates only. Abundances of organic matter were estimated from the abundances of total organic carbon (Table 1).

This method of component determination probably underestimates dolomite relative to calcite inasmuch as dolomite in the Monterey Formation tends to have CaO in excess of the ideal values used here and may also have significant Fe (Murata and others, 1972). Moreover, a previous report noted that bulk X-ray diffraction analysis showed no detectable calcite in a number of samples estimated by these conversion parameters (Table 1) as having minor (5-10%) calcite (Isaacs and others, 1989b). However, Isaacs and others (1989a) compared the abundances of carbonate carbon represented by dolomite + calcite as estimated above (0.13 x dolomite + 0.12 x calcite) with the analytical determination of carbonate carbon. In that study, the average difference between each pair of calculated and measured values was 0.13 wt% carbonate carbon (about 1 wt% carbonate minerals), and the maximum difference was 0.30 wt% carbonate carbon (about 2.5 wt% carbonate minerals). These comparisons show that the total abundance of carbonate minerals is reliably estimated from major oxide analyses by the methods used here (see also Figure 3).

In contrast to samples previously reported (Isaacs and others, 1989a, b), all analyses were made on powder fractions containing adsorbed water (H_2O^-). Because all analytical values are thus easily comparable, abundances of major sedimentary components (silica, terrigenous detritus, calcite, dolomite, apatite, and organic matter) were all normalized to sum to 100%. Previously reported data were normalized to 100% on an organic-matter-free basis.

Reproducibility of Analyses

Previous studies (Isaacs and others, 1989a, b) showed that the reproducibility of analytical results is excellent. The relative standard deviation is generally less than 2% of major oxide values (av 1.1%) for blind duplicate powder splits analyzed by the techniques used here. Reproducibility of the

Table 1. Formulas used to convert elemental abundances to abundances of sedimentary components. Formulas for detritus and silica abundances and the average abundance of major elements in detritus are derived from the evaluation in Isaacs (1980, appendix B) for the Monterey Formation in the western Santa Barbara coastal area. CaO and P_2O_5 abundances in apatite are based on published references (see Isaacs, 1980, p. 228), and calculations for calcite and dolomite are based on their molecular formulas. Because most dolomite in the Monterey Formation contains excess CaO, dolomite abundances may be slightly underestimated and calcite abundances slightly overestimated.

Quantity	Explanation	Formula
Detritus	Equals aluminosilicates + detrital quartz	$5.6 \times Al_2O_3$
Aluminosilicates	Based on Al_2O_3 content	$4.2 \times Al_2O_3$
Detrital quartz	Based on a proportion of aluminosilicates	Aluminosilicates ÷ 3
Silica (biogenic and diagenetic)	Based on SiO_2 content adjusted for amounts in detritus	$SiO_2 - (3.5 \times Al_2O_3)$
Apatite	Based on P_2O_5 content adjusted for 0.7% P_2O_5 in aluminosilicates and assuming 42.4% P_2O_5 in apatite	$[P_2O_5 - (0.032 \times Al_2O_3)] \div 0.424$
Dolomite	Based on MgO content adjusted for 2.6% MgO in aluminosilicates and assuming 21.9% MgO in dolomite	$[MgO - (0.11 \times Al_2O_3)] \div 0.219$
Calcite	Based on CaO content adjusted for 1.9% CaO in aluminosilicates, 55.5% CaO in apatite, and 30.4% CaO in dolomite, and assuming 56.0 % CaO in calcite	$[CaO - (0.08 \times Al_2O_3 - (0.555 \times \text{apatite}) - (0.304 \times \text{dolomite})] \div 0.56$
Organic matter	Based on organic carbon content	(Organic carbon) $\times$ 1.5

Table 2. Elemental abundances in bulk cuttings from the Union Hobbs 22 well (in weight %). Each sample represents a 30-foot interval; the given depth is the mid-point of the interval. "LOI" is loss on ignition at 920°C. Total Fe is reported as Fe_2O_3. Analysts: Kathleen C. Stewart (oxides and LOI), Edythe E. Engleman (carbon).

Depth	Si02	Al203	Fe203	Mg0	Ca0	Na20	K20	Ti02	P205	Mn0	LOI	Organic Carbon	Carbonate Carbon
335	52.4	7.37	3.53	2.07	2.16	0.92	1.14	0.36	0.60	0.11	27.6	8.11	0.56
455	51.8	8.46	3.65	1.63	1.79	1.27	1.16	0.42	0.49	< 0.02	28.3	17.2	0.28
575	57.3	9.51	3.44	1.24	2.22	1.98	1.39	0.42	0.74	< 0.02	19.5	12.2	0.41
695	58.2	10.1	4.32	1.64	1.30	1.50	1.43	0.49	0.31	0.02	19.6	10.4	0.40
755	60.8	10.4	4.15	1.67	1.64	1.73	1.53	0.49	0.28	0.02	16.4	8.10	0.35
815	58.2	12.0	4.60	1.90	1.77	2.03	1.74	0.55	0.31	0.03	12.8	3.87	0.54
935	62.7	12.4	4.08	1.63	2.14	2.37	1.95	0.57	0.28	0.02	10.8	2.96	0.44
1055	63.1	11.1	3.55	1.48	2.32	2.25	1.72	0.49	0.39	0.02	11.7	4.43	0.47
1175	64.6	11.2	3.64	1.71	2.43	2.20	1.66	0.50	0.40	< 0.02	10.1	2.25	0.53
1235	63.9	11.6	4.43	2.16	2.08	1.99	1.87	0.56	0.42	0.02	9.10	1.14	0.64
1285	67.1	10.3	3.98	1.81	1.96	1.84	1.62	0.49	0.38	< 0.02	9.15	0.98	0.56
1315	66.4	10.3	4.12	1.90	1.92	1.84	1.58	0.49	0.38	< 0.02	9.64	0.92	0.58
1375	66.7	9.66	3.82	1.82	2.14	1.68	1.52	0.45	0.41	< 0.02	9.19	1.06	0.64
1435	65.6	11.2	4.01	1.68	2.18	2.10	1.75	0.51	0.60	< 0.02	9.10	1.26	0.48
1465	64.9	11.5	4.27	1.75	1.86	2.01	1.90	0.53	0.44	0.02	9.27	1.40	0.46
1495	64.7	11.6	4.33	1.97	2.04	2.01	1.73	0.53	0.46	0.03	9.73	1.17	0.60
1525	64.6	11.2	4.16	1.94	2.26	1.94	1.68	0.52	0.45	0.02	9.69	1.31	0.62
1555	66.5	11.0	4.11	1.83	1.94	1.93	1.72	0.51	0.41	0.02	8.99	1.08	0.56
1585	67.8	10.9	3.89	1.65	1.71	2.01	1.75	0.48	0.32	0.02	8.46	0.84	0.62
1615	67.2	11.5	3.45	1.59	2.08	2.22	1.93	0.46	0.40	< 0.02	7.35	0.80	0.48
1645	67.7	10.2	3.59	1.64	2.18	1.81	1.59	0.45	0.48	< 0.02	8.11	0.99	0.54
1675	66.7	10.9	3.94	1.75	2.45	2.01	1.73	0.47	0.56	0.02	7.97	0.88	0.64
1705	67.0	11.4	3.69	1.65	2.41	2.14	1.82	0.47	0.57	< 0.02	7.39	0.67	0.54
1735	68.1	6.17	2.09	1.11	4.26	1.18	1.28	0.32	0.32	< 0.02	12.0	5.56	0.82
1765	69.0	6.51	2.15	0.97	3.75	1.29	1.34	0.33	0.39	< 0.02	11.4	5.48	0.67
1795	61.2	5.07	1.78	1.59	9.13	0.91	1.05	0.26	0.36	< 0.02	14.9	5.40	1.96
1825	57.3	6.41	2.37	1.68	8.82	1.19	1.27	0.33	0.34	< 0.02	15.5	6.15	1.85
1855	49.1	5.36	1.87	2.61	13.8	1.05	1.05	0.26	0.36	< 0.02	19.6	6.02	3.36
1885	51.7	5.74	1.95	2.27	11.7	1.13	1.11	0.29	0.39	< 0.02	17.8	5.92	2.83
1915	58.7	5.79	2.07	1.44	10.2	1.03	1.13	0.30	0.40	< 0.02	14.7	5.29	1.96
1945	56.8	5.59	2.01	1.52	12.0	1.00	1.11	0.28	0.44	< 0.02	16.0	4.90	2.52
1975	63.3	8.32	2.96	1.38	4.40	1.22	1.52	0.43	0.52	< 0.02	13.2	5.00	0.83

