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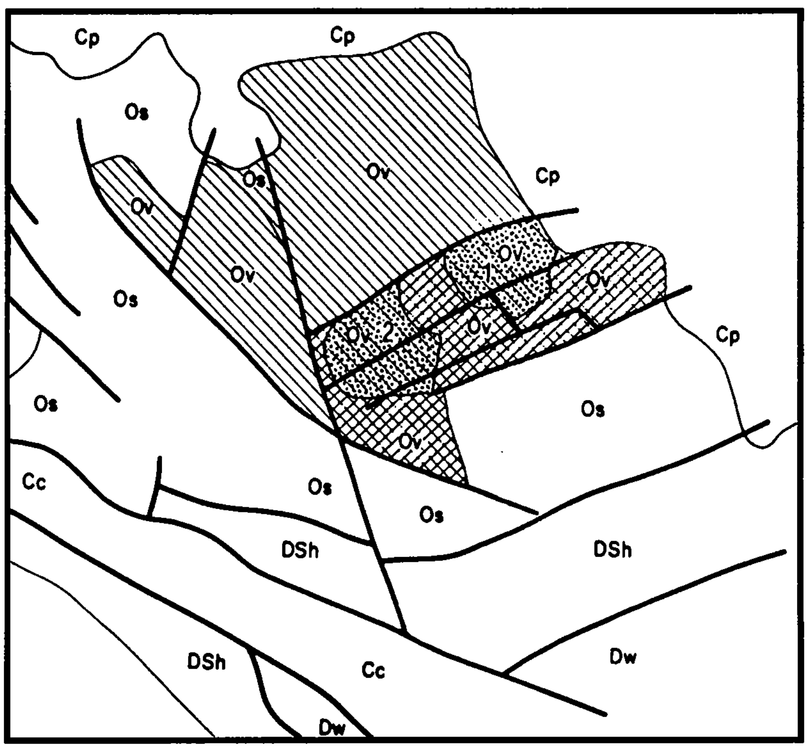
Tar-Sand Potential of Selected Areas in Carter and Murray Counties, South-Central Oklahoma

William E. Harrison
Margaret R. Burchfield



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Tar-Sand Potential of Selected Areas in Carter and Murray Counties, South-Central Oklahoma

William E. Harrison and Margaret R. Burchfield

INTRODUCTION

Tar sands and heavy-oil deposits have been known in Oklahoma since the late 1800s, and these deposits, or certain aspects of particular deposits, have been described in a number of early publications (Eldridge, 1901; Taff, 1904; Hutchison, 1911; Snider, 1913, 1914; Tomlinson, 1928; Shelley, 1929; Wolfard, 1929; Woodruff, 1934). Jordan (1964) used the H. P. Goodrich File (unpublished) to compile data on 298 occurrences of petroleum-impregnated outcrops and asphaltite deposits as well as several shallow (<500 ft) oil fields. The Goodrich data are on file at the Oklahoma Geological Survey and constitute a fairly comprehensive summary of surface and shallow occurrences of petroleum and petroleum-related material in the State.

Most of the reported tar-sand occurrences are in the Wichita Mountain, Ardmore-Marietta basin, and Arbuckle Mountain areas of Oklahoma. Solid bitumens (material soluble in organic solvents) such as grahamite and asphaltite are known only from the Ouachita Mountain region. The bitumen-bearing rocks in Oklahoma are mainly sandstones, although one of the major deposits, Dougherty, occurs in Ordovician limestone. The geologic age of the deposits in southern Oklahoma varies from Middle Ordovician to Early Cretaceous.

Carter and Murray Counties contain a total of 45 tar-sand deposits, which vary from small outcrops and prospect pits to the large quarries that were actively worked until 1960. The production data (Table 1) for the Sulphur and Dougherty quarries are on file at the Oklahoma Department of Mines.

Carter and Murray Counties also have both shallow heavy oil (<25° API) and conventional crude-oil production. In 1982, the latter production amounted to 17.2 million barrels, and the cumulative production for Carter and Murray Counties is approximately 750 million barrels. Oil seeps and bitumen-impregnated outcrops contributed to the discovery of some of the major fields in the area.

The Oklahoma Geological Survey has, for the last few years, conducted studies to evaluate the heavy-oil and tar-sand potential of the State (Harrison, 1980; Harrison and others, 1979, 1981a,b). The major objectives of this program are to provide information on heavy-oil and tar-sand deposits upon which more detailed exploration and development efforts might be based. The present and projected energy situation in the United States is heavily oriented toward fossil fuels, and it is obvious that extraction technology directed toward enhanced oil recovery, oil shales, and tar sands will become increasingly important. If resource-appraisal studies are maintained at reasonable levels, then perhaps such technology can be implemented as it is developed, and significant delays in producing these "unconventional" resources may be avoided.

The present DOE–OGS (Department of Energy–Oklahoma Geological Survey) coring program involves four areas in the Arbuckle Mountain–Ardmore basin region (Fig. 1). The specific sites in Carter and Murray Counties are shown in Figure 2. Area 3, the West Ardmore site, was not evaluated because of access problems. Information pertinent to this site is included in this report in the hope that the deposit will be studied at some future date. Area 1 is composed of the Sulphur-Dougherty deposits (also known in the literature as the Buckhorn and Brunswick Districts, respectively) and is fairly well known from previous investigations. The South Woodford area (Area 2 on Fig. 2) is located ~1.5 mi south of the community of Woodford, and this deposit is in Upper Mississippian–Lower Pennsylvanian strata. Relatively little is known about the deposit located a few miles west of Ardmore (Area 3, Fig. 2), which occurs in Desmoinesian-age (Deese) sandstones. These sandstones also are bitumen-impregnated in the Overbrook area (Area 4, Fig. 2) at the edge of the oil field of the same name.

GEOLOGIC HISTORY OF THE ARBUCKLE MOUNTAIN–ARDMORE BASIN AREA

The geology of the Arbuckle Mountain region has been studied for many years and has been summarized by Ham (1969). Figure 3 shows Cambrian through Mississippian strata in the study area. The stratigraphic columns shown in Figure 3 show the sharp contrast between sedimentation patterns in the geosynclinal (column A, Fig. 3) and cratonic (column B, Fig. 3) areas. Late Cambrian through Early Devonian strata consist primarily of carbonates and make up more than 11,000 ft of the section at A. The same stratigraphic interval at B is approximately 6,500 ft thick.

Ordovician, Silurian, and Devonian sequences are characterized by laterally persistent unconformities. Mississippian rocks show a major change in lithology and consist primarily of dark-gray shales. The strong contrast between thick shallow-water carbonate sequences deposited during the early Paleozoic and the deep-water clastics of Mississippian age constitutes one of the more prominent geologic features involving Paleozoic rocks in southern Oklahoma. During Pennsylvanian time, the geosyncline accumulated as much as 13,000 ft (possibly up to 17,000 ft) of interbedded shales, sandstones, and thin marine limestones. Pennsylvanian deposits on the craton are only 3,000 ft thick and contain thicker limestone units. Areas immediately adjacent to the Hunton anticline contain numerous thin conglomerates of Missourian through middle Virgilian age. Epeirogenic movement of this structurally positive feature also caused the removal of significant intervals of pre-Pennsylvanian sedimentary strata. A later phase of the Arbuckle orogeny occurred during late Virgilian–Early Permian time and resulted in high-angle thrust faulting of geosynclinal sediments and prominent folding. Features such as the Arbuckle anticline and Mill Creek syncline owe their origin to this last major orogenic activity.

SPECIFIC TAR-SAND DEPOSITS

The three areas investigated under Contract DE-AS20-8ILCIO7730 are areas which, on the basis of previous studies and field work, appeared to hold the greatest potential for significant tar-sand development in south-central Oklahoma. Although reported occurrences of tar sands, heavy oil, and asphaltic outcrops are relatively numerous in the study areas, additional sites in Carter and Murray Counties probably warrant further investigation. Such sites may be known from obscure and imprecise sources such as (1) landowners who submit samples to the OGS for analysis, (2) verbal descriptions, and (3) written requests for technical assistance and information. Such sites may eventually be documented as tar-sand deposits, but each area will require a considerable amount of additional study before intensive evaluation programs can be justified.

TABLE 1.—Latest Available Production Data for Sulphur and Dougherty Asphalt Quarries

Operator	Quarry	Year	Production (tons)
Southern Rock Asphalt	Sulphur	1954	38,743
U.S. Asphalt	Sulphur	1955	21,502
		1956	77,315
		1957	44,438
		1958	60,026
		1959	no record
U.S. Asphalt	Dougherty	1960	9,275

AREA 1: Sulphur-Dougherty

The bitumen-impregnated sandstones and limestones that exist in much of T. 1 S., R. 3 E. (Fig. 2) have been known for many years. The two major quarry areas, Sulphur and Dougherty, were exploited as sources of road-paving material until 1958 and 1960, respectively. The Sulphur area, located in secs. 15, 21, and 22, T. 1 S., R. 3 E., contains 10 major quarries and several smaller ones. Most of the bitumen occurs in the sandstone member of the Oil Creek Formation of Ordovician age. The Dougherty area is located in sec. 25, T. 1 S., R. 2 E., and in sec. 30, T. 1 S., R. 3 E., and consists of two major quarries and a number of smaller quarries and prospect pits. At this location, the bitumen occurs in

