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Whole-rock and Clay Mineralogies of Deeply-buried Rocks, Permian Upper Part of the Minnelusa Formation, Powder River Basin, Wyoming

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Abstract

Core from three wells from the Permian upper part of the Minnelusa Formation was recovered at depths >15,000 ft in the west-central Powder River basin, Wyoming. The core consists mainly of alternating cycles of dolomite and sandstone. Quartz, dolomite, clay minerals, and potassium feldspar are the common components of these rocks, as determined by X-ray powder diffraction analysis (XRD). Calcite, anhydrite, and pyrite are also present in smaller amounts. The clay mineral content in all samples studied was <8 weight percent with a mean of 3 percent. Point-to-point mineral logs of the semiquantitative XRD data mimic lithology and provide insight for recognition of zones of cementation.

Illite is the dominant clay mineral in most samples; however, corrensite was more abundant than illite in three samples. R3 ordered mixed-layer illite/smectite (I/S) with less than 10 percent expandable layers was found in most samples. Discrete chlorite was also present in minor amounts in some samples. The clay mineral composition of the <2-µm fraction was about 83 percent illite, 15 percent I/S, and 2 percent chlorite (mean values). The corrensite was R1 ordered with a 50/50 composition. Minimum burial temperatures from the I/S and C/S geothermometers are estimated to be about 170 °C.

Introduction

The Permian upper part of the Minnelusa Formation in the Powder River basin, Wyoming, is a major producer of hydrocarbons, particularly at depths between about 6,000 to 10,000 ft. This upper part represents four transgressive-regressive cycles composed of marine carbonates and sabkha and eolian sandstones (Fryberger, 1984; George, 1984). The major reservoirs for hydrocarbons are the eolian sandstones (James, 1989; Schenk, 1990a). Diagenesis is the main control on porosity in the sandstones where early, pervasive cementation by anhydrite inhibited compaction and preserved intergranular space (Markert and Al-Shaieb, 1984; Schenk and Richardson, 1985; James, 1989; Schenk, 1990a, b). Late dissolution of anhydrite cement produced varying degrees of secondary porosity prior to the migration of hydrocarbons into the eolian sandstones (Schenk and Richardson, 1985; James, 1989; Schenk, 1990a).

Although numerous studies have investigated sandstone reservoirs of the Minnelusa at depths of about 11,000 ft or less (Markert and Al-Shaieb, 1984; James, 1989; Schenk, 1990a), few have studied the sandstones at depths to 15,000 ft or greater. The purpose of this report is to describe the whole-rock and clay mineralogies, as determined by X-ray powder diffraction (XRD) analysis, of rocks from the Permian Upper part of the Minnelusa Formation in three wells at about 15,000 ft. This report represents only a part of a more extensive investigation on the sedimentology, petrology, diagenesis, and reservoir characteristics of the Minnelusa Formation, and was performed in cooperation with studies by Schenk (1990b).

Well Locations, Sampling, and Analytical Methods

A total of 48 samples of core were analyzed by XRD for whole-rock and clay mineralogies. The samples were taken from core from three wells located along the basin axis in the west-central part of the Powder River basin, Johnson

County, Wyoming (fig. 1), and correspond to many of the samples studied by Schenk (1990b). The locations of the wells and depths of the cored intervals studied are listed in table 1; specific sample depths are given in table 2.

Samples were washed and scrubbed to remove surficial contaminants, dried, and then ground to <35 mesh. Each sample was then split into two portions, using a Jones splitter, for (1) whole-rock XRD, and (2) carbonate dissolution and clay mineral analysis. Carbonate (and sometimes anhydrite) was dissolved in 1N HCl acid and the residue filtered and washed immediately after effervescence stopped, so as to minimize solution of noncarbonate minerals (Pollastro, 1977). The insoluble residue was dried overnight at 65 °C. The weight percent of the residue and/or carbonate was then determined. A small portion of the residue was spot-checked for undissolved carbonate with 6N HCl.

Qualitative and semiquantitative estimates of the minerals in whole rock were made through XRD analysis of randomly-oriented powders that were ground to a maximum grain size of 44-µm (<325 mesh), and packed from the back side into aluminum specimen holders. A fine random texture was imparted onto the surface to be irradiated to reduce any preferred orientation created while mounting the sample (see Schultz, 1978). All samples were analyzed using copper K-alpha radiation. Semiquantitative weight percent values for total clay (phyllosilicates) and other minerals or mineral groups were calculated by comparison with several prepared mixtures of minerals with similar XRD characteristics by the procedures outlined by Schultz (1964) and Hoffman (1976) with some modification. The semiquantitative relative weight percent values calculated for total carbonate minerals by XRD then were compared against those determined by chemical dissolution.

Oriented clay aggregates of the <2-µm and <0.25-µm (equivalent spherical diameter) fractions were prepared using a modified filter-membrane-peel technique (Pollastro, 1982) similar to that described by Drever (1973). Semiquantitative XRD analysis of the clay minerals in the <2-µm fractions was made using the method of Schultz (1964) with some modification. Composition and ordering of interstratified illite/smectite (I/S) and chlorite/smectite (C/S) clay were determined on oriented, ethylene glycol-saturated specimens of both the <2-µm and <0.25-µm fractions. Interpretations of I/S are based on the methods of Reynolds and Hower (1970) and Reynolds (1980) (also see Moore and Reynolds, 1989), with the understanding that the XRD patterns may also be interpreted as physical mixtures of fundamental particles (Nadeau and others, 1984a,b), rather than mixed-layer clays.

Results and Interpretation

Whole-rock Mineralogy

The results of the whole-rock analysis is shown in table 2. The whole-rock data are also displayed in graphic form for each of the wells in figures 2-4. The common components of the deep Minnelusa samples are quartz, dolomite, clay minerals, and potassium feldspar. Anhydrite is occasionally present and, rarely, calcite and pyrite. The clay mineral content in all samples was <8 percent with a mean of 3 percent. Minor potassium feldspar was found in most sandstones, however, it was rare to absent in dolomites.