Table 2. continued

Depth	SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO	LOI	Organic Carbon	Carbonate Carbon
2005	62.4	8.40	3.02	1.45	5.02	1.12	1.53	0.43	0.65	< 0.02	13.2	5.06	0.91
2035	47.1	8.17	3.15	3.62	11.0	1.16	1.58	0.42	3.23	0.03	15.5	4.97	2.10
2065	51.5	9.16	3.37	3.24	7.13	1.22	1.66	0.44	1.67	0.03	16.3	5.98	1.53
2095	73.4	5.47	2.10	1.02	1.59	0.84	1.11	0.29	0.49	< 0.02	12.5	6.13	0.25
2125	34.4	4.56	1.82	2.63	20.7	0.65	0.94	0.23	3.96	< 0.02	25.3	9.5	3.93
2155	39.7	6.16	2.86	1.52	15.7	0.93	1.24	0.35	3.06	< 0.02	23.3	10.4	2.72
2185	47.1	5.46	2.39	3.60	12.3	0.87	1.06	0.30	3.83	< 0.02	19.1	8.1	2.38
2215	53.0	2.94	1.36	5.36	12.4	0.53	0.59	0.17	1.65	< 0.02	19.2	5.25	3.57
2245	49.1	3.65	1.82	5.71	12.9	0.62	0.72	0.21	1.97	< 0.02	19.5	5.53	3.74
2275	51.4	4.02	1.98	4.93	11.4	0.66	0.84	0.23	2.09	< 0.02	18.2	6.11	3.14
2305	51.4	4.02	2.02	4.56	11.9	0.71	0.85	0.23	2.94	< 0.02	17.5	6.30	2.89
2335	48.7	4.72	2.19	5.92	11.8	0.84	1.01	0.25	1.20	< 0.02	18.8	4.47	3.70
2365	47.9	6.24	2.63	5.85	10.8	1.07	1.24	0.32	1.02	0.03	18.1	5.04	3.47
2390	35.8	4.56	2.12	9.11	16.6	0.83	0.88	0.23	0.83	0.04	25.2	3.70	5.78
2415	33.5	5.66	2.20	9.63	17.8	1.25	1.09	0.22	0.96	0.07	24.7	2.42	6.16
2445	47.0	8.24	3.20	5.92	10.3	1.35	1.74	0.38	0.68	0.04	16.1	3.54	3.48
2470	23.2	3.63	2.07	12.6	22.2	1.08	0.72	0.16	0.45	0.06	30.9	1.8	8.21
2505	19.6	3.07	3.13	12.9	24.2	0.71	0.58	0.13	0.64	0.08	31.4	1.4	8.71
2535	26.9	4.58	3.41	11.0	20.5	0.97	0.78	0.17	0.54	0.09	26.9	1.71	7.37
2565	28.9	5.33	3.63	10.1	19.7	1.13	0.98	0.22	0.54	0.08	25.2	1.53	6.85
2595	36.9	5.88	2.25	4.25	22.3	1.56	1.04	0.21	0.33	0.05	22.5	1.95	5.76
2625	33.0	5.59	2.15	3.31	25.9	1.28	1.07	0.24	1.38	< 0.02	23.7	2.30	5.82
2625B	44.2	7.64	3.95	4.69	14.3	1.65	1.40	0.34	0.74	0.04	15.5	2.01	4.02
2655	25.4	3.62	2.78	10.9	23.0	0.98	0.65	0.14	0.74	0.05	28.3	1.08	7.89
2685	55.8	10.9	3.83	3.02	7.01	2.30	2.09	0.51	0.39	0.04	10.1	2.30	1.94
2715	30.8	5.83	3.36	9.44	18.7	1.26	1.07	0.26	0.40	0.05	25.3	2.00	6.51
2745	45.9	8.38	3.34	5.42	11.9	1.79	1.55	0.39	0.55	0.04	17.0	2.78	3.71
2775	48.7	8.87	3.12	5.48	10.6	1.97	1.54	0.39	0.28	0.04	15.6	2.27	3.49
2805	42.9	8.76	3.48	6.91	12.9	1.72	1.41	0.36	0.34	0.06	18.1	1.59	4.47
2835	55.5	10.6	3.82	4.26	6.43	2.22	2.01	0.47	0.28	0.04	11.1	1.81	2.15
2865	47.0	8.45	3.78	6.33	10.8	1.72	1.59	0.37	0.28	0.05	16.2	2.10	3.80
2895	46.7	8.19	3.65	5.30	12.3	1.73	1.51	0.37	0.31	0.04	15.9	2.24	3.78
2925	30.8	4.69	2.43	10.2	20.3	1.25	0.82	0.17	0.28	0.05	26.1	1.32	6.90
2955	29.8	4.71	2.62	10.4	20.3	1.23	0.84	0.18	0.27	0.07	26.6	1.17	7.25
2985	50.1	7.90	2.76	5.85	10.7	1.88	1.43	0.29	0.26	0.04	14.8	1.61	3.76
3015	40.8	7.27	2.93	7.83	14.5	1.53	1.32	0.29	0.30	0.07	19.7	1.27	5.10
3045	48.8	8.75	3.34	5.19	11.2	1.92	1.63	0.38	0.36	0.04	14.7	1.97	3.42
3075	42.1	7.05	2.91	7.54	14.5	1.70	1.24	0.29	0.24	0.04	19.1	1.54	4.96
3105	47.0	7.95	3.12	5.71	12.9	1.81	1.43	0.33	0.42	0.05	15.9	1.34	3.93
3128	39.6	7.26	3.35	7.99	14.8	1.44	1.32	0.33	0.48	0.05	19.5	1.54	4.98

Table 3. Abundances of sedimentary components (in weight %) and other derived parameters in bulk cuttings from the Union Hobbs 22 well. Each sample represents a 30-foot interval; the given depth (in ft) is the mid-point of the interval. Values listed in columns 2 through 7 ("Detritus" through "Organic matter") have been normalized to sum to 100%. The quantity "Sum" represents the pre-normalized sum of components (detritus + silica + apatite + dolomite + calcite + organic matter) derived from data in Table 2 using formulas in Table 1; this sum is consistently less than 100% due to the presence of H_2O^-. See text for comments on negative values and problems with the calcite-dolomite partition.