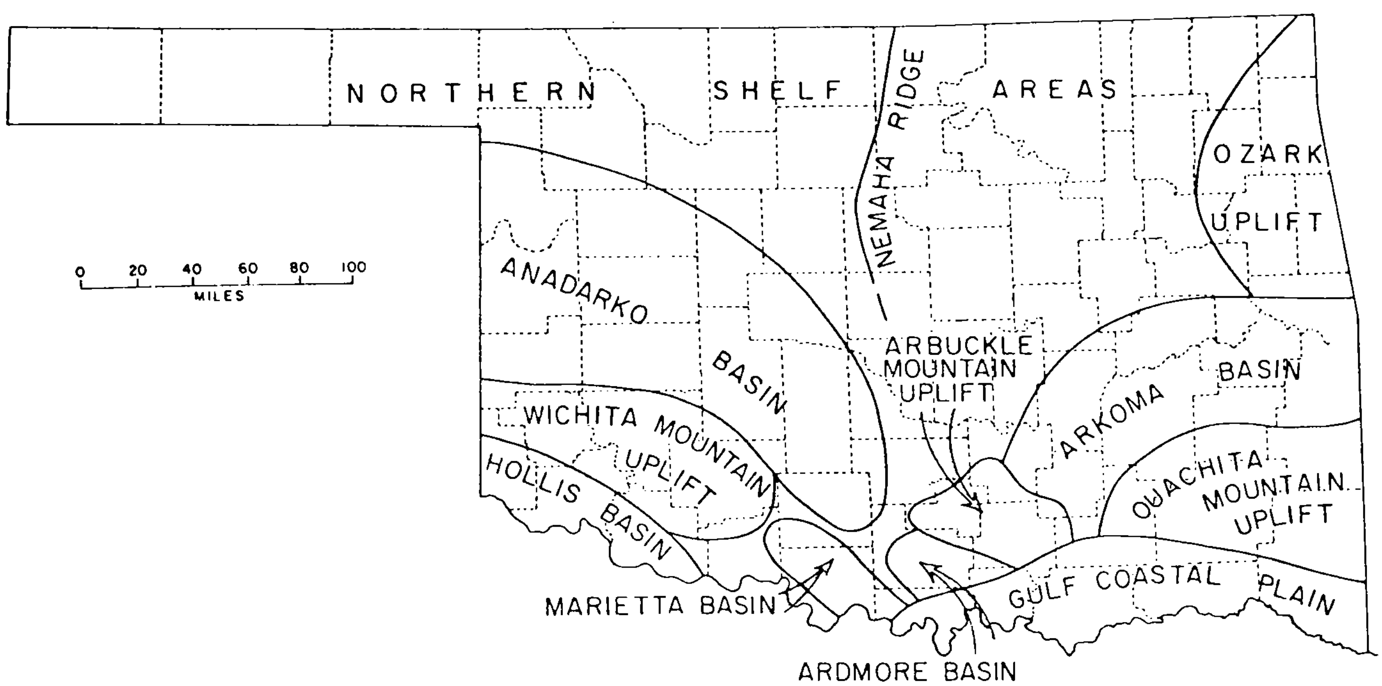

Figure 1. Major geologic features in Oklahoma. Most of the known tar-sand deposits are in the southwestern and south-central regions of the State. There are about 200 reported occurrences of tar sand and shallow heavy-oil deposits in the Wichita Mountain uplift, Marietta basin, Ardmore basin, and Arbuckle Mountain areas.

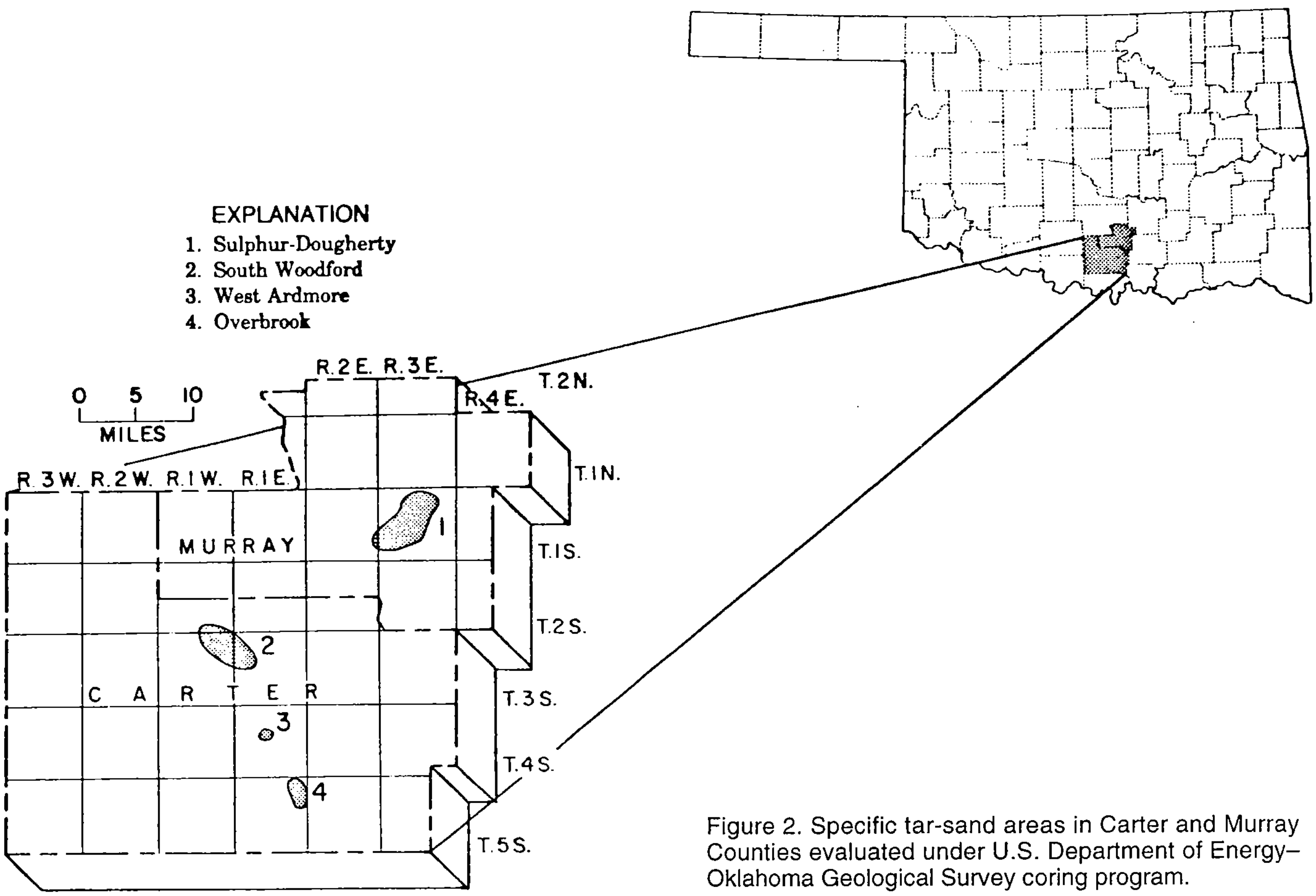

Figure 2. Specific tar-sand areas in Carter and Murray Counties evaluated under U.S. Department of Energy–Oklahoma Geological Survey coring program.

the Ordovician Viola limestone. These deposits are well known from the literature (Grandone and others, 1955; Ball and Associates, 1965), as well as from more detailed studies (Gorman and Flint, 1944; Gorman and others, 1944; Williams, 1983). The Sulphur deposit has been of sporadic interest to industry and has been evaluated by at least two major companies. The results of these coring programs have not been generally available to the public, however.

The studies by Gorman and Flint (1944) and Gorman and others (1944) include brief historical summaries of production from each of the areas. The Dougherty area was being actively worked as early as 1890 and was operated more or less continuously until 1960. The bitumen content of the Viola Limestone at this locality is fairly consistent and varies between 3.0 and 3.5 weight percent (wt.%). Approximately 800,000 tons of bitumen-impregnated limestone was removed from the Dougherty area as of 1943 (Gorman and Flint, 1944), and it is reasonable to assume total production in excess of a million tons.

The Sulphur area also has been worked since about 1890 and has yielded at least 1.5 million tons of bitumen-bearing sandstone. Most of the bitumen occurs in the Oil Creek sandstone and varies between 0.4 and 13.0 wt.%.

The material from the Sulphur deposit was mixed with that obtained from Dougherty, and the resulting material, when used for paving purposes, apparently possessed superior qualities (Snider, 1913, 1914).

Sulphur Deposit

Geology.—As mentioned earlier, the geology of south-central Oklahoma is quite complex, and only recently (Williams, 1983) has an attempt been made to reconcile the shallow subsurface and surface geology in one of the tar-sand areas (Sulphur).

Detailed geologic maps have been made of both the Sulphur and Dougherty areas (Gorman and Flint, 1944; Gorman and others, 1944). Williams (1983) made a structural and geochemical study of the Sulphur tar-sand area, and his interpretations are summarized briefly here.

Figure 4 shows the surface geology of the Sulphur area, as well as the locations of boreholes. Gorman and others (1944) interpreted most of the faults shown in Figure 4 as normal faults and identified a "Central Fault Block" as a graben. By contrast, Williams concluded that a series of five major thrust faults was responsible for most of the structural features present in the Sulphur tar-sand area. The three interpretive cross sections shown in Figure 5 illustrate the structural complexity of the region. These sections also show how