Alternating cycles of quartz-rich sandstone and dolomite can be recognized in the vertical profiles from both the numerical data listed in table 2 and the area graphs of figures 2 and 4. In particular, cycles are well displayed in the Energetics 12-34 Ackerman samples of figure 2. The cycles represent alternating transgressive (marine dolomite) and regressive (commonly eolian sandstone) events that characterize the Permian upper part of the Minnelusa (Fryberger, 1984; George, 1984). It should be noted, however, that the distribution of data plotted in figures 2-4 are biased by selective sampling. The data are thus plotted as point-to-point logs where data for each sample point is extrapolated to the next; the graphs do not represent a continuous mineral log over the depth intervals studied. The XRD mineral logs of figures 2-4 interpreted to represent quartz sandstone and dolomite rock cycles, however, agree with lithologies from visual core examination. In general, the mineral logs mimic unpublished lithologic logs of the same core described and interpreted by C. J. Schenk (U.S.G.S., personal communication). Such aggreement suggests that the sample selection was probably made with the intent to represent the general distribution and abundance of lithologic types.

Clay Mineralogy

The qualitative and semiquantitative interpretation of the <2-um clay mineralogy is shown in table 2. Five samples did not contain sufficient amounts of clay for fractionation and specimen preparation and are designated by "no clay" in table 2. A typical XRD pattern for the <2-μm fraction is shown in figure 5. The amount and distribution of clay minerals in the <2-μm fraction from the cores studied are displayed in the graphs of figures 6-8. The dominant clay mineral in all but three samples analyzed was illite. All but two samples contained a small to moderate amount (3-44 weight percent) of I/S. The I/S in all samples was R3 ordered and contained only few (<10 percent) expandable layers after solvation with ethylene glycol (fig. 5). The mean clay mineral composition for 40 samples is 83 percent illite, 15 percent I/S, and 2 percent chlorite plus interstratified chlorite/smectite (C/S); however, only 4 of the 40 samples dominated by illite contained chlorite and(or) C/S.

C/S was the dominant clay mineral in three samples. The C/S is as R1 ordered with a 50/50 composition and is trioctahedral, low charge corrensite (see calculated patterns in Moore and Reynolds, 1989). The XRD patterns of corrensite from both the <2- and <0.25-μm fractions exhibit strong superlattice reflections, particularly upon saturation with ethylene glycol where the superlattice expands to about 31.5 angstroms (fig. 9); the superlattice collapses to about 24 angstroms after heating to 550 °C (fig. 9). Corrensite is commonly associated with evaporites and carbonates, particularly dolomite (Grim et al., 1959; Lucas and Ataman, 1968; Kopp and Fallis, 1974). The formation of corrensite suggests the presence of magnesium-rich fluids. Common sources are hypersaline environments and hydrothermal events, and transformation of precursor clays during deep diagenesis. April (1980) suggested that dedolomitization may also contribute to the formation of corrensite.

Ordered I/S and corrensite are commonly used as geothermometers (Hoffman and Hower, 1979; Pollastro, 1990). Corrensite suggests minimum burial temperatures of about 90-100 °C and R3 ordered I/S, assuming that it formed by smectite diagenesis, is documented to form at temperatures of about 170-180 °C (Hoffman and Hower, 1979). The presence of these phases in core of the deep Permian upper part of the Minnelusa are in accordance with clay-mineral assemblages commonly reported from deeply-buried rocks (Hower, 1981). The present geothermal gradient in the study area is 30-35 °C/km (Kron and Heiken, 1980). Temperature data from wells produciing from Permian reservoirs of the Minnelusa in the Hawk Point field reported by James (1989) suggests a geothermal gradient of 33 °C. Without considering uplift and erosion for maximum burial conditions, the temperature calculated from the present geothermal gradient of 33 °C/km to 15,000 ft for deep Minnelusa samples is about 160 °C.

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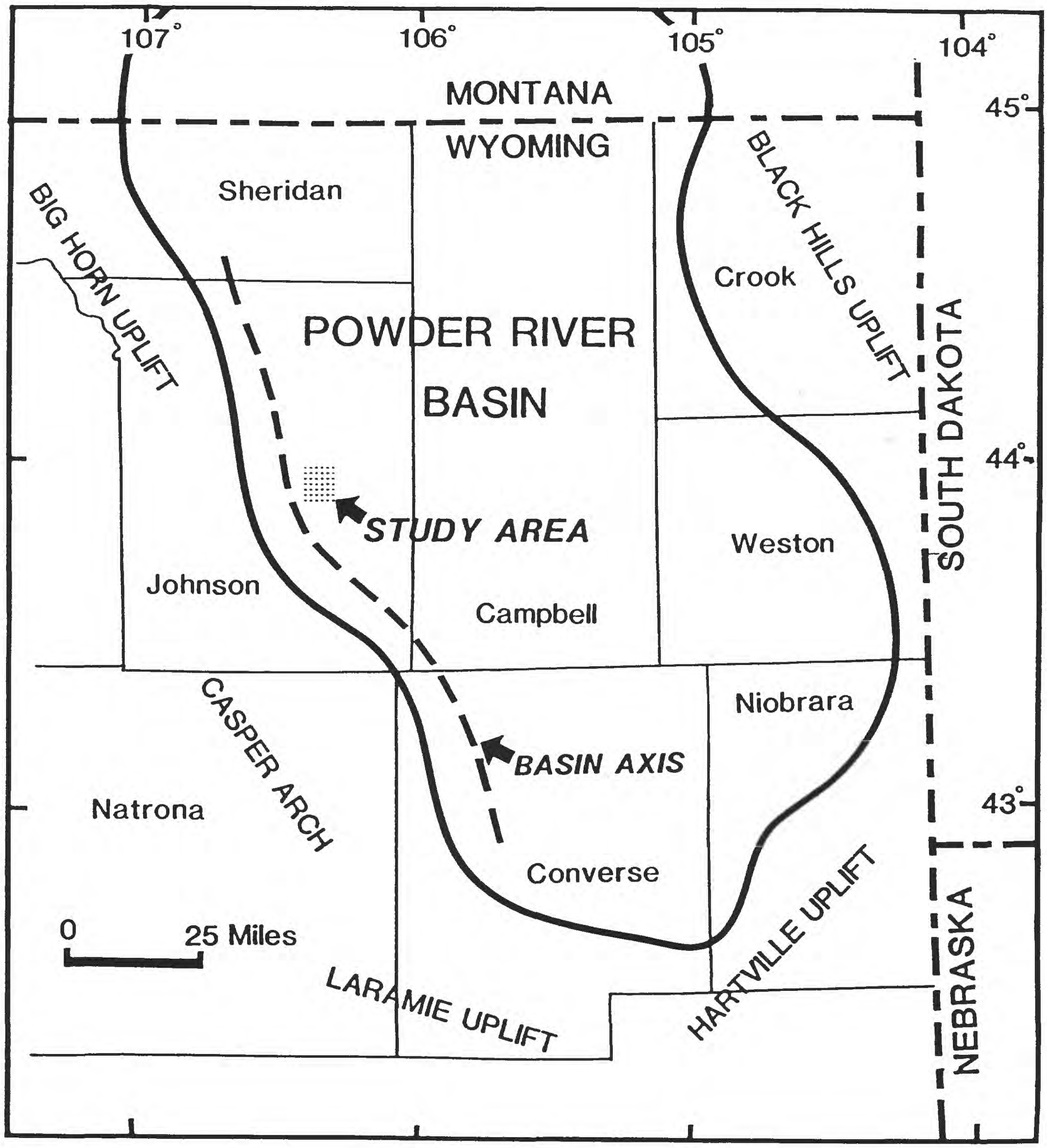