Depth	Detritus	Silica	Apatite	Dolomite	Calcite	Organic Matter	Sum	Silica/ Silica+Carb	Silica/ Silica+Detritus
335	48	31	1.0	6.7	-1.4	14.2	85.5	0.85	0.39
455	48	22	0.5	3.2	-0.3	26.1	98.8	0.88	0.32
575	54	24	1.0	0.9	1.1	18.6	98.6	0.92	0.31
695	58	24	.0	2.5	-0.4	16.1	97.0	0.92	0.29
755	60	25	-0.1	2.5	0.3	12.5	97.3	0.90	0.30
815	73	18	-0.2	2.9	0.2	6.3	91.9	0.85	0.19
935	72	20	-0.3	1.3	1.7	4.6	95.8	0.87	0.22
1055	65	25	0.1	1.2	1.9	6.9	96.2	0.89	0.28
1175	66	27	0.1	2.3	1.5	3.5	95.2	0.87	0.29
1235	69	25	0.1	4.3	-0.3	1.8	93.9	0.86	0.26
1285	62	33	0.1	3.3	0.2	1.6	93.6	0.90	0.35
1315	62	33	0.1	3.8	-0.1	1.5	93.0	0.90	0.34
1375	58	36	0.3	3.7	0.4	1.7	92.6	0.90	0.38
1435	67	28	0.6	2.2	0.7	2.0	94.2	0.91	0.30
1465	69	26	0.2	2.4	0.3	2.2	93.8	0.91	0.28
1495	69	26	0.2	3.4	0.1	1.9	94.3	0.88	0.27
1525	67	27	0.2	3.4	0.5	2.1	94.0	0.87	0.29
1555	65	30	0.1	3.0	0.2	1.7	94.4	0.90	0.31
1585	65	31	-0.1	2.2	0.5	1.3	94.4	0.92	0.33
1615	68	28	0.1	1.6	1.2	1.3	95.3	0.91	0.30
1645	61	34	0.4	2.5	0.8	1.6	94.1	0.91	0.36
1675	64	30	0.5	2.7	1.0	1.4	94.9	0.89	0.32
1705	67	28	0.5	1.9	1.3	1.1	95.5	0.90	0.30
1735	36	48	0.3	2.0	5.5	8.6	97.0	0.86	0.57
1765	38	48	0.4	1.2	4.8	8.5	97.2	0.89	0.56
1795	29	44	0.5	4.8	12.9	8.3	97.7	0.72	0.60
1825	37	36	0.3	4.6	12.5	9.5	96.9	0.68	0.49
1855	31	31	0.5	9.5	18.9	9.3	97.5	0.52	0.50
1885	33	33	0.5	7.8	16.2	9.2	96.1	0.58	0.50
1915	33	39	0.5	3.7	15.2	8.1	97.9	0.67	0.54
1945	32	38	0.6	4.2	18.1	7.5	98.4	0.63	0.54
1975	49	36	0.6	2.2	5.1	7.8	95.9	0.83	0.42

Table 3. continued

Depth	Detritus	Silica	Apatite	Dolomite	Calcite	Organic Matter	Sum	Silica/ Silica+Carb	Silica/ Silica+Detritus
2005	49	34	0.9	2.5	5.8	7.9	96.5	0.81	0.41
2035	48	19	7.3	13.0	5.0	7.8	95.9	0.52	0.29
2065	54	20	3.4	10.6	2.8	9.4	95.8	0.60	0.27
2095	32	56	0.8	2.0	0.3	9.5	97.0	0.96	0.64
2125	26	19	9.1	9.8	22.3	14.4	99.1	0.37	0.42
2155	35	19	6.9	4.0	18.9	16.0	97.2	0.45	0.34
2185	31	28	8.8	13.9	5.3	12.4	98.2	0.60	0.48
2215	17	43	3.7	23.2	5.6	7.9	99.3	0.60	0.72
2245	21	37	4.4	24.6	5.1	8.4	98.7	0.55	0.64
2275	23	38	4.7	20.9	4.1	9.3	98.2	0.60	0.62
2305	23	38	6.7	19.1	4.0	9.6	98.6	0.62	0.62
2335	27	33	2.6	25.4	4.7	6.9	97.0	0.52	0.55
2365	36	27	2.0	24.1	3.8	7.7	97.8	0.49	0.43
2390	26	20	1.6	40.2	6.2	5.7	97.9	0.30	0.44
2415	32	14	1.9	41.6	6.9	3.7	98.8	0.22	0.30
2445	47	19	1.0	23.5	3.9	5.5	97.3	0.40	0.28
2470	21	11	0.8	56.8	8.3	2.8	98.1	0.14	0.34
2505	18	9	1.3	59.0	10.7	2.2	97.2	0.12	0.34
2535	26	11	1.0	49.4	9.3	2.6	97.0	0.16	0.30
2565	31	11	0.9	44.9	10.3	2.4	96.7	0.16	0.26
2595	33	17	0.3	16.7	30.1	3.0	98.7	0.26	0.33
2625	32	14	2.9	12.4	36.2	3.5	99.3	0.22	0.30
2625B	45	18	1.2	18.4	14.4	3.1	95.7	0.36	0.29
2655	21	13	1.5	49.4	13.5	1.7	97.1	0.17	0.39
2685	63	18	0.1	8.6	6.6	3.6	96.9	0.55	0.22
2715	34	11	0.5	41.4	10.6	3.1	97.0	0.17	0.24
2745	48	17	0.7	21.1	8.5	4.3	97.1	0.37	0.26
2775	51	18	.0	21.0	6.7	3.5	97.8	0.39	0.26
2805	50	13	0.1	27.7	7.1	2.4	97.9	0.26	0.20
2835	61	19	-0.1	14.6	2.5	2.8	96.9	0.53	0.24
2865	49	18	.0	25.4	4.8	3.2	97.2	0.37	0.27
2895	47	19	0.1	20.7	10.1	3.5	97.2	0.38	0.28
2925	27	15	0.3	44.9	11.5	2.0	98.4	0.21	0.35
2955	27	14	0.3	46.2	11.1	1.8	97.7	0.19	0.34
2985	45	23	.0	23.3	5.8	2.5	97.5	0.44	0.34
3015	42	16	0.2	32.9	7.5	2.0	97.5	0.28	0.27
3045	50	19	0.2	19.8	8.3	3.0	97.7	0.40	0.27
3075	40	18	.0	31.4	8.2	2.4	98.2	0.31	0.31
3105	46	20	0.4	22.6	9.8	2.1	97.7	0.38	0.30
3128	42	15	0.6	33.7	7.2	2.4	97.6	0.26	0.26