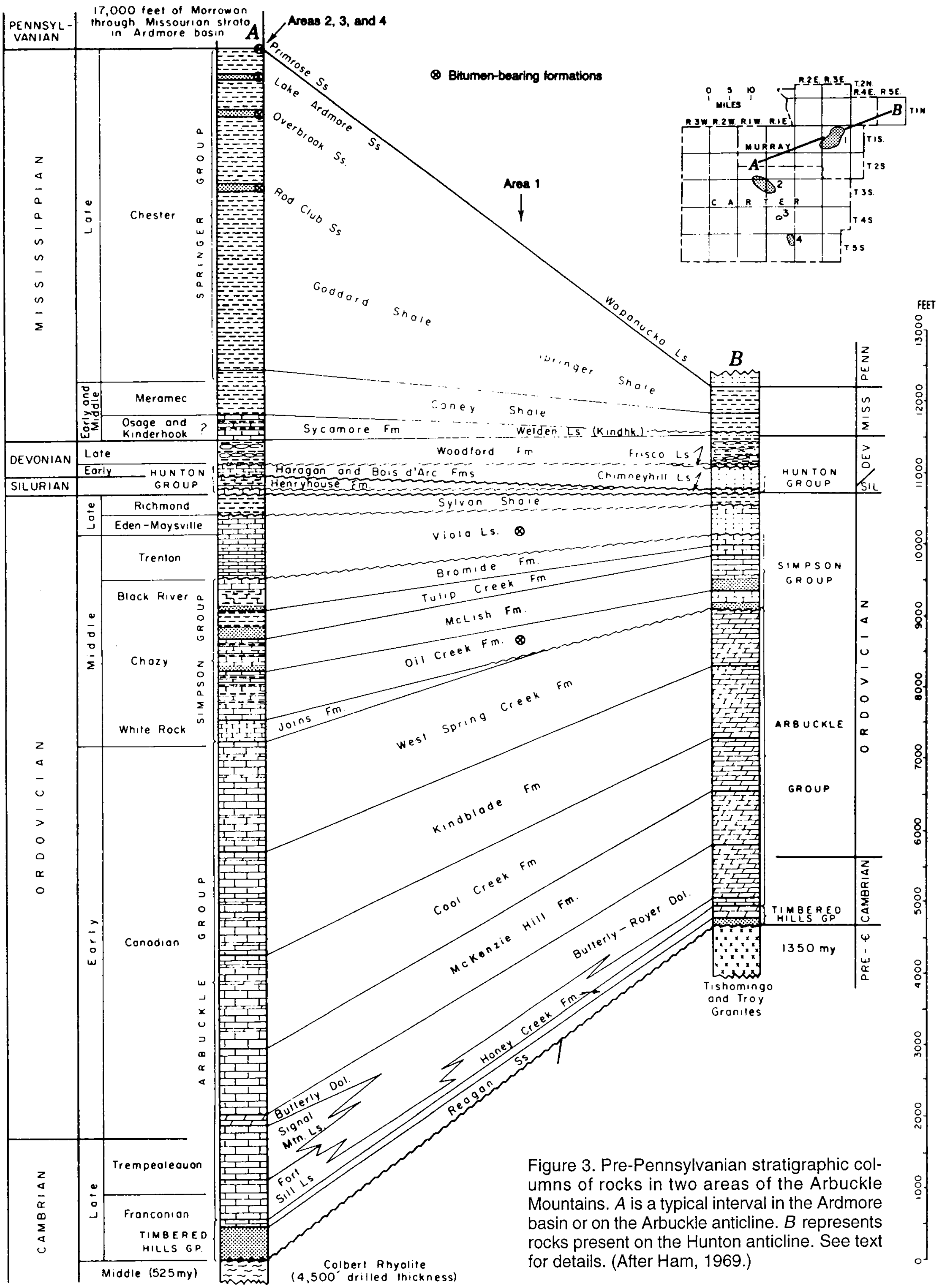

Figure 3. Pre-Pennsylvanian stratigraphic columns of rocks in two areas of the Arbuckle Mountains. *A* is a typical interval in the Ardmore basin or on the Arbuckle anticline. *B* represents rocks present on the Hunton anticline. See text for details. (After Ham, 1969.)

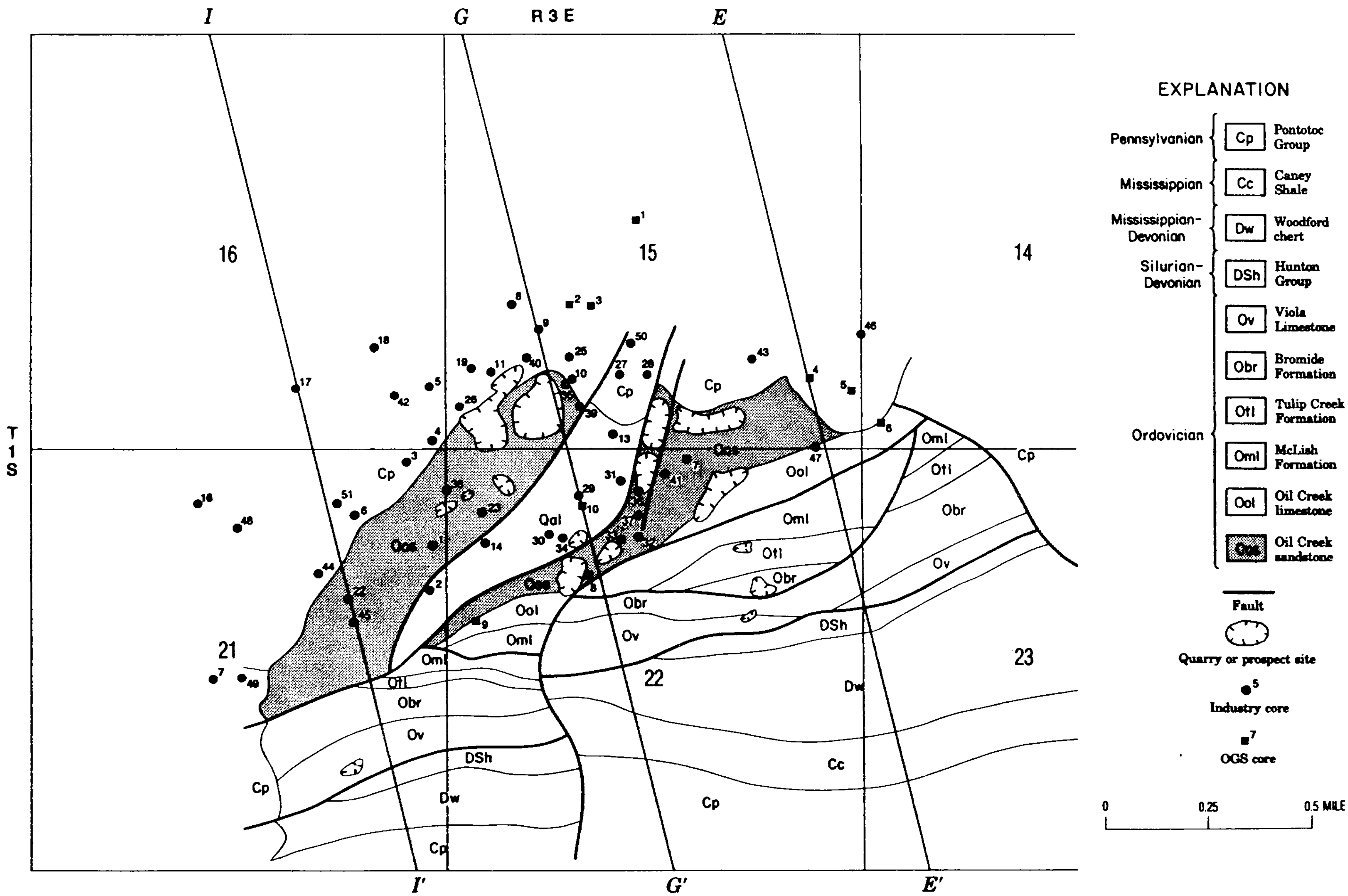

Figure 4. Geologic map of the Sulphur tar-sand area, Murray County, Oklahoma. Most of the bitumen at this locality occurs in the Oil Creek sandstone of Ordovician age. (After Gorman and Flint, 1944; Williams, 1983.)

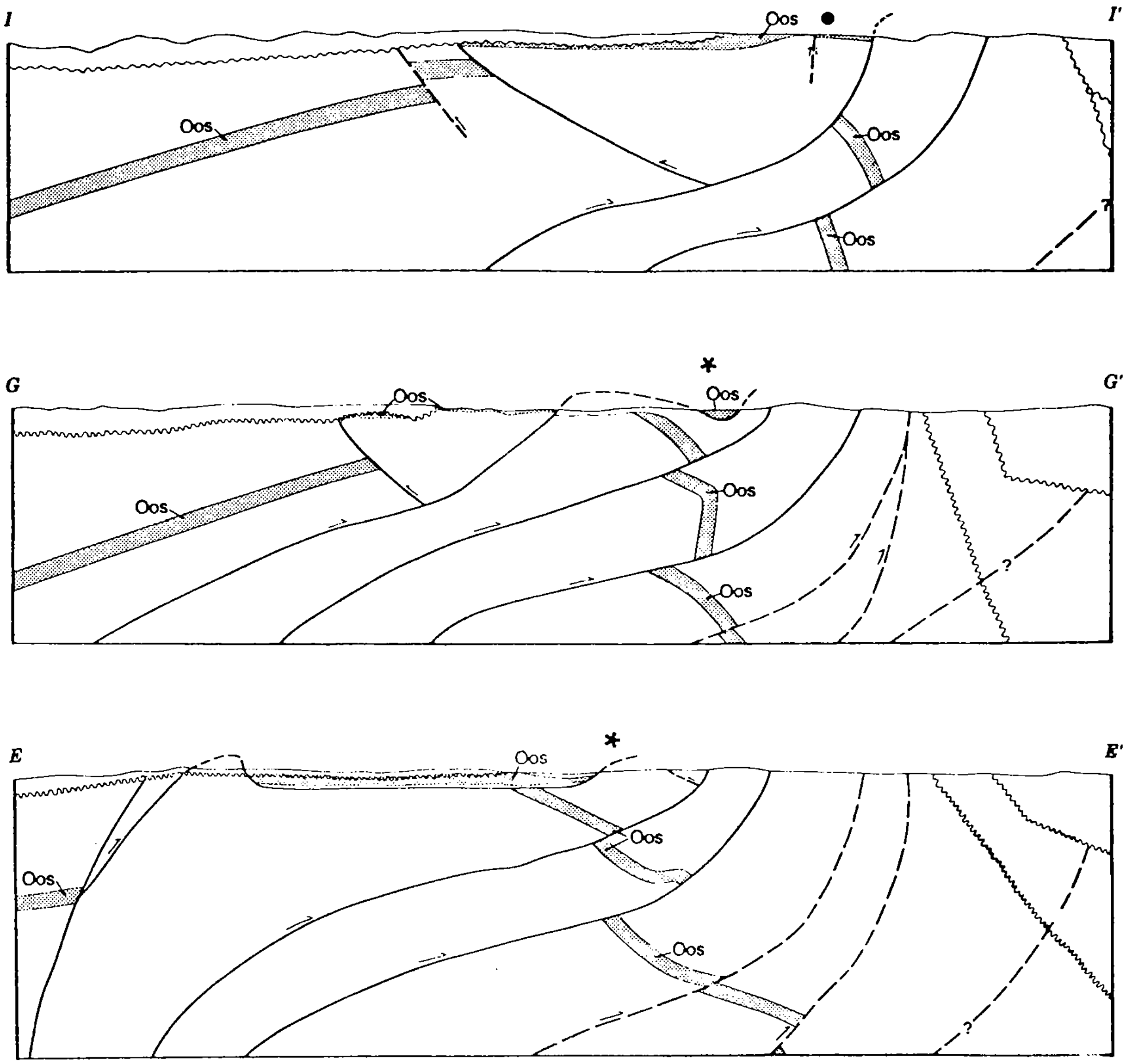

Figure 5. Interpretive cross sections through the Sulphur tar-sand area. See Figure 4 for locations. These interpretations provide multipay bitumen-bearing zones and increase tar-sand potential appreciably. (After Williams, 1983.)