Figure 1.--Map showing outline of Powder River basin, Wyoming, major adjacent stuctural features, county lines, and study area.

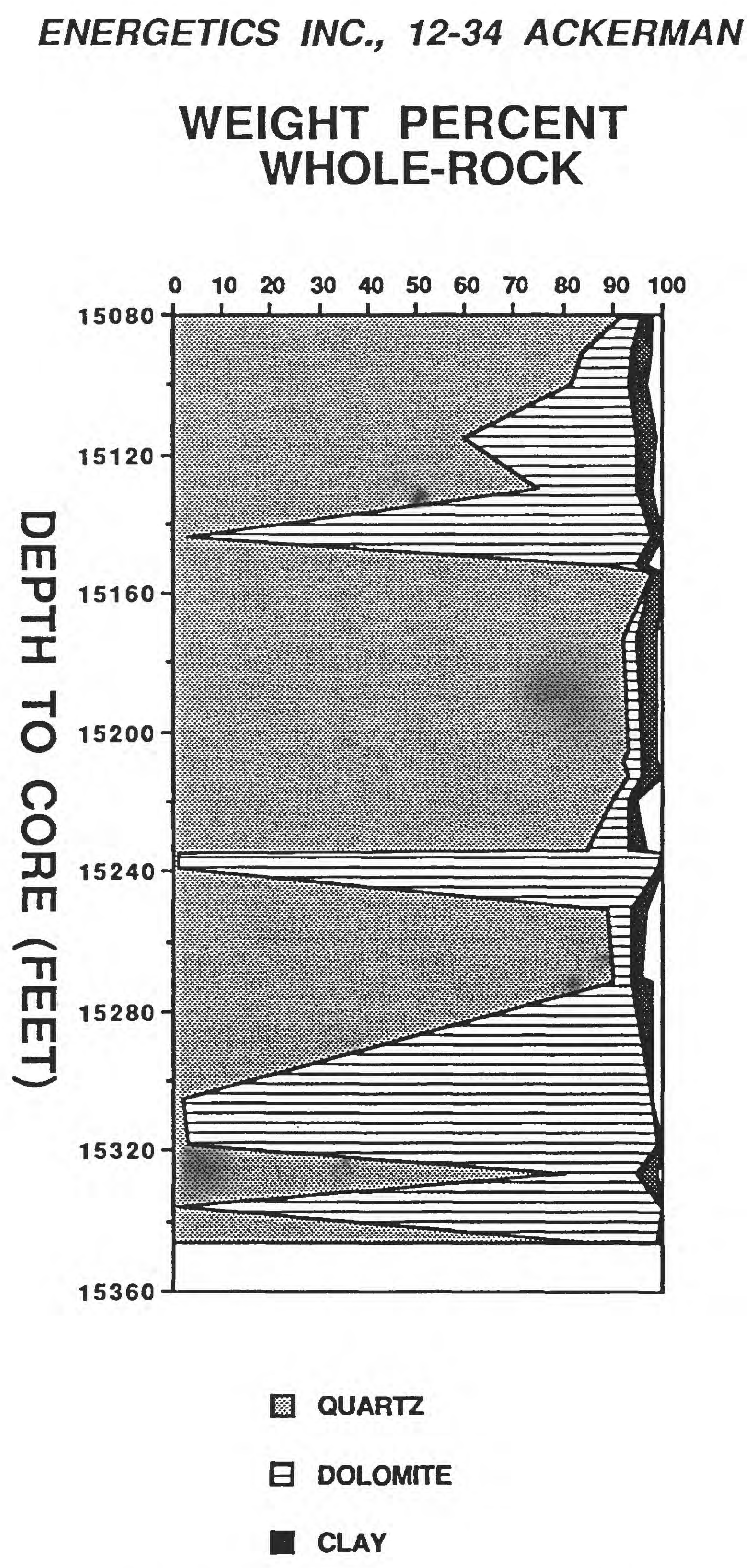

Figure 2.--Point-to-point area graph of main minerals in whole-rock, in weight percent, from X-ray powder diffraction analysis of samples from core, Energetics Inc., 12-34 Ackerman well. White area in graph represents balance of other mineral components.