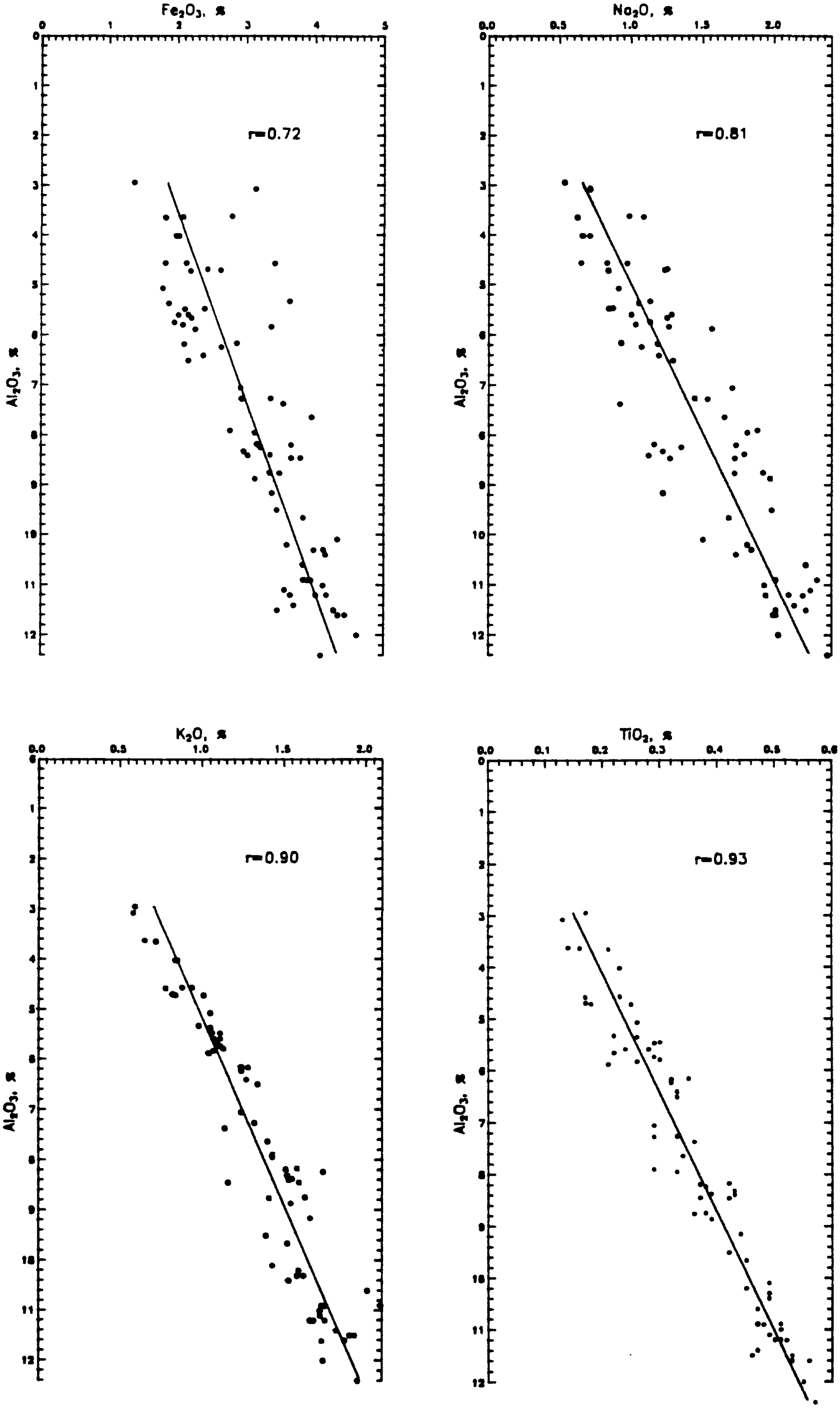

Figure 4. Al_2O_3 versus other major oxides in bulk cuttings from the Union Hobbs 22 well. Correlations were calculated by least-squares linear regression; "r" is the correlation coefficient.

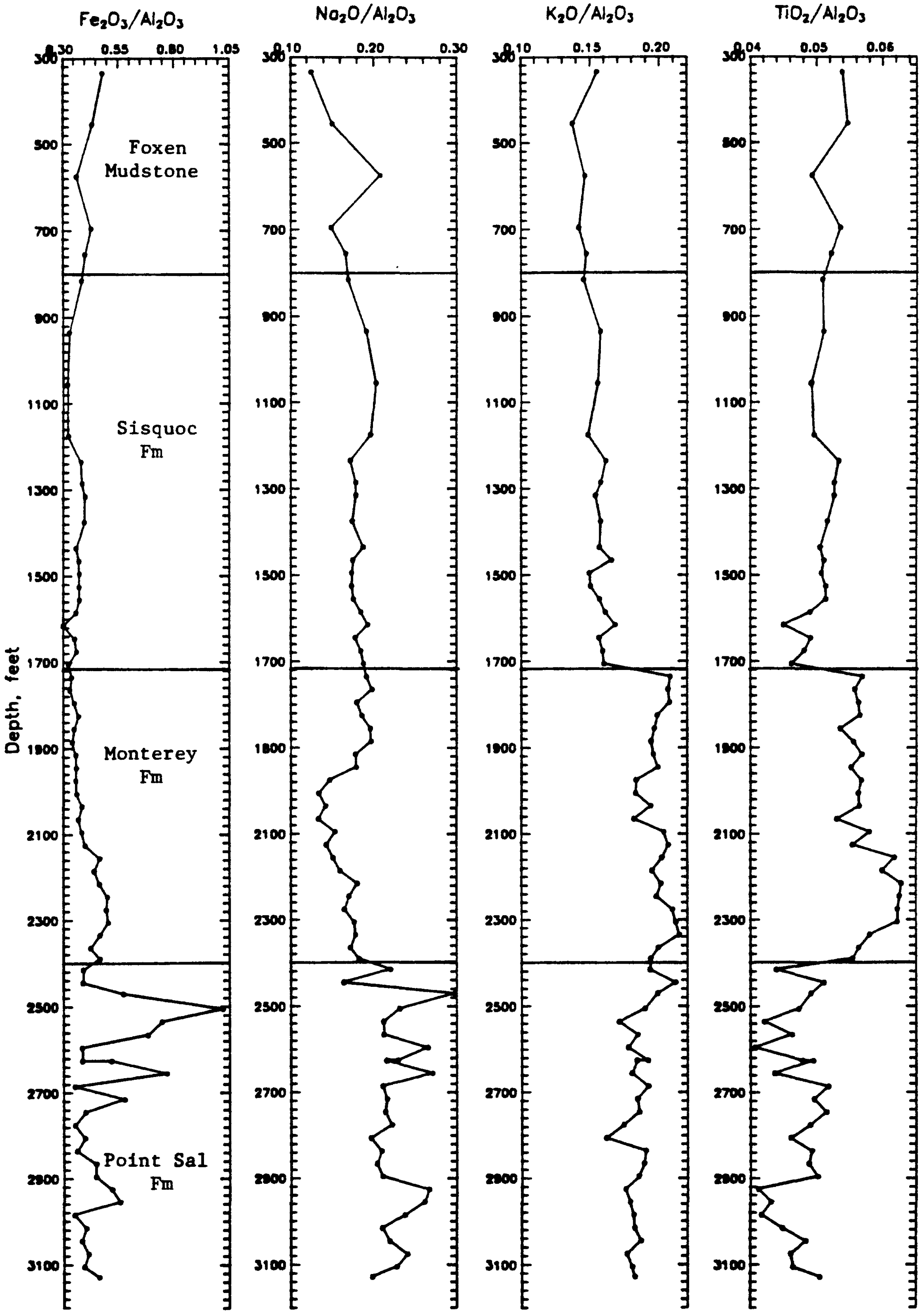

Figure 5. Selected oxide ratios versus depth in bulk cuttings from the Union Hobbs 22 well.