structural geology affects tar-sand potential. The thrust faults and folding have, in some parts of the study area, resulted in several repeated sections of potential bitumen-bearing lithology. For instance, wells drilled at the positions indicated by an asterisk (*) on sections E–E′ and G–G′ would penetrate three separate Oil Creek sandstone intervals. This results in a situation somewhat analogous to multipay productive zones in conventional oil fields. Depth will probably be the limiting factor for surface operations such as strip mining, and it is doubtful if bitumen-impregnated zones deeper than a few hundred feet could be exploited without some type of *in situ* process. Locally, the geologic setting might be conducive to such operations. Consider a vertical borehole at the position indicated by the open circle on section I–I′. If the interpretation shown is correct, then such a borehole would encounter near-vertical Oil Creek sandstone at 1,800 ft. Because of the attitude of the beds, the Oil Creek sandstone would be ~500 ft thick instead of the usual 150 ft. An *in situ* technique involving downhole heating might be successful in such a situation because most of the thermal energy (in the 1,800–2,300-ft interval) would affect the tar sand, and significant heat losses to non-bitumen-bearing lithology would be minimal. Thus, there may be certain geologic conditions that lend themselves to specific types of *in situ* applications in the Sulphur tar-sand area.

The presence of bitumen-impregnated Oil Creek sandstone at depths >2,500 ft was documented by sample examination of a well in sec. 23, T. 1 S., R. 3 E. Figure 6 shows a portion of the SP (spontaenous potential) and resistivity logs for the California Oil No. 1 G. E. Snethen. Samples were immersed in dichloromethane, which immediately became darker in color owing to dissolved bitumen. The discrepancy between the first appearance of bitumen-bearing samples and the diagnostic log pattern of Oil Creek sandstone is probably sample lag owing to circulating drilling fluid. The presence of bitumen-impregnated Oil Creek sandstone at depth is an important consideration because some type of *in situ* method may be considered in conjunction with surface recovery operations when these deposits are developed. Several factors (API° gravity, depth, temperature, etc.) have a major influence on the design of *in situ* recovery methods, and these factors would have to be determined for site-specific applications.

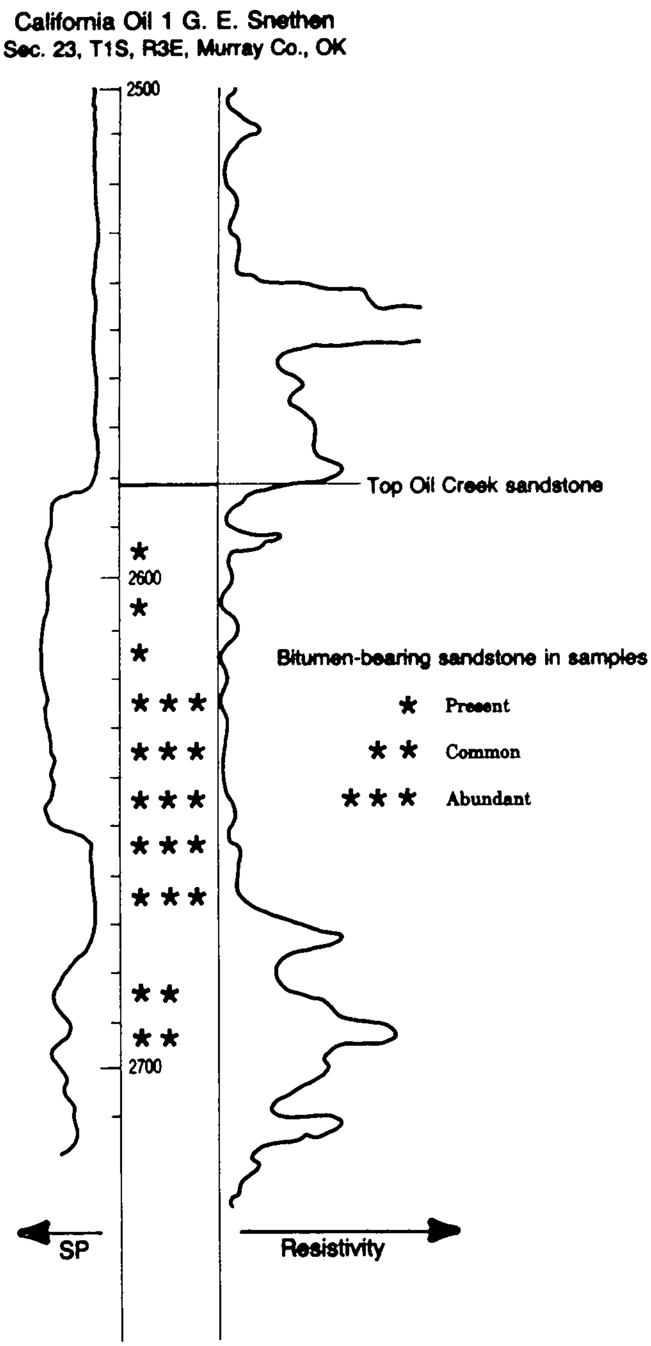

Figure 6. Spontaneous-potential and resistivity log showing the characteristic response of Oil Creek sandstone, and the depths from which bitumen-bearing samples were recovered from the California Oil No. 1 Snethen.

Wells 16, 18, and 19 (Fig. 4) were apparently terminated in limestone of the Arbuckle Group, the oldest unit present in the Sulphur tar-sand area. Units which crop out in the area include the Simpson Group (Ordovician), Viola Limestone (Ordovician), Sylvan Shale (Ordovician), Hunton Group (Silurian-Devonian), Woodford Shale (Devonian-Mississippian), Caney Shale (Mississippian), and Deese-Vanoss conglomerates (Pennsylvanian).

Simpson Group formations typically exist in sandstone-limestone pairs, with the clastic sequence at the base. Thus, the Oil Creek, McLish, Tulip Creek, and Bromide units consist of sandstone overlain by limestone. The sandstone of the Oil Creek is friable enough to be hydraulically mined in other parts of southern Oklahoma and contains an unusually pure silica sand (Ham, 1945; Harrison and others, 1981a). Total thickness of the Simpson Group in the study area varies from 50 to 400 ft (Williams, 1983).

The Viola Limestone is ~600 ft thick in the Sulphur tar-sand area and 650 ft thick at the Dougherty quarry area. This unit is a dense gray limestone where it crops out at the Sulphur quarries and is a fossiliferous, thinly bedded limestone at Dougherty. This formation is the major bitumen-bearing unit at the latter site.

Hunton Group limestone occurs at the Sulphur site as a dense and fossiliferous unit and is ~250 ft thick. Overlying the Hunton is the Woodford Shale. This unit is made up of brown chert and black fissile shale and is 450–500 ft thick.

The conglomerates in this area are the result of the Pennsylvanian orogeny. The Deese conglomerate consists mainly of Hunton through Arbuckle cobbles and pebbles and attains a thickness of 1,100 ft in the study area (Williams, 1983). This is also the thickness of the Vanoss conglomerate, which not only contains coarse limestone material but also Precambrian pebbles and cobbles. Williams (1983) noted that the Vanoss is often impregnated where it is in contact with saturated sandstones.

Reservoir Characteristics of the Oil Creek Sandstone.—Reservoir characteristics of the sandstone unit of the Oil Creek Formation are very good. One sample had an air permeability of >7 darcies after the core had been cleaned with toluene. The data presented in Table 2 are for OGS cores 4 and 5 and were provided by a commercial service company; samples were subjected to the following treatment.

Frozen 1-in. plugs were put in lead sleeves, and screens were attached at each end to prevent grain loss. Air permeabilities were determined after the samples thawed. Samples were then subjected to "Dean-Stark Distillation," and oil and water saturations were calculated. Air permeabilities and porosities were measured on the cleaned and dried samples.