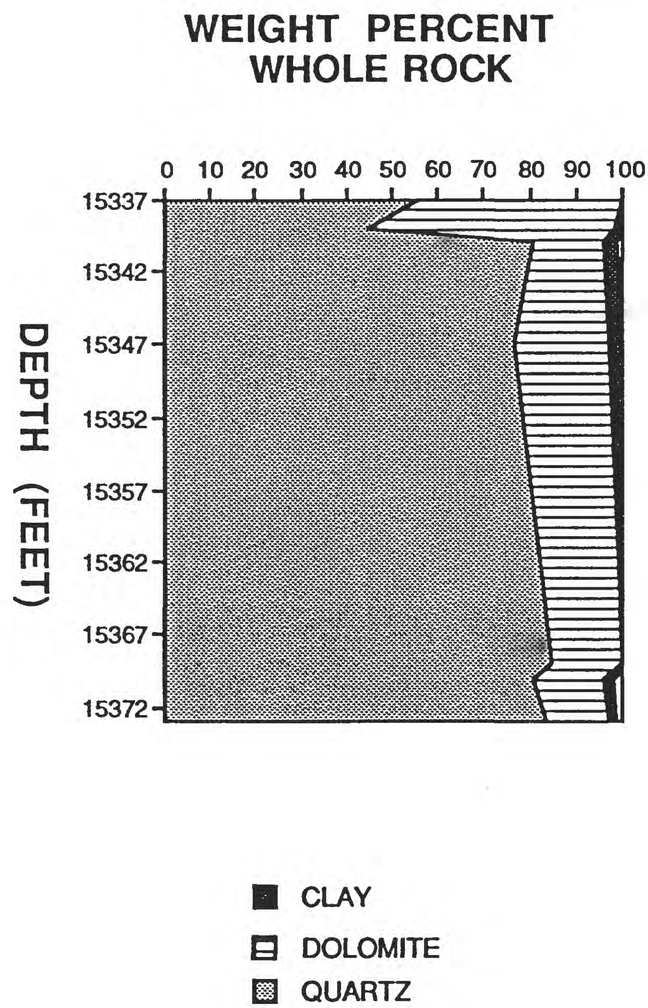

Figure 3.--Point-to-point area graph of main minerals in whole-rock, in weight percent, from X-ray powder diffraction analysis of samples from core, Hershey Oil Corp., 3-34 Carr well. White area in graph represents balance of other mineral components.

UNION OIL CO., #1 FRYE

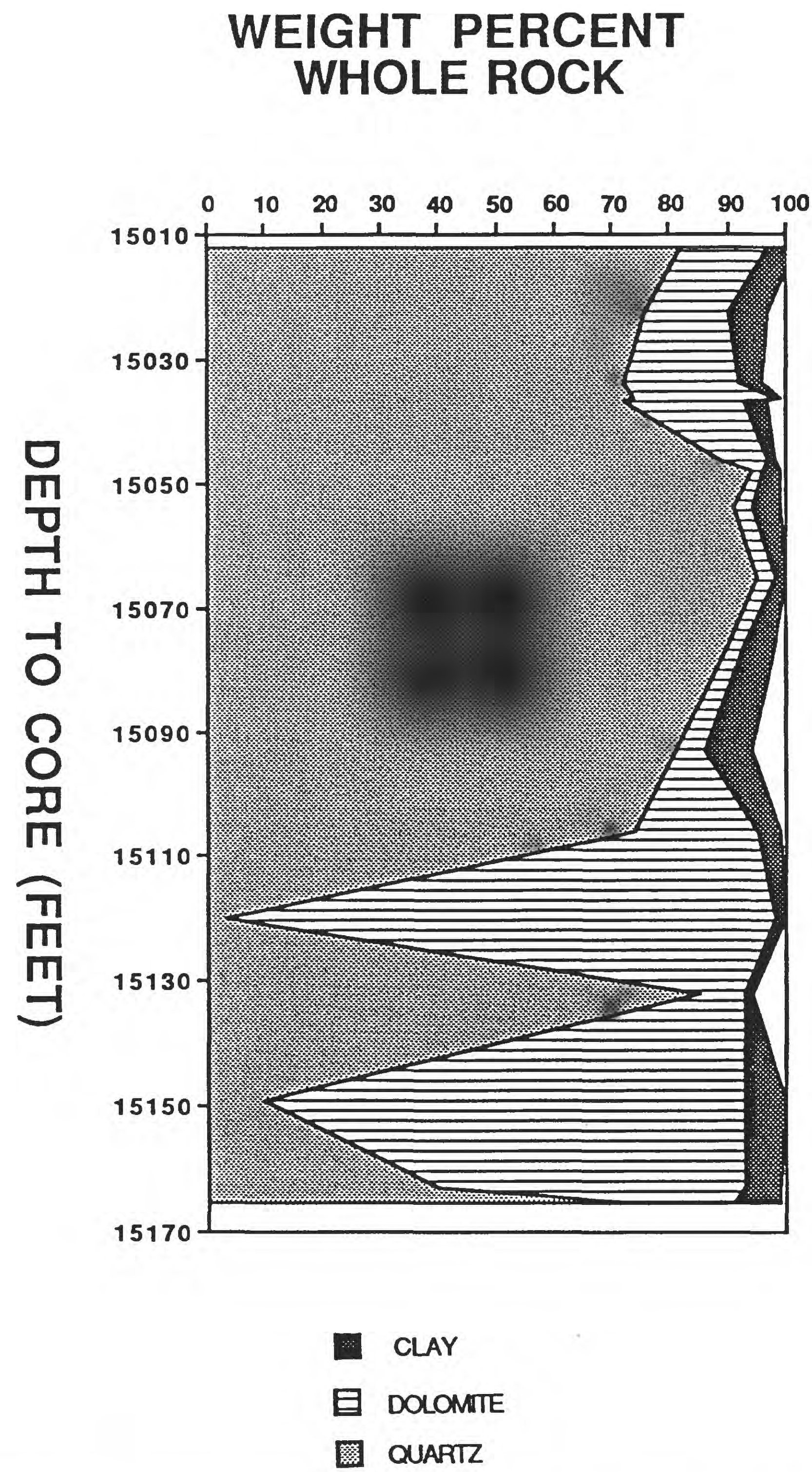

Figure 4.--Point-to-point area graph of main minerals in whole-rock, in weight percent, from X-ray powder diffraction analysis of samples from core, Union Oil Co., #1 Frye well. White area in graph represents balance of other mineral components.