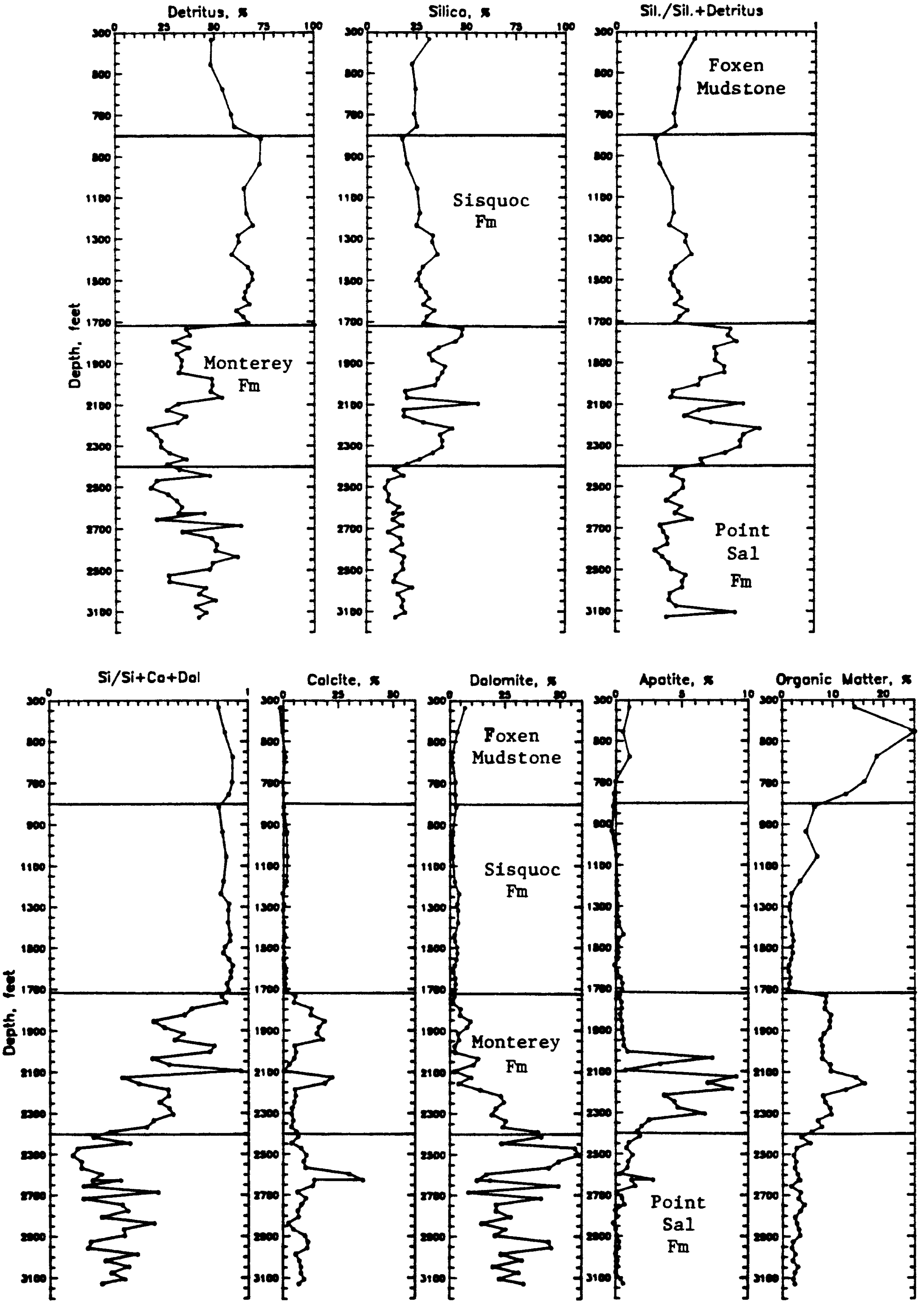

Figure 6. Summary of sedimentary components and derived parameters versus depth in bulk cuttings from the Union Hobbs 22 well.

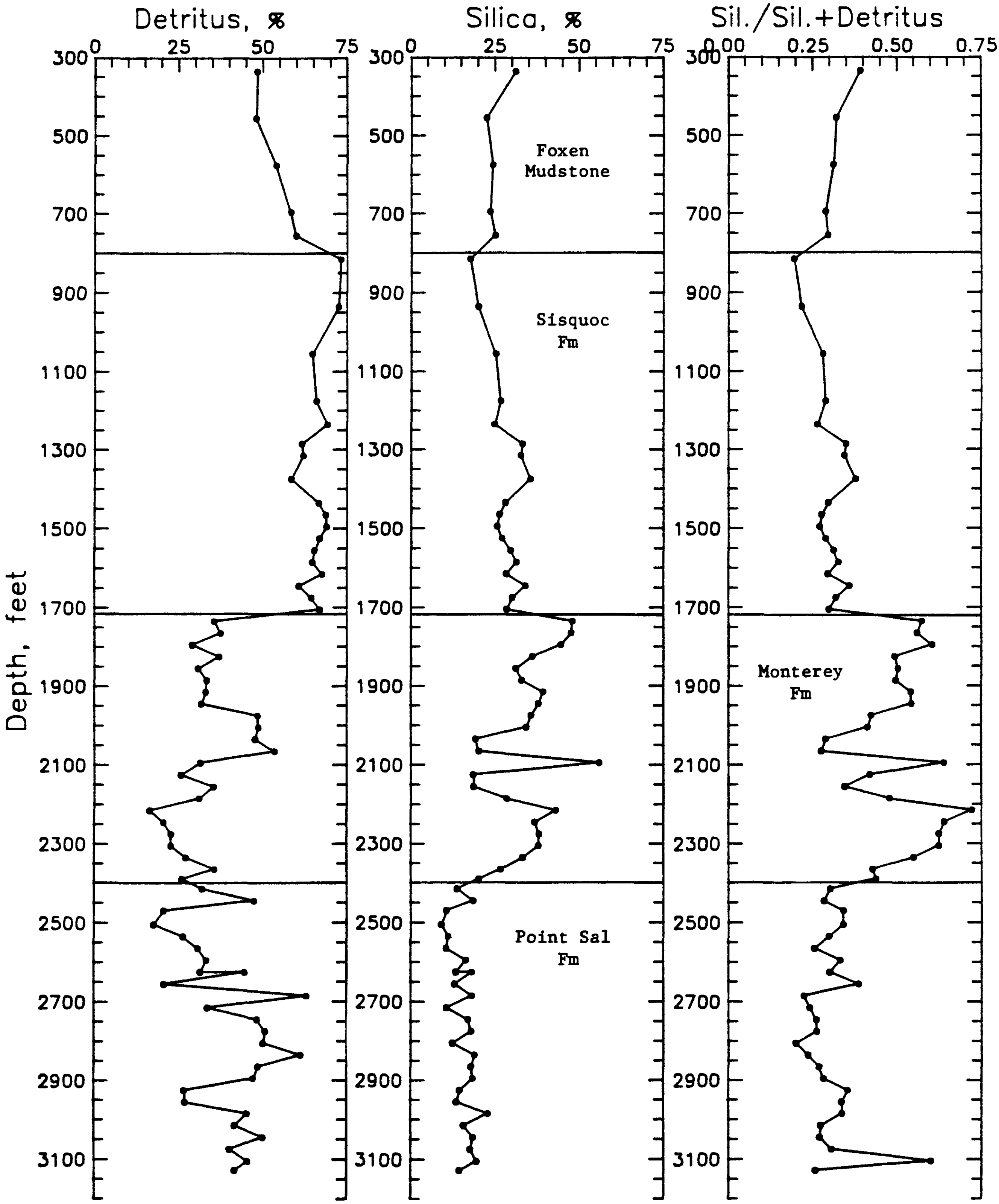

Figure 7. Abundances of detritus and silica, and the ratio silica/(silica + detritus), versus depth in bulk cuttings from the Union Hobbs 22 well.