The results of previous coring programs as well as core material were made available to Williams (1983)

TABLE 2.—Reservoir Characteristics of Selected Oil Creek Sandstone Cores

Core	Depth (ft)	Air permeability (md) Before cleaning	Air permeability (md) After cleaning	Porosity (%)	Saturation (%) Oil	Saturation (%) Water
OGS 4	98	1,541	3,138	24.2	40.5	6.6
	123	1,032	7,131	28.1	78.2	3.8
OGS 5	107	481	1,055	22.0	58.1	4.8
	123	897	2,950	25.4	72.6	4.2

for his study. These data were combined with that obtained from the present DOE–OGS program in an effort to produce an estimate of tar-sand potential of the Sulphur area. A summary of the results of the coring programs is presented in Table 3. Industry cores are indicated by circles in Figure 4 and are listed as cores 1 through 51 in Table 3. OGS cores are shown as squares in Figure 4 and are listed as OGS 1 through 10 in Table 3. As can be seen from Table 3, bitumen-impregnated strata in the Sulphur tar-sand area occur from the surface to >600 ft deep. The tops and bottoms of bitumen-bearing zones (listed in Table 3) are independent of lithology and bitumen quantity, and simply indicate the shallowest and deepest levels at which bitumen was noted. The numerical difference between these occurrences is listed in a separate column in Table 3 in order to emphasize the variation in intervals affected by bitumen impregnation. Data concerning the thickness of bitumen-bearing sandstone in individual boreholes were compiled from core and sample (rotary cuttings) descriptions, and represent minimum values. Although the various sandstone units in Simpson Group formations usually contain at least trace quantities of bitumen, such units would probably not be considered major objectives in a tar-sand-development program. These sandstones, at least in the Sulphur area, usually have bitumen-impregnated zones <3 ft thick and are separated by many feet of strata that have no visible bitumen or that contain only trace amounts of bitumen. The Oil Creek sandstone, by comparison, is usually much thicker and contains a few percent bitumen by weight. Thus, the total bitumen-bearing sandstone intervals shown in Table 3 are either (1) the thickness of the Oil Creek sandstone or (2) the thickness of the Oil Creek sandstone plus other sandstones which constitute reasonable objectives for development.

The bitumen yields shown in Table 4 are both estimates and measurements. Williams (1983) determined bitumen concentrations in 13 of the cores utilized in his study and made estimates for the cores not analyzed. A comparison of estimated bitumen values with measured values on the same core interval suggests that Williams' estimates are somewhat optimistic (Table 4). Because of the systematic variation between estimated and measured bitumen yields in Williams' work, the present authors made revised estimates which, in most cases, are substantially lower than the minimum value of the original estimate. Where measurements were available for industry cores (cores 1 through 51), these values were used for the bitumen-bearing sandstone intervals. Numerical averages were used when more than one measurement was made on a given core. Several samples were analyzed for each of the OGS cores, and the average values obtained were applied to the entire bitumen-bearing interval and appear in Table 3.

A description of the extraction technique employed, as well as bitumen and lithologic data for the cores from the Sulphur area, may be found in Appendixes I and II-1, respectively.

In-Place Bitumen.—Estimates of in-place bitumen for the Sulphur area were made using isopach maps of total bitumen-bearing sandstone and bitumen content (Figs. 7, 8). Values used in the preparation of these two maps were taken from Table 3 (total bitumen-bearing sandstone), Table 4 (measured and revised estimate of bitumen content), and Appendix III-1. These two maps were constructed at a scale of 1 in. = 500 ft and were superimposed on each other in order to indicate the total thickness of sandstone at a given bitumen content (wt.%). The areas bounded by the bitumen isopach lines and the sandstone isopach lines were planimetered to the nearest one one-hundredth of an acre. The three parameters—sandstone thickness, bitumen content, and area—were used to calculate the number of barrels of bitumen in the study area.

Calculations were made using the numerical average between isopach lines. For example, if a given area were bounded by bitumen isopach lines of 1% and 2% and sandstone isopach lines of 40 ft and 60 ft, then the values used in calculations were 1.5% bitumen and 50 ft. Appendix IV-1 shows the area immediately southwest of the intersection of sections 15, 16, 21, and 22 and illustrates the method used to calculate in-place bitumen content. Calculations for 597 area, sandstone-thickness, and bitumen-content combinations were made. The total in-place bitumen content of the area defined by industry and OGS cores was calculated to be 33.8 million barrels. It should be noted that this figure does not include (1) bitumen-impregnated Oil Creek sandstone at depths greater than a few hundred feet (i.e., the California-Snethen well), or (2) adjacent areas where no cores were taken. Reasonable projections of these two factors could increase in-place bitumen estimates significantly. Consider, for example, the N½ of sec. 22 (Fig. 4). The 100-ft sandstone isopach line runs almost east-west, and the 8% bitumen line is subparallel to it. If an additional 320 acres in this area is considered to have sandstone and bitumen content at one-half the values suggested by mapping (50 ft of sandstone instead of 100 ft and 4% bitumen instead of 8%), then an additional 12.6 million barrels could be added to the estimate.

Dougherty Deposit

Geology.—The Dougherty area was not accessible for coring because of National Park Service boundary conditions. Thus, the estimates for in-place bitumen at the Dougherty quarry area were made on the basis of sur-

TABLE 3.—Summary of Bitumen-Bearing Strata Cored at the Sulphur Tar-Sand Deposit

Borehole[a]	Total depth (ft)	Thickness of interval which contains bitumen-bearing strata (ft)	Total bitumen-bearing sandstone (ft)	Bitumen-bearing zone Top (ft)	Bitumen-bearing zone Bottom (ft)	Bitmen content of sandstone (wt.%)[b]		
OGS 1	200	0	0	—	—	—		
OGS 2	119	107	18	12	119	3.7	(8)	*
OGS 3	150	132	40	14	146	3.1	(15)	*
OGS 4	150	126	126	16	142	4.3	(22)	*
OGS 5	150	122	122	18	140	4.9	(28)	*
OGS 6	120	0	0	—	—	—		
OGS 7	118	0	0	—	—	—		
OGS 8	70	55	55	15	70	2.4	(2)	*
OGS 9	90	80	80	10	90	0.8	(7)	*
OGS 10	80	54	6	26	80	1.4	(8)	*
1	100	90	15	10	100	1.5	e	
2	50	35	0	15	50	—		
3	180	145	75	15	160	1.5	e	
4	220	185	20	5	190	2.2	*	
5	300	295	20	5	300	1.3	*	
6	280	170	20	40	210	1.6	*	
7	350	319	162	6	325	0.9	*	
8	242	219	128	10	229	3.0	e	
9	200	190	0	10	200	—		
10	40	28	13	12	40	3.0	e	
11	152	132	103	20	152	8.4	*	
13	645	60	60	10	70	5.6	*	
14	275	270	0	5	275	—		
16	660	655	100	5	660	4.0	e	
17	568	563	95	5	568	2.0	e	
18	560	555	0	5	560	—		
19	510	505	110	5	510	3.0	e	
22	440	230	0	120	350	—		
23	120	115	25	5	120	2.9	*	
25	85	80	10	5	85	4.1	*	
26	137	122	115	15	137	2.6	*	
27	104	84	60	20	104	2.0	e	
28	65	60	0	5	65	—		
29	50	50	0	0	50	—		
30	60	55	0	5	60	—		
31	60	50	0	10	60	—		
32	113	104	94	9	113	7.0	*	
33	65	27	27	10	37	12.9	*	
34	80	48	35	5	53	3.8	*	
35	75	60	56	5	65	10.8	*	
36	33	23	4	10	33	1.5	e	
37	33	26	7	7	33	1.5	e	
38	196	33	33	30	63	1.5	e	
39	84	0	0	—	—	—		
40	137	68	68	30	98	3.0	e	
41	144	0	0	—	—	—		
42	292	149	149	91	240	3.0	e	
43	107	9	9	18	27	1.5	e	
44	220	157	157	48	205	3.0	e	
45	66	28	28	21	49	3.0	e	
46	96	38	38	6	44	3.0	e	
47	106	0	0	—	—	—		
48	169	26	26	124	150	3.0	e	
49	324	225	154	84	309	3.0	e	
50	87	0	0	—	—	—		
51	246	161	161	81	242	3.0	e	

[a]See Figure 4 for locations. Gaps occur in core-numbering sequence for industry boreholes.
[b]e = estimate; * = measurement; ( ) = number of samples.

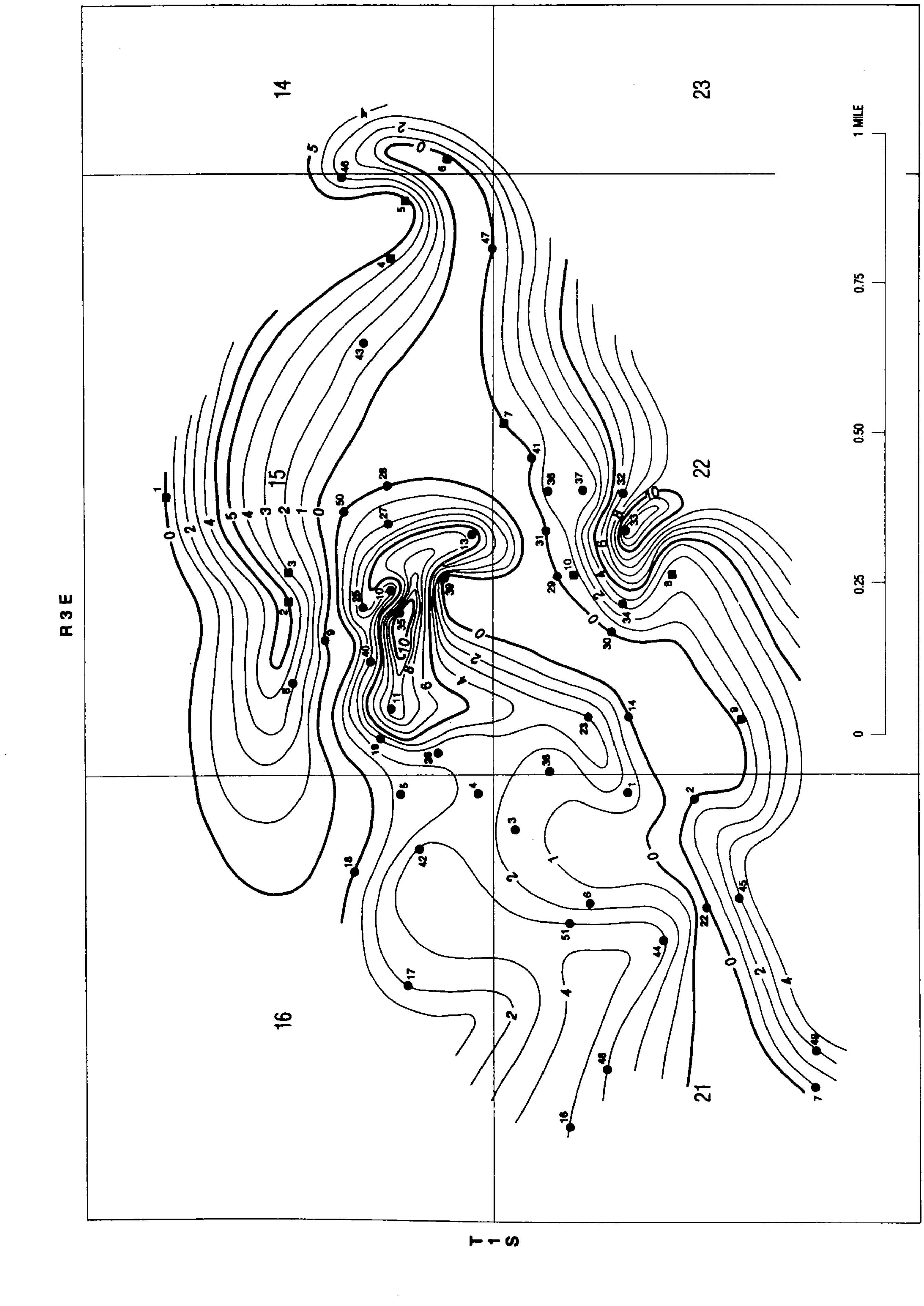

Figure 7. Isopach map of bitumen content (expressed as percentages) in the Oil Creek sandstone, Sulphur tar-sand area. Contour interval, 1%.