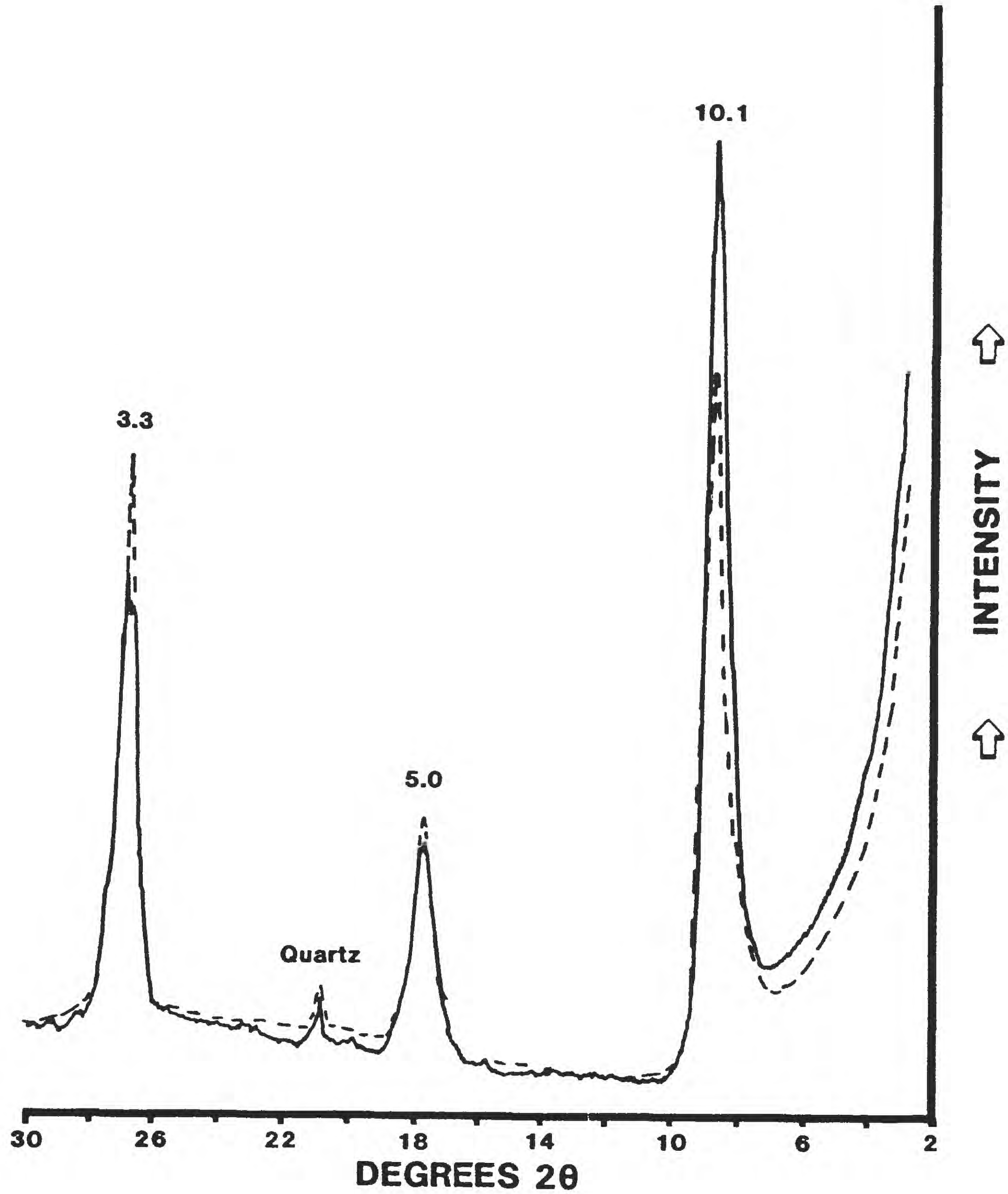

Figure 5.--X-ray powder diffraction profiles of illite and ordered, low expandable, mixed-layer illite/smectite in oriented, <2-μm fraction (Union Oil Co., #1 Frye well; sample 15,106). Profiles such as these are characteristic of clay minerals in the Permian upper part of Minnelusa core samples below 15,000 ft. Solid profile is for air-dried specimen and dashed line is after saturation with ethylene glycol. Peak positions labeled in angstroms. Copper K-alpha radiation.