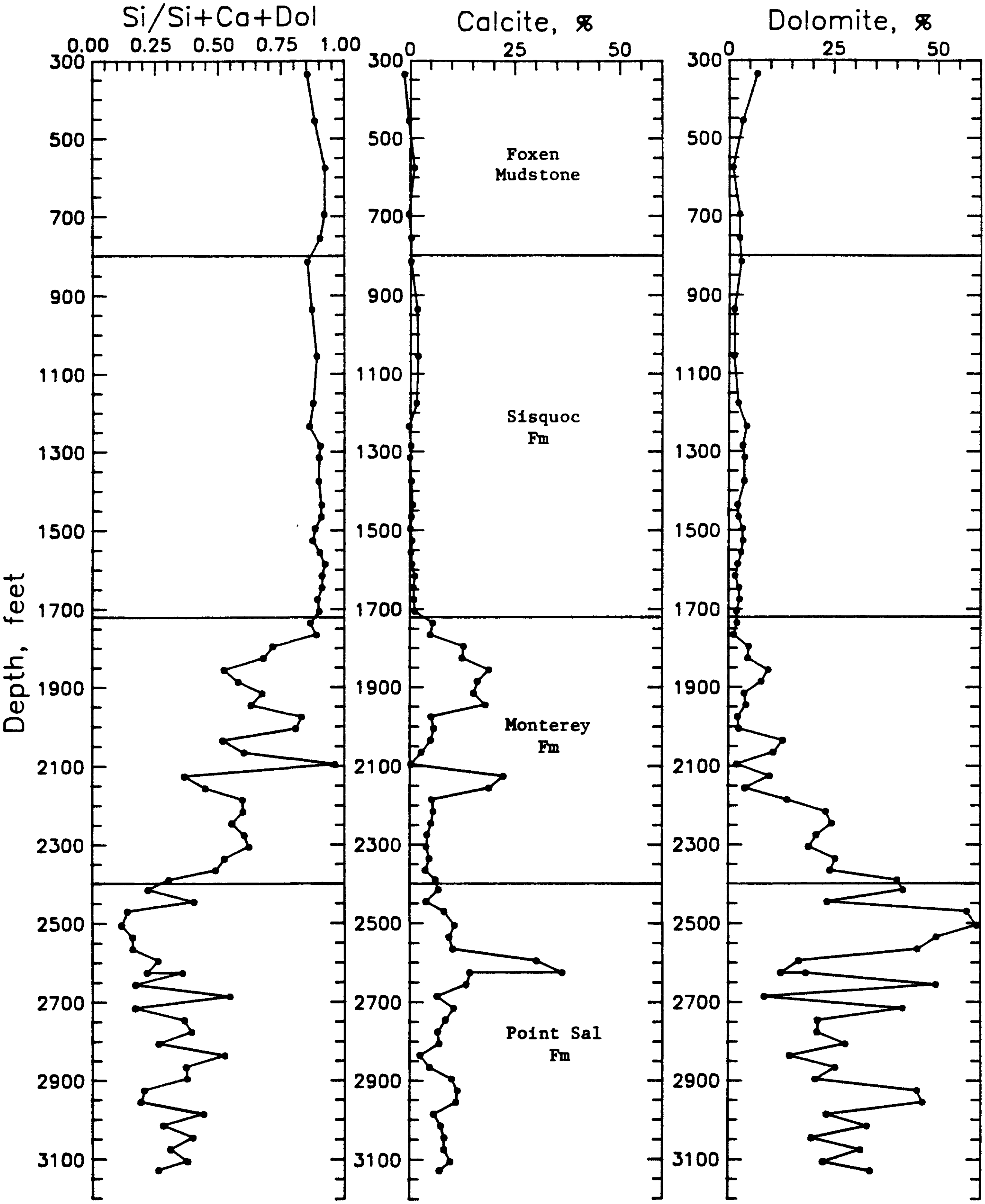

Figure 8. The ratio silica/(silica + carbonates) and abundances of dolomite and calcite versus depth in bulk cuttings from the Union Hobbs 22 well.