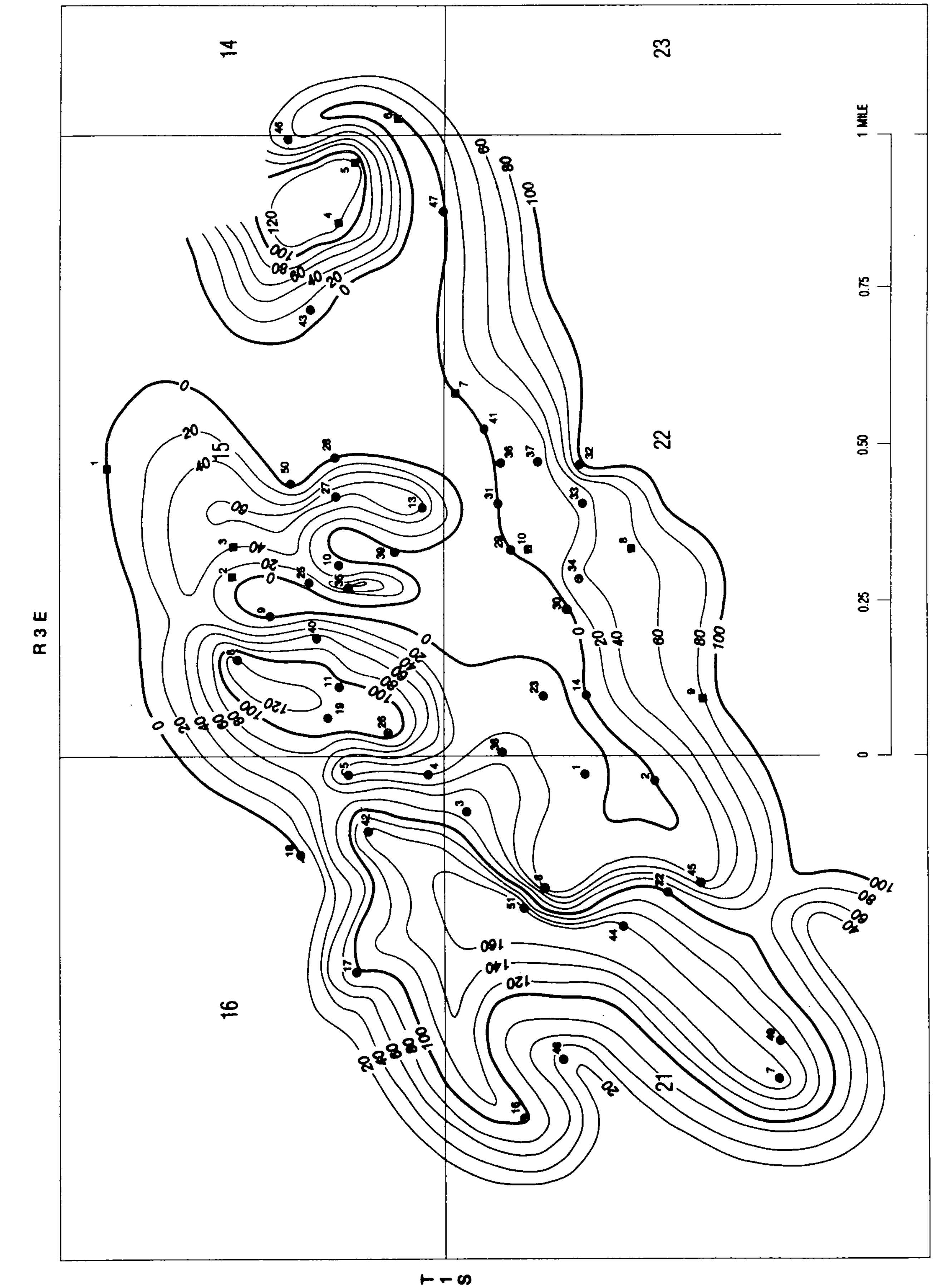

Figure 8. Isopach map of bitumen-bearing portion of the Oil Creek sandstone, Sulphur tar-sand area. Contour interval, 20 ft.

TABLE 4.—Measured and Estimated Bitumen Concentrations for Cores from the Sulphur Deposit

Core[a]	Original estimate[b] (wt.%)	Measured (wt.%)	Revised estimate (wt.%)
1	0–3	—	1.5
2	nbp	—	0.0
3	0–3	—	1.5
4	3–11	2.2	2.2
5	3–11	1.3	1.3
6	5–11	1.6	1.6
7	0–3	0.9	0.9
8	5–11	—	3.0
9	snp	—	0.0
10	5–11	—	3.0
11	0–11	8.4	8.4
13	3–16	5.6	5.6
14	snp	—	0.0
16	3–11	—	4.0
17	3–5	—	2.0
18	snp	—	0.0
19	5–11	—	3.0
22	nbp	—	0.0
23	5–11	2.9	2.9
25	5–11	4.1	4.1
26	5–11	2.6	2.6
27	3–5	—	2.0
28	snp	—	0.0
29	snp	—	0.0
30	snp	—	0.0
31	snp	—	0.0
32	3–11	7.0	7.0
33	3–11	12.9	12.9
34	5–11	3.8	3.8
35	3–11	10.8	10.8
36	0–3	—	1.5
37	0–3	—	1.5
38	0–3	—	1.5
39	snp	—	0.0
40	5–11	—	3.0
41	snp	—	0.0
42	5–11	—	3.0
43	0–3	—	1.5
44	5–11	—	3.0
45	5–11	—	3.0
46	5–11	—	3.0
47	nbp	—	0.0
48	0–11	—	3.0
49	5–11	—	3.0
50	snp	—	0.0
51	3–11	—	3.0
OGS 1	—	nbp	0.0
OGS 2	—	4.9	4.9
OGS 3	—	3.1	3.1
OGS 4	—	4.3	4.3
OGS 5	—	5.4	5.4
OGS 6	—	nbp	0.0
OGS 7	—	nbp	0.0
OGS 8	—	2.4	2.4
OGS 9	—	0.8	0.8
OGS 10	—	0.9	0.9

[a]See Fig. 4 for location. Gaps occur in core-numbering sequence for industry boreholes. OGS core data based on average values.
[b]Williams (1983).
Note: nbp = no bitumen present; snp = sand not present.

face geology and information presented by Gorman and Flint (1944). The surface geology at the Dougherty site is summarized in Figure 9. As at Sulphur, the geology is structurally very complex and is characterized by faulting and by highly fractured strata. Gorman and Flint suggested that bitumen ascended from underlying Simpson units along fault and fracture planes. The following comments are taken from their summary.

> The fault that forms the northern boundary of these quarries also forms the northern boundary of the asphalt deposit. South of this fault the Viola limestone is fairly uniformly impregnated with asphalt, and convenience of quarrying operations rather than asphalt content has been the determining factor in development of the workings. . . . The east face of the No. 1 quarry is impregnated the entire 100 feet of its height, and according to Mr. Ross asphaltic cuttings were recovered from the full length of a churn drill hole that penetrated the rocks at the bottom of the quarry to a depth of 400 feet.

The Viola outcrops immediately southeast and adjacent to the U.S. Asphalt quarries are bitumen impregnated, and samples collected from these areas during the last few years have averaged about 3% bitumen. Two smaller quarries are located southeast of the U.S. Asphalt quarries and apparently were not developed owing to "lack of market for the asphalt and inconvenience of mining."

In-Place Bitumen.—Thus, it appears that the Dougherty area still holds development potential and that termination of mining activities was not related to either depletion of the deposit or diminution of bitumen content. Calculations of remaining in-place bitumen at this site were based on the following observations and considerations.

1) The undeveloped area which contains bitumen-impregnated Viola Limestone immediately southeast of the U.S. Asphalt quarries is approximately 7.6 acres.

2) The total area of the two large quarries is 5.7 acres.

3) The average bitumen content is 3% by weight.

4) The average thicknesses of bitumen-impregnated Viola Limestone in the large quarries and the reported borehole are representative.

For the area adjacent to the two large quarries, a bitumen-impregnated interval of 500 ft (100 ft at the quarry face plus 400 ft penetrated by a wellbore) was assumed. Using these parameters, the in-place bitumen contained in undeveloped Viola Limestone is estimated to be 2.25 million barrels. Development of the two large existing quarries to an additional depth of 400 ft would yield ~1.35 million barrels of bitumen, giving a total in-place estimate of 3.6 million barrels. This figure does not include the Viola outcrop area northwest of the present quarries. Bitumen-bearing Viola Limestone in this area is demonstrated by the presence of a small quarry (Eldridge No. 2 of Gorman and Flint); thus, the total undeveloped area may be somewhat larger than considered in the present calculations.