ENERGETICS INC., 12-34 ACKERMAN

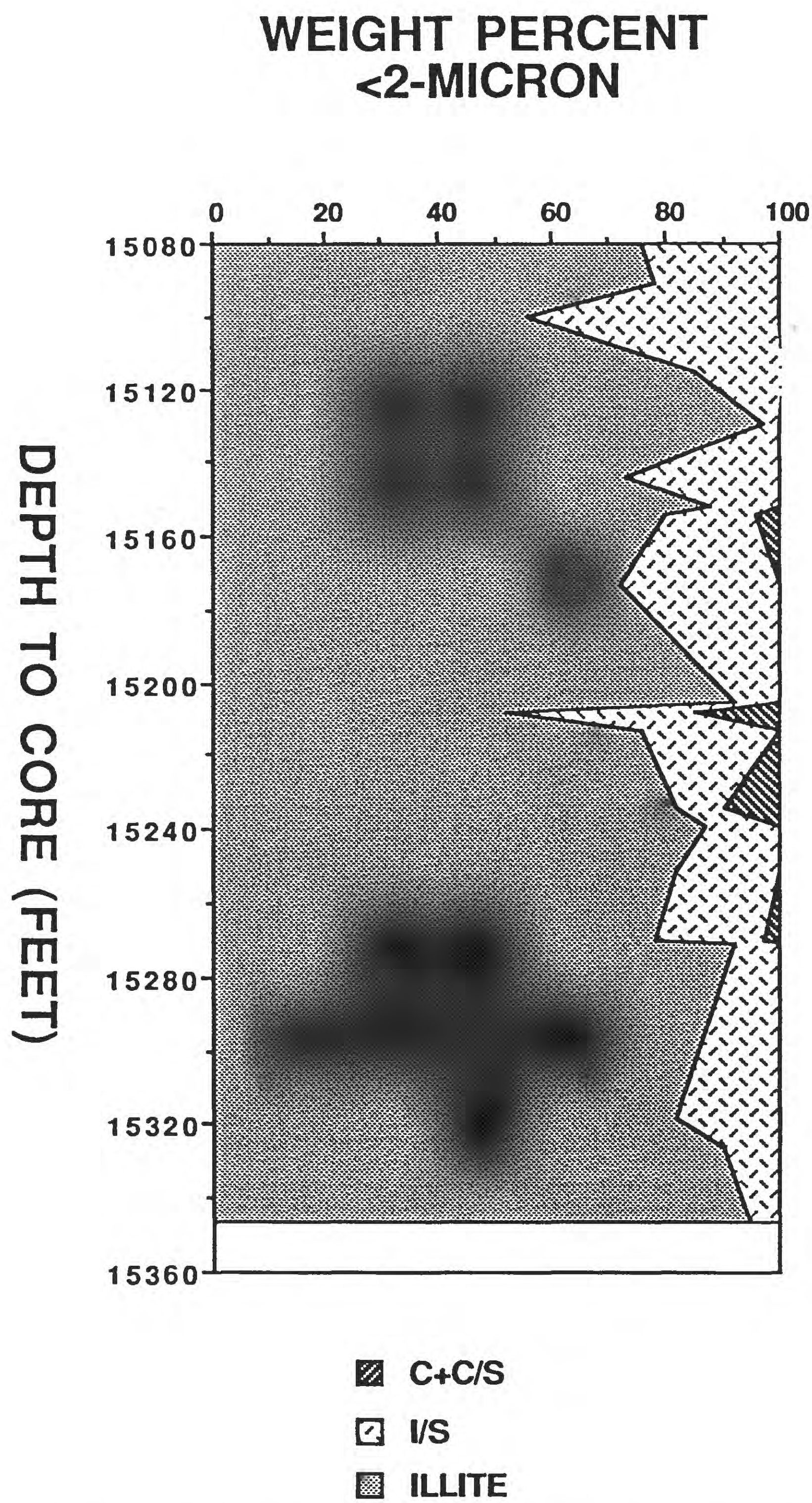

Figure 6.--Point-to-point area graph of clay minerals in <2-μm fraction, in relative weight percent, from sampes of core, Energetics Inc., 12-34 Ackerman well.

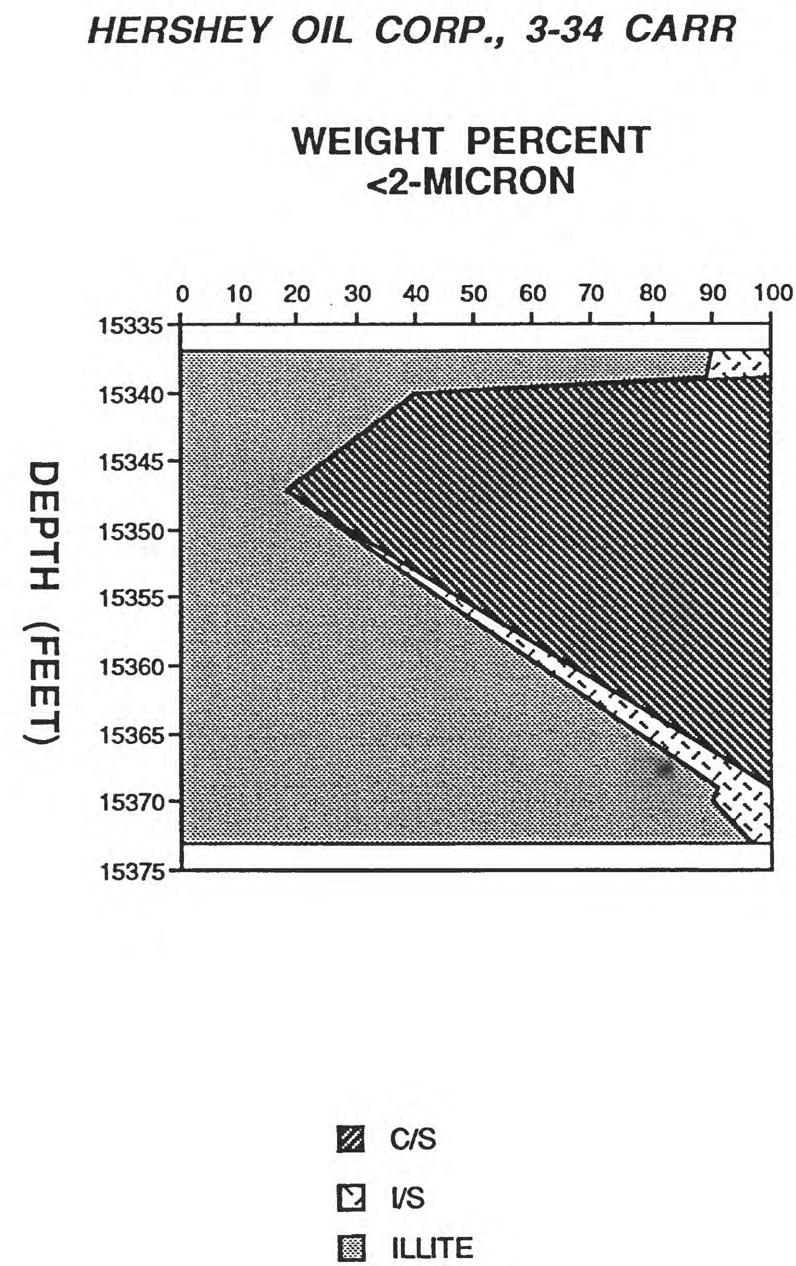

Figure 7.--Point-to-point area graph of clay minerals in <2-µm fraction, in relative weight percent, from samples of core, Union Oil Co., #1 Frye well.