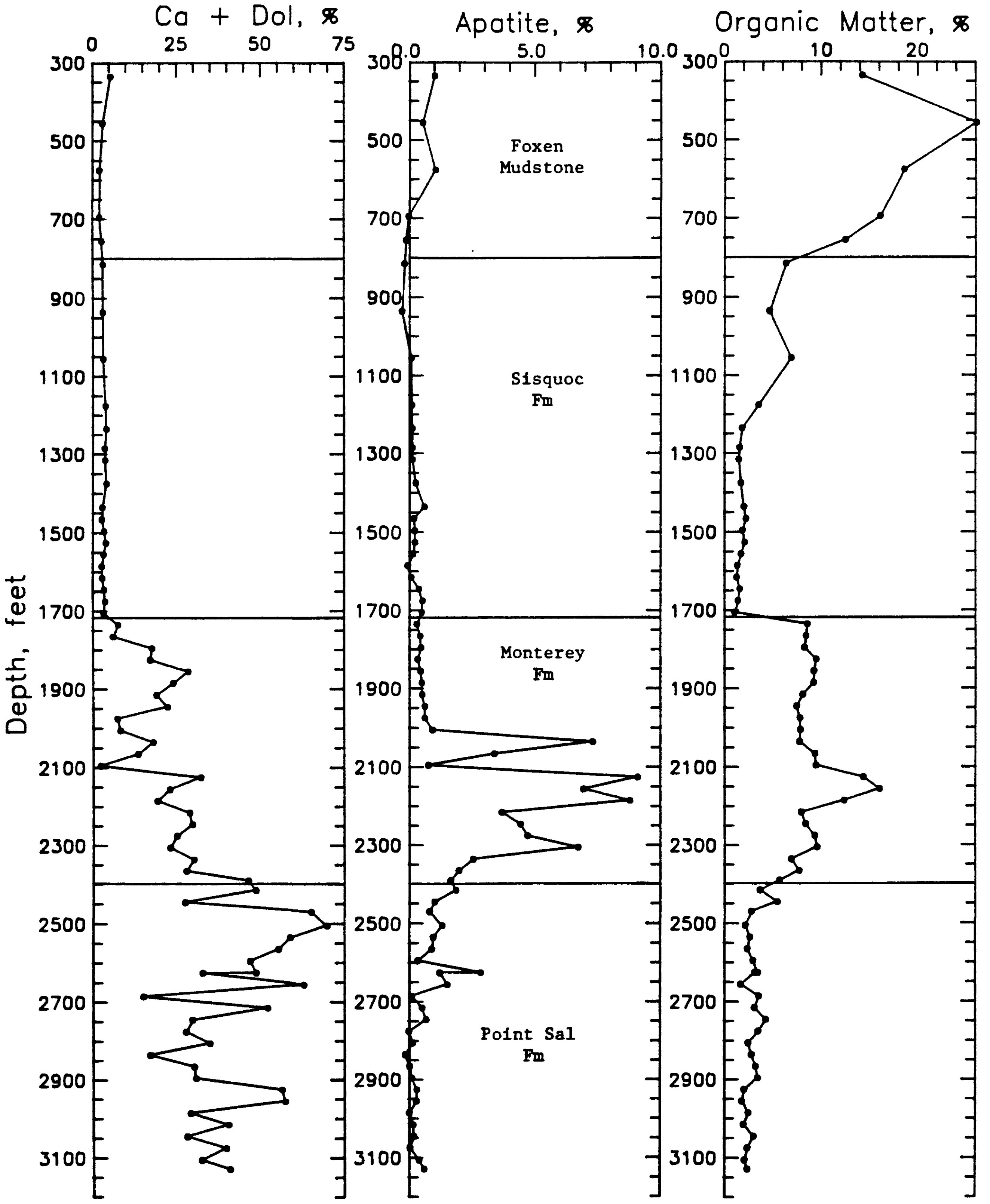

Figure 9. Abundances of carbonates, apatite, and organic matter versus depth in bulk cuttings from the Union Hobbs 22 well.

abundance of sedimentary components based on major oxide analyses is also excellent, with average standard deviations of 0.5 wt% detritus, 0.4 wt% silica, 0.1 wt% dolomite, 0.2 wt% calcite, and 0.01 wt % apatite. Reproducibility of carbon analyses (total carbon, carbonate carbon, and organic carbon) was not tested for the techniques used here on blind duplicate powder splits, only on duplicate splits of bulk (unpowdered) cuttings (see below).

Because some cuttings samples included individual pieces that were large (2-5 g) relative to sample size (10-15 g), some bias and (or) variability may have been introduced into analytical results by splitting. A previous report studied the additional variability introduced by the inhomogeneous character of cuttings, and showed that this variability results in larger average relative standard deviations - in the range 1-2.6% (av. 2.0%) - of major oxides analyzed among blind duplicate splits of the same cuttings materials (Isaacs and others, 1989a). In that study, the average relative standard deviation for organic carbon was 3.5%, and for carbonate carbon 2.9%. Average standard deviations of sedimentary components in blind duplicate bulk (unpowdered) cuttings were 0.7 wt% detritus, 0.7 wt% silica, 0.5 wt% dolomite, 0.1 wt% calcite, 0.01 wt% apatite, and 0.1 wt% organic matter. This reproducibility is so excellent that variation due to analytical methods is negligible for practical purposes.

RESULTS

The abundances of major oxides, organic carbon, and carbonate carbon in cuttings samples from the Union Hobbs 22 well are presented in Table 2, and the abundances of major sedimentary components and values of other derived parameters in Table 3. Figure 4 shows the abundances of oxides that are present mainly in the detritus fraction (Fe_2O_3, Na_2O, K_2O, and TiO_2) graphed against Al_2O_3, and Figure 5 shows the ratios of these oxides to Al_2O_3 graphed against depth. Figures 6-9 show the abundance of major sedimentary components and values of other derived parameters graphed against depth. In these tables and figures, the depth is given as the mid-point of the 30-foot interval analyzed; for example, the sample listed at 3045 feet represents the interval 3030-3060 feet.

PRELIMINARY COMPARISON OF CORES AND CUTTINGS

A major purpose of analyzing cuttings from the Union Hobbs 22 well was to compare results with analyses of core samples from the nearby Union Newlove 51 well previously reported by Isaacs and others (1989b). The two wells do not represent an ideal comparison between cores and cuttings for two major reasons: (1) real (geologic) lateral variation and (2) sample heterogeneity.

In terms of lateral variation, the Union Newlove 51 well is located in the center of the Orcutt oil field, 1.0 miles (1.6 km) south of the Union Hobbs 22 well in the northern part of the field (Figure 2). The distance between the two wells is comparatively large for an ideal comparison. According to Dunham and others (in press), marked facies and thickness differences are common over short distances in subsurface sequences of the lower part of the Monterey Formation and Point Sal Formation in the Santa Maria basin. Particularly marked differences between Point Sal strata in the two wells are shown by Lagoe's (1987) study of the area, which indicates that the Union Newlove 51 well penetrates the thickest part (>300 ft or >100 m) of a lenticular turbidite sandstone body in the upper part of the Point Sal

Formation, whereas the Union Hobbs 22 well penetrates the thin fringe of the sandstone body. For these reasons, the Point Sal sequences in the two wells cannot be considered sufficiently similar to compare cores and cuttings properly. Moreover, some caution is indicated in comparing Monterey samples, particularly in the lower part of the formation.

The second major problem in comparing cores and cuttings in the two wells is compositional heterogeneity and sampling bias. As is widely recognized and demonstrated clearly in Figure 10 for the Union Newlove 51 well, the Sisquoc Formation is relatively homogeneous in composition compared to the Monterey and Point Sal Formations. In fact, sample heterogeneity in the Monterey and Point Sal Formations is so high as to preclude precise determination of averages from the number of core samples analyzed (14-20) in the sets compared here. For example, based on actual (non-Gaussian) sample distributions in the Monterey Formation of the area, to determine with 90% confidence a true mean of 50 wt% silica within 5 wt% (i.e., in the range 45-55%) would require at least 100 randomly selected samples in each interval (Isaacs, 1987), whereas even 25 samples give 90% confidence of being only within 10 wt% of that mean (i.e., in the range 40-60%). In addition, core samples from the Union Newlove 51 well cannot in fact be described as randomly selected, inasmuch as (1) core recovery was not complete; (2) cores have been handled and divided by numerous persons for over 50 years; and (3) most samples were chosen to match porosity plugs, thus selecting against friable or fractured samples.

As a result, only the two Sisquoc data sets can be considered to represent a good basis for comparison between cores and cuttings. The value of comparing the Monterey data sets is somewhat limited by sampling problems and probable geologic variation, and the value of comparing the Point Sal data sets is very limited by sampling problems and marked geologic variation.

Nonetheless, overall trends can be compared between the two wells, and the less heterogeneous Sisquoc Formation can be more exactly compared. A correlation between the 2 wells is shown in Figure 10. Comparison shows the following features (see also Table 4):

1. Cuttings from the lower part of the Sisquoc Formation in the Union Hobbs 22 well (1150-1720 ft) are extremely similar in average composition to cores from that interval in the Union Newlove 51 well (808-1884 ft). The 15 cuttings samples average 65% detritus, 29% silica, 3% carbonate minerals, 0.2% apatite, and 1.8% organic matter. The 14 core samples average 67% detritus, 28% silica, 4% carbonate minerals, 0.2% apatite, and 1.2% organic matter.
2. Compared to the lower part of the Sisquoc Formation, cuttings from the upper part of the Monterey Formation in the Union Hobbs 22 well (1720-2050 ft) show sharply lower detritus, sharply higher organic matter, markedly higher carbonate minerals, and somewhat higher silica (Figure 10). Each of these features is also shown by the average of 18 core samples from the upper part of the Monterey Formation (1884-2289 ft) in the Union Newlove 51 well. Also, average compositions of the cuttings are similar to average compositions of the cores and are well within the confidence limits of these averages (Table 4).
3. Cuttings from the remainder of the Monterey Formation in the Union Hobbs 22 well (2050-2400 ft) vary considerably in detritus abundance (30-foot intervals range from 17-54%), silica (range, 19-56%), and carbonate minerals (range, 2-46%). Organic matter shows about the same abundance as in the uppermost part of the Monterey, with some higher values (to 16%).