Total In-Place Bitumen, Sulphur-Dougherty Area

The total bitumen content for the Sulphur-Dougherty area was estimated on the basis of the previously described methods, with the following results.

Sulphur	
Measured in-place bitumen	33.8 million bbls
Probable in-place bitumen	12.6 million bbls
Dougherty	
Probable in-place bitumen	3.6 million bbls
TOTAL Measured bitumen	33.8 million bbls
Probable bitumen	50.0 million bbls

AREA 2: South Woodford

The tar-sand area in the northeast part of T. 3 S., R. 1 W., and east-central part of T. 3 S., R. 1 E. (Fig. 2) has been mined, to a limited extent, and is somewhat unusual in that the deposit exists in vertical strata. Photographs (Hutchison, 1911; Snider, 1913) of the Woodford Asphalt Pit (when it was being actively worked) show the quarry being developed essentially down bedding planes and permit an estimate of the depth to which the deposit was worked (75 ft) at that time. Other specific sites were not exploited as fully as was the Woodford Pit, and the potential of this general area was relatively unknown prior to this study.

Geology and Tar-Sand Occurrences.—Figure 10 is a geologic map of the South Woodford deposit and shows the locations of quarry sites and tar-sand outcrops. The tar-sand deposits are controlled by the geologic feature known locally as the South Woodford anticline. The stratigraphic positions of the formations that crop out in this area are shown in Figure 3. Fay (1997), in his recent compilation for the COSUNA (Correlation of Stratigraphic Units of North America) project, developed cooperatively by the U.S. Geological Survey and the American Association of Petroleum Geologists, has placed the Otterville, Primrose, and Lake Ardmore Formations in the Morrowan (Lower Pennsylvanian) and considers the Overbrook and Rod Club sandstones as members of the Goddard Formation, the latter being of Chesterian (Late Mississippian) age.

Site 1 in Figure 10 shows the location of several shallow (165–480 ft) wells that produce heavy oil from vertical Pennsylvanian (probably Otterville) sandstone. The bitumen-impregnated outcrops in this area most likely resulted from surface degradation of heavy oil that migrated from relatively shallow depths.

Sites 2–7 are either quarries or propect pits, which vary in size from about 100 ft^2, to the Woodford Asphalt Pit (site 4, Fig. 10), which is presently ~2,500 ft^2. Except for the Woodford Pit, the maximum depth to which the quarries were worked cannot be determined inasmuch as they have collapsed and, for the most part,

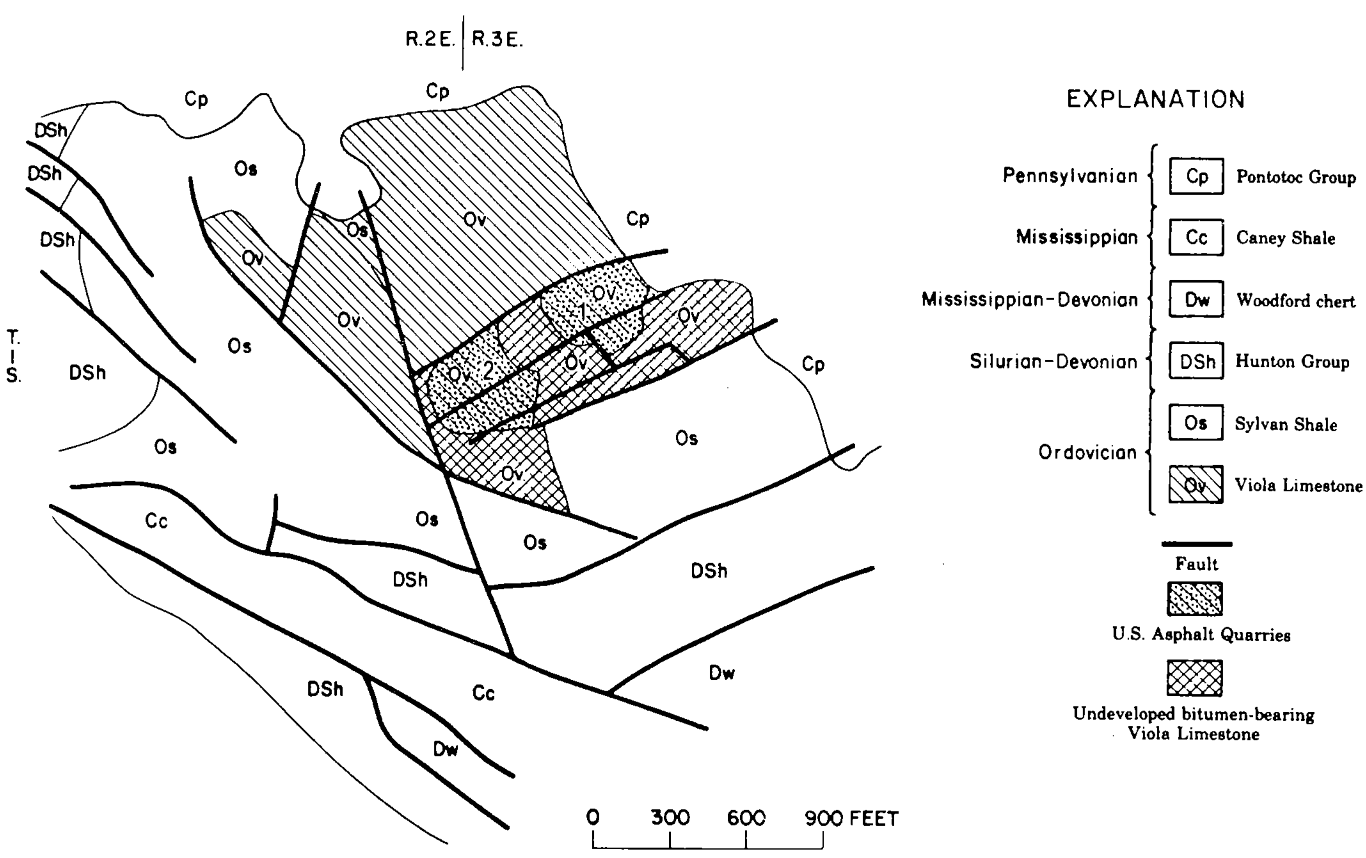

Figure 9. Geologic map of the Dougherty tar-sand area in Murray County, Oklahoma. The bitumen at this locality is restricted to the Viola limestone of Ordovician age. (After Gorman and Flint, 1944.)

have been partially back-filled. The average bitumen content for these quarries is about 11 wt.%. Site 8 is an outcrop of Primrose sandstone, which contains 6.5–8.5% bitumen.

Several active oil seeps exist along the axis of the South Woodford anticline in the Rod Club sandstone. The tar-like material that is ascending along bedding planes builds up layers of several inches and affects areas up to several hundred square feet in size.

Lithologically, the sandstones that crop out in this area are similar and usually consist of brown to tan, fine to very fine sand with abundant clay laminations and stringers. See Appendix II-2 for lithologic descriptions.

TABLE 5.—Reservoir Characteristics of Selected Sandstone Cores from the South Woodford Deposit

Core[a]	Depth (ft)	Porosity (%)	Permeability (md)	Saturation (%) Oil	Water
Fitzgerald 1	14.8	27.5	—	90	1
	66.3	27.6	—	91	1
	148.2	26.6	—	77	1
Fitzgerald 3	7.7	30.9	—	82	1
	51.8	28.8	—	81	1
	106.2	23.9	—	73	1
Fitzgerald 4	9.3	26.7	—	67	1
	77.4	27.9	—	90	1
	168.3	27.5	—	89	1

[a]See Figure 11 for locations.

Reservoir Characteristics.—Some intervals are friable and undoubtedly had very high original permeability, inasmuch as selective removal of the bitumen resulted in collapse of the sandstone. Table 5 contains reservoir parameters for selected core samples from the South Woodford area. The service company that made the analyses reports that all samples were essentially bitumen-cemented, and permeability measurements were not made.

Figure 11 shows the locations of the OGS boreholes that were used to help evaluate the tar-sand potential of the South Woodford area. The cores were taken along the axis of the anticline and, except for the No. 1 Skelton (which was shale), are Rod Club sandstone. This sandstone varies in thickness from about 60 ft to 150 ft in the study area.

In-Place Bitumen.—The in-place bitumen estimate for South Woodford is based on data in Table 6, Appendix III-2, and the following assumptions.

1) The bitumen-impregnated outcrop is 85 ft wide.

2) The specific gravity of South Woodford bitumen is 0.996 g/cc; sandstone specific gravity is 2.65 g/cc.

Appendix IV-2 illustrates the method used to calculate in-place bitumen.