UNION OIL CO., # FRYE

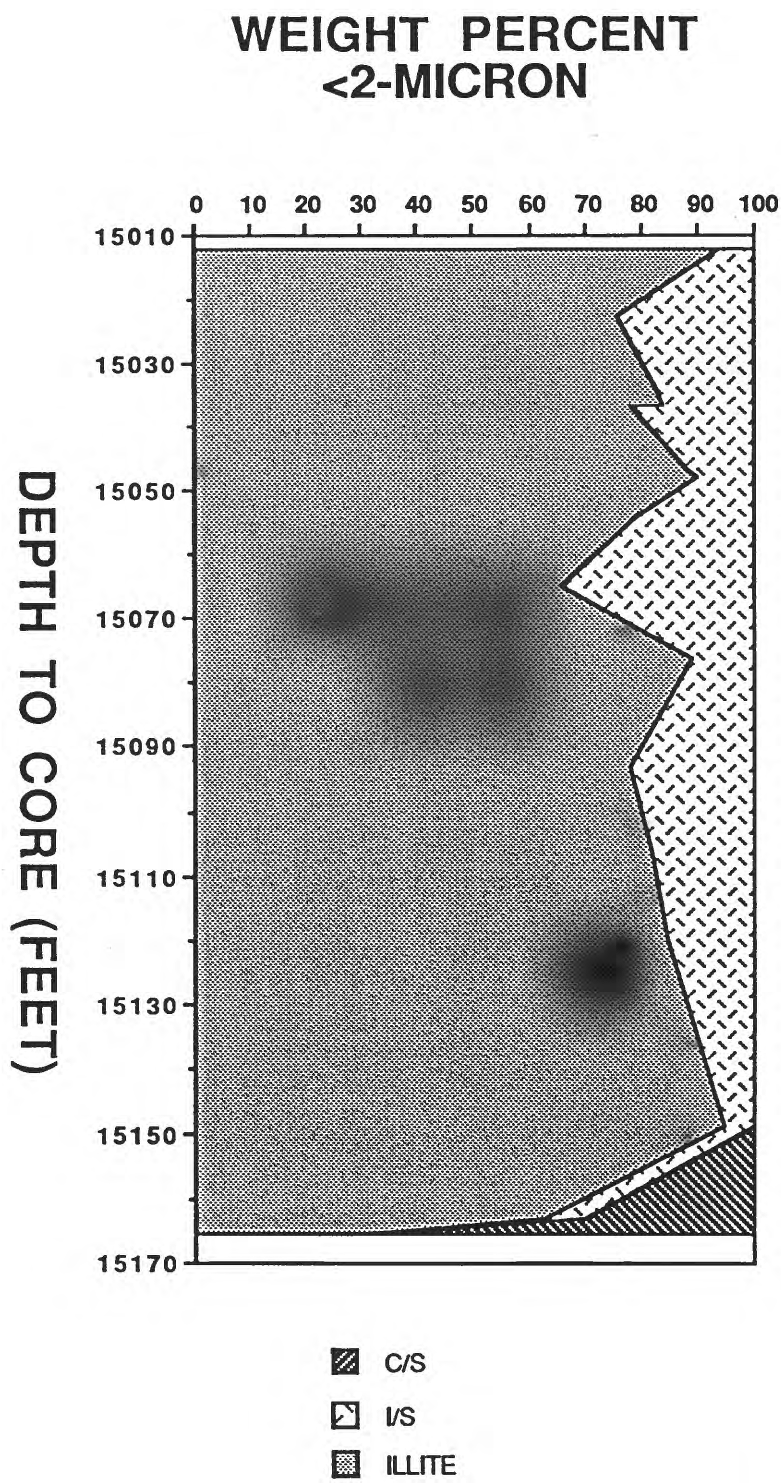

Figure 8.--Point-to-point area graph of clay minerals in <2-μm fraction, in relative weight percent, from samples of core, Hershey Oil Corp., 3-34 Carr well.