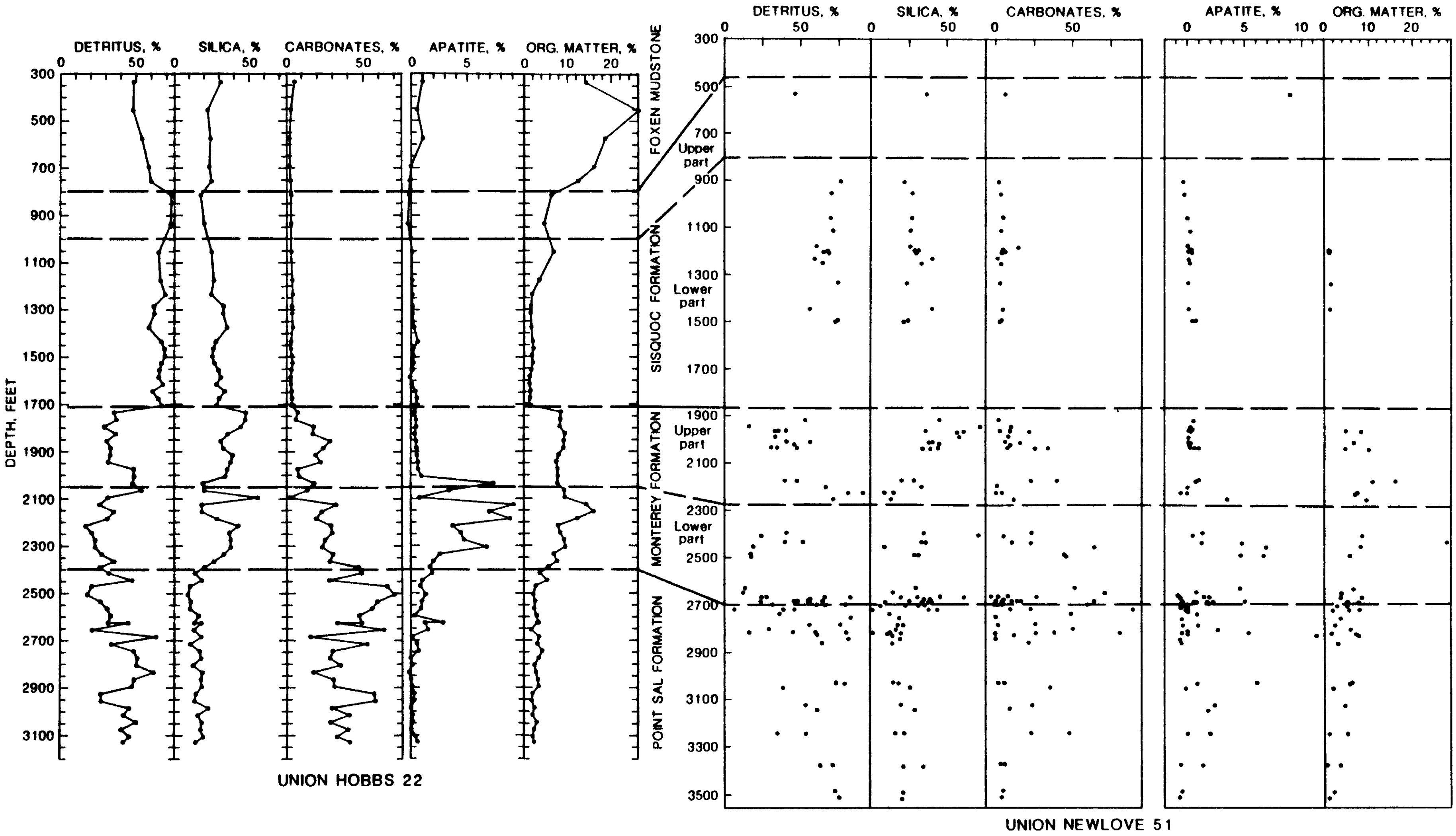

Figure 10. Comparison of compositional data based on well cuttings (Union Hobbs 22 well) and core samples (Union Newlove 51 well); all abundances in weight %. Union Newlove 51 data are from Isaacs and others (1989b); correlation is from Gregg Blake and Mary Lou Thornton (written communications, 1989, 1990).

Table 4. Comparison of average composition (in weight %) of selected intervals based on cuttings from the Union Hobbs 22 well and cores from the Union Newlove 51 well, as correlated in Figure 10. Values given as "±" are standard deviations assuming normal distribution of values. N is the number of samples. Not all cores were measured for organic carbon; values for sedimentary components in the Union Newlove 51 well were re-calculated from Isaacs and others (1989b) to include the average abundance of organic matter for each interval.

Formation	N	Detritus	Silica	Carbonates	Apatite	Organics
Sisquoc Fm, lower						
cuttings (1150-1720 ft)	15	65 ± 3	29 ± 3	3.4 ± 0.5	0.2 ± 0.2	1.8 ± 0.6
cores (808-1884 ft)	14	67 ± 6	28 ± 6	3.7 ± 2.9	0.2 ± 0.3	1.2 ± 0.1
Monterey Fm, upper						
cuttings (1720-2050 ft)	11	38 ± 7	37 ± 8	16 ± 8	1.1 ± 2.1	8.4 ± 0.7
cores (1884-2289 ft)	18	44 ± 17	35 ± 16	12 ± 11	0.5 ± 0.8	8.5 ± 3.3
Monterey Fm, lower						
cuttings (2050-2400 ft)	12	29 ± 10	32 ± 12	25 ± 11	4.6 ± 2.8	9.8 ± 3.0
cores (2289-2696 ft)	20	36 ± 19	31 ± 14	23 ± 22	2.1 ± 2.2	8.6 ± 6.9

Apatite is comparatively abundant, with 30-foot intervals as high as 9.1% and averaging 4.6%. The same overall features are shown by the average of 20 core samples from the Union Newlove 51 well. Also, average compositions of the cuttings are similar to average compositions of the cores and are well within the confidence limits of these averages (Table 4).

4. In the Point Sal Formation, lateral geologic differences between the two wells are probably so great (Lagoe, 1987) that detailed comparison of the two sets of data is not meaningful. In general, cuttings from the Point Sal Formation in the Hobbs 22 well (2400-3135 ft) vary considerably in detritus (30-foot interval range, 18-63%) but are consistently lower in silica, organic matter, and apatite than overlying Monterey strata and are also on average higher in carbonate minerals. The same features are shown by the 30 core samples in the Union Newlove 51 well except that carbonate mineral abundance is much lower.

In summary, the comparison of cores and cuttings confirms that cuttings are reasonably representative of the compositional sequence drilled. The similarity of results in the relatively homogeneous Sisquoc Formation is excellent. General trends in the more heterogeneous Monterey Formation are also within the limits of confidence for the number of core samples analyzed, especially considering the uncertainties in lateral trends in the lower part of the sequence.

Figure 10 also demonstrates the efficiency of cuttings analyses. The analyses of 83 core samples from the Union Newlove 51 well result in an extremely spotty record with ill-defined compositional trends of uncertain meaningfulness. The 72 analyses of cuttings from the Union Hobbs 22 well, by contrast, yield a complete sequence with well-defined compositional trends and surprisingly good resolution of major lithologic units.

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