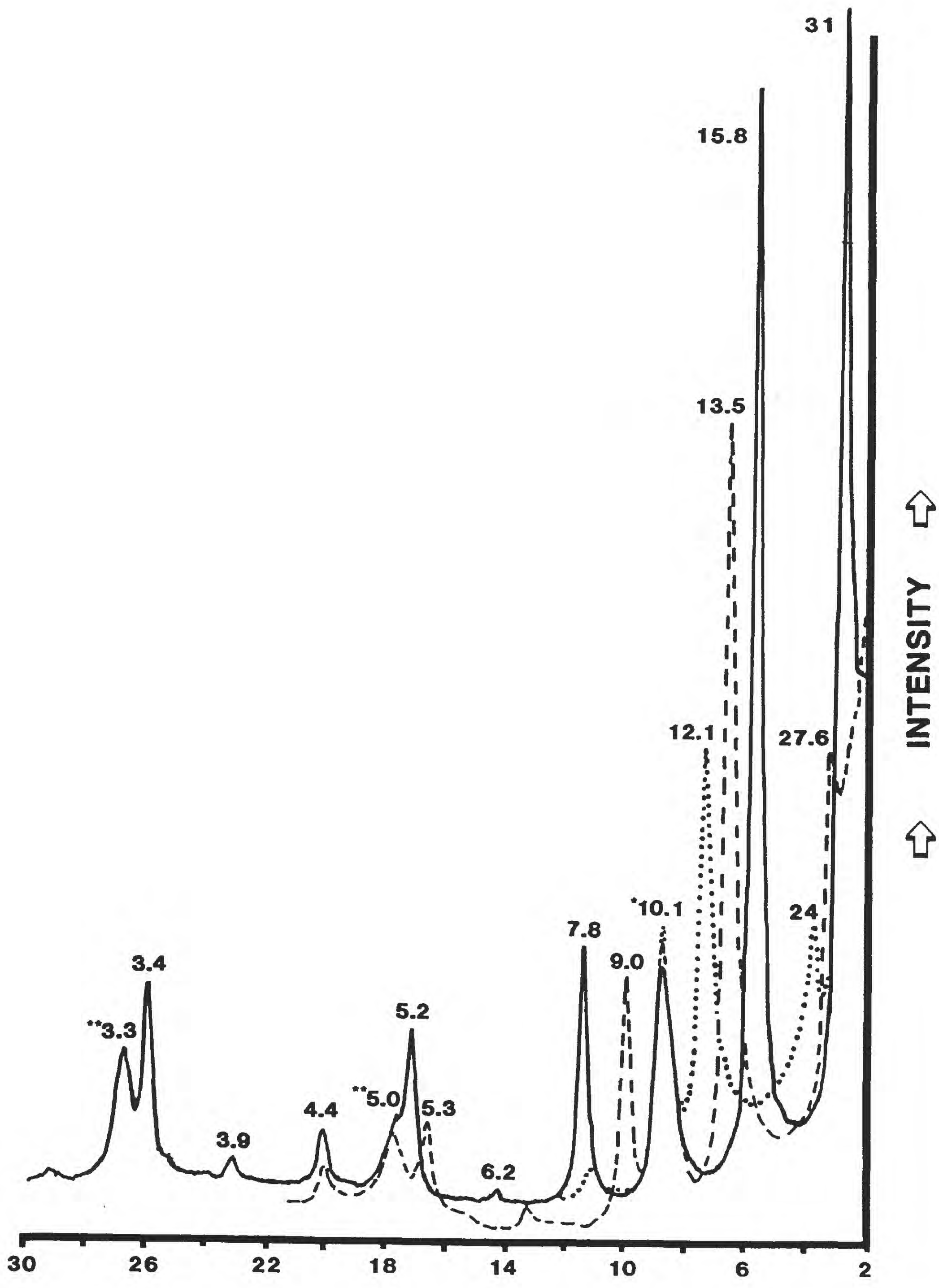

Figure 9.--X-ray powder diffraction profiles of corrensite in oriented, <2-µm fraction, Permian upper part of Minnelusa Formation, Union Oil Co., #1 Frye well, sample 15,165.5. Peak positions labeled in angstroms. Note strong supperlattice reflections and integral series of basal reflections. * indicates reflection supperimposed of corrensite, illite, and mixed-layer illite/smectite (I/S); ** indicates peak of illite and I/S. Copper K-alpha radiation.

Table 1.--Well names, locations, and intervals (depth to core in feet) for samples of Permian upper part of the Minnelusa Formation, Powder River basin, Wyoming.

Company/Well name	Location	Intervals cored
Energetics Inc./ 12-34 Ackerman	SW NW sec. 34, T. 45 N., R. 80 W.	15,087-15,387 (incomplete)
Hershey Oil Corp./ 3-34A Carr	SW NE sec. 34, T. 45 N., R. 80 W.	15,337-15,373 (incomplete)
Union Oil Co./ #1 Frye	NW NE sec. 30, T. 45 N., R. 79 W.	15,006-15,200 (incomplete)

Table 2.--Semiquantitative bulk-rock and <2-μm clay mineralogy from X-ray powder diffraction in weight percent. Samples from core of Permian upper part of Minnelusa Formation from wells in the Powder River basin, Wyoming. K-Feldspar, potassium feldspar; Anhy(Other), anhydrite or other phase; tr, trace (<1%); --, none detected, P, pyrite; C, calcite.

Sample	Bulk-Rock Mineralogy					<2 μm Clay Mineralogy			
Depth (feet)	Quartz	Clay	Dolomite	K-Feldspar	Anhy(Other)	Illite	Illite/smectite	Chlorite	Chlorite/smectite
ENERGETICS INC. 12-34 ACKERMAN									
15,080/81	92	2	4	2	--	76	24	--	--
15,091	84	4	10	2	--	78	22	--	--
15,100	82	4	11	3	--	56	44	--	--
15,115	60	4	35	1	--	84	16	--	--
15,130/31	75	3	20	2	--	97	3	--	--
15,144	3	2	95	--	--	73	27	--	--
15,152/53	88	2	7	3	--	88	12	--	--
15,154	98	2	--	--	--	80	16	4	--
15,173	92	4	3	1	--	72	28	--	--
15,205/06	93	3	3	1	--	92	8	--	--
15,208/09	92	3	4	1	--	52	33	15	--
15,213/14	93	4	3	tr	tr	76	24	--	--
15,219	90	2	3	--	5		no clay		
15,234	85	4	8	tr	(3C)	82	8	--	10
15,235	tr	--	99	--	--		no clay		
15,239/40	1	1	98	--	--	87	13	--	--
15,251/52	89	3	5	3	--	82	18	tr	--
15,270/71	90	2	4	4	--	78	19	1	2
15,271	90	4	4	2	--	92	8	--	--
15,305	2	--	96	--	(2P)		no clay		
15,318/19	3	1	96	--	--	82	18	--	--
15,326/27	80	4	15	1	--	90	10	--	--
15,336/37	1	--	99	tr	--		no clay		
15,346/47	87	1	12	tr	--	95	5	--	--
HERSHEY OIL CORP. 3-34 CARR									
15,337	56	tr	44	--	--	90	10	--	--
15,339	45	2	53	tr	--	89	11	--	--
15,340	81	3	15	1	--	40	--	--	60*
15,346	77	3	20	tr	--	18	--	--	82*
15,369	85	1	15	tr	--	91	9	--	--
15,370	81	2	15	1	1	90	10	--	--
15,373	84	2	13	1	--	97	3	--	--

(table 2.--continued)

UNION OIL CO. #1 FRYE

15,012	82	5	15	3	tr	94	6	--	--
15,022.5	76	7	14	3	tr	76	24	--	--
15,034	72	4	20	4	--	83	17	--	--
15,036.5	74	1	24	1	tr	84	16	--	--
15,036.6	72	4	21	2	1	78	22	--	--
15,046.5	89	1	8	--	2	88	12	--	--
15,048	94	3	2	1	--	90	10	--	--
15,054	91	5	3	1	--	79	21	--	--
15,065	95	2	3	tr	--	66	34	--	--
15,076	90	5	3	2	--	89	11	--	--
15,093	81	8	5	5	1	78	22	--	--
15,106	74	4	21	1	--	82	18	--	--
15,120	3	2	95	--	--	85	15	--	--
15,132	85	1	8	2	4	no clay			
15,149	10	7	83	--	--	95	5	--	--
15,163	40	6	53	1	--	64	7	--	30*
15,165.5	75	8	16	1	--	31	1	--	68*

* nearly perfectly ordered (50:50) interstratification of chlorite/smectite