The total amount of bitumen at South Woodford is estimated to be 8.0 million barrels. Several factors are

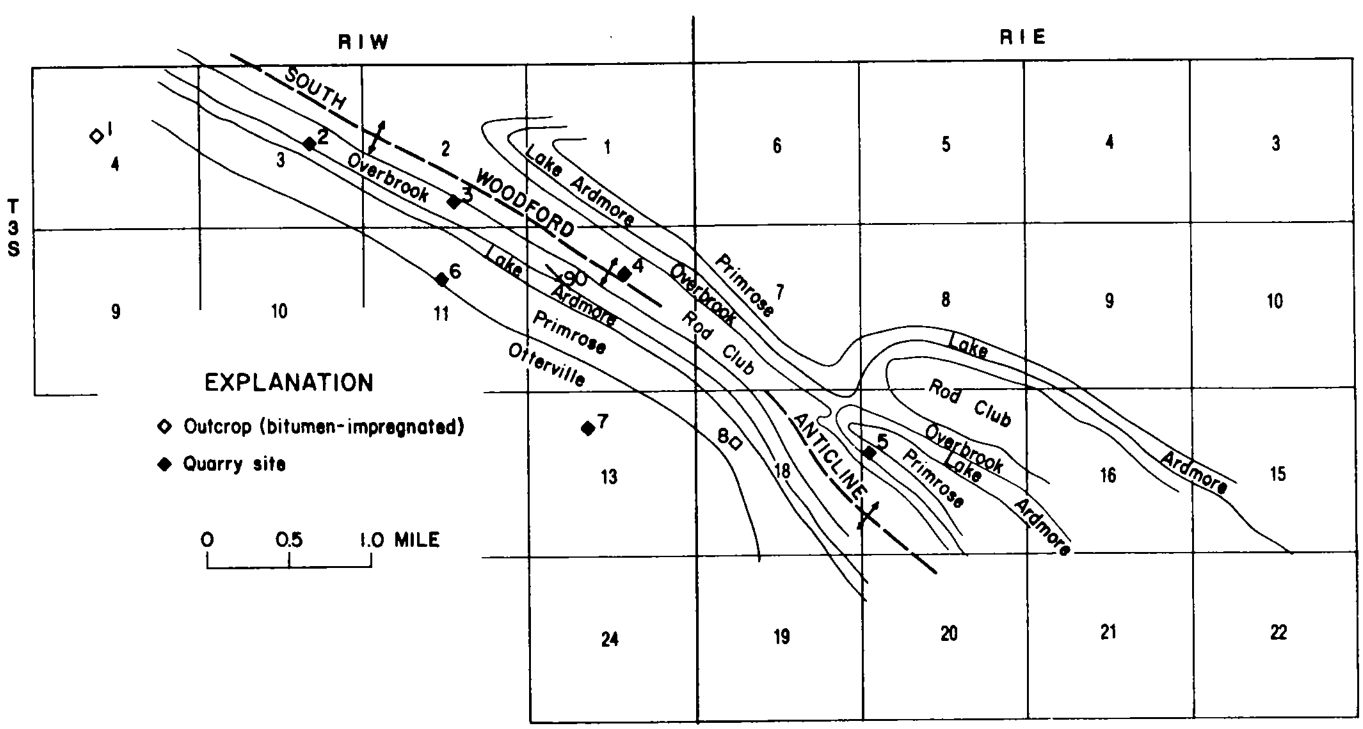

Figure 10. Geologic map of the South Woodford area, Carter County, Oklahoma. See Figure 2 for location. Bitumen deposits and active oil seeps occur in Lower Pennsylvanian and Upper Mississippian sandstones. (After R. O. Fay, unpublished.)

TABLE 6.—Summary of Bitumen-Bearing Strata Cored at the South Woodford Deposit

Borehole[a]	Total depth (ft)	Thickness of bitumen-bearing sandstone (ft)	Bitumen-bearing zone Top (ft)	Bitumen-bearing zone Bottom (ft)	Bitumen content (wt.%)	( ) no. of samples
Fitzgerald 1	170	149	8.5	157.5	13.3	(42)
Fitzgerald 2	130	108	7.0	115.0	9.6	(31)
Fitzgerald 3	120	108	6.0	114.0	12.5	(31)
Fitzgerald 4	190	174	5.0	179.0	14.0	(48)
Fitzgerald 5	270	263[b]	7.0	270.0	10.8	(66)
Fitzgerald 6	150	143[b]	7.0	150.0	9.5	(34)
Skelton 1	50	0	—	—		
Skelton 2	40	0[c]	—	—		
Skelton 3	150	141[b]	9.0	150.0	10.2	(35)

[a]See Figure 11 for locations.

[b]Deepest core recovered contained trace quantities of bitumen; thus thickness and depth of impregnation may be greater than listed for these boreholes.

[c]Bottom core may have been saturated with a light oil that was lost quickly through volatilization.

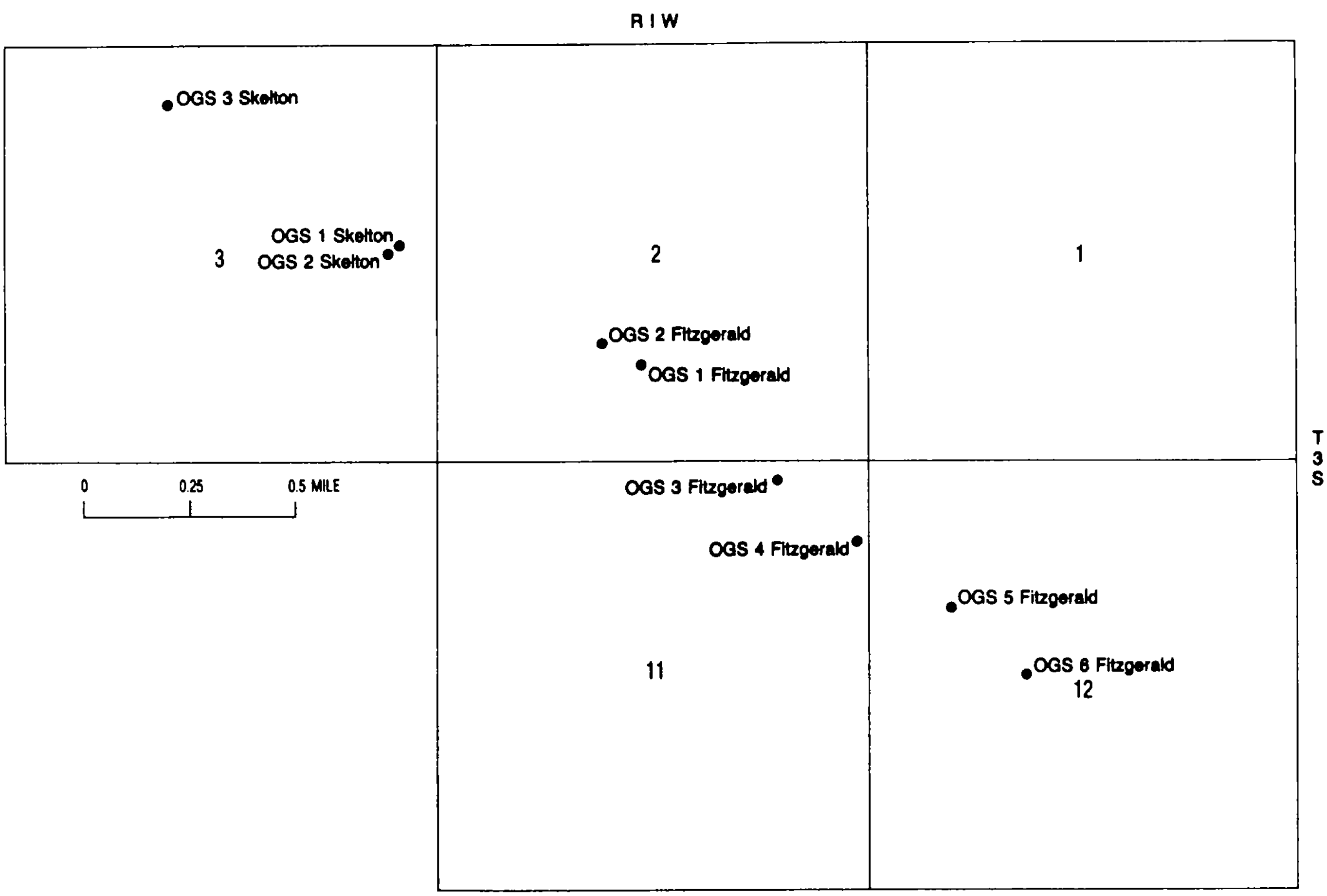

Figure 11. Locations of Oklahoma Geological Survey boreholes in the South Woodford area.

favorable for some type of development program at this site. The overburden is thin, the bitumen-bearing sequence is relatively well confined, and the bitumen yields are among the highest encountered in the present study. Because the bitumen yields at the terminal wells in the transect are quite good, it is reasonable to expect bitumen-bearing strata to continue for some distance beyond the area evaluated in this study.

Projection of conditions encountered in the OGS No. 3 Skelton and OGS No. 6 Fitzgerald boreholes for half a mile to the northwest and southeast results in an additional 2.4 million barrels of probable bitumen.

AREA 3: West Ardmore

There were no cores from the West Ardmore area, and the geologic map and related text are included in this report because (1) this site was in the original proposed study and (2) the data presented herein may serve as background information for a future resource-assessment program. Figure 12 shows the surface geology of secs. 20 and 21 of T. 4 S., R. 4 E., and the approximate locations of three quarry sites. These deposits are in sandstones of Pennsylvanian age, and production was apparently capable of supporting a crushing plant (Jordan, 1964). Bitumen content varies from 8.5% to >13%. The largest of the quarries was site 3 (Fig. 12) and was approximately 40 ft deep and covered about half an acre.

AREA 4: Overbrook

The Overbrook tar-sand area is in T. 5 S., R. 1 E. (Fig. 2) and consists of a number of prospect pits, bitumen-impregnated outcrops, and small quarries. The area evaluated with a single OGS borehole is adjacent to wells in Overbrook Field, which produces 38°–40° API gravity oil from Springer sandstones at 4,000 ft.

Geology and Tar-Sand Occurrences.—The surface geology of the Overbrook area is shown in Figure 13. Outcrops in this region vary in age from Permian to Ordovician, and Quaternary alluvium occupies the major drainage areas. Most of the bitumen-impregnated sandstones are either Permian or Pennsylvanian, and continuous exposures are rare because of thick soil profiles and vegetative cover. The latter conditions probably restricted development of the deposits. A number of local structures occur in this general area, but bitumen impregnation appears to be independent of such features because the bitumen-bearing strata occur in connection with both anticlines and synclines.

Sites 1 and 2 are prospect pits in Pontotoc (Permian) sandstone, with reported bitumen content varying from 6 to 9 wt.%. Sites 3 and 4 are small quarries in Pontotoc and Morrow sandstone, respectively. The bitumen-bearing units are not very thick (~5 ft) but are more or less continuous for a few miles (Jordan, 1964). Bitumen content is 12–17%. Site 5 is a bitumen-bearing sandstone outcrop of Late Pennsylvanian (Missourian) age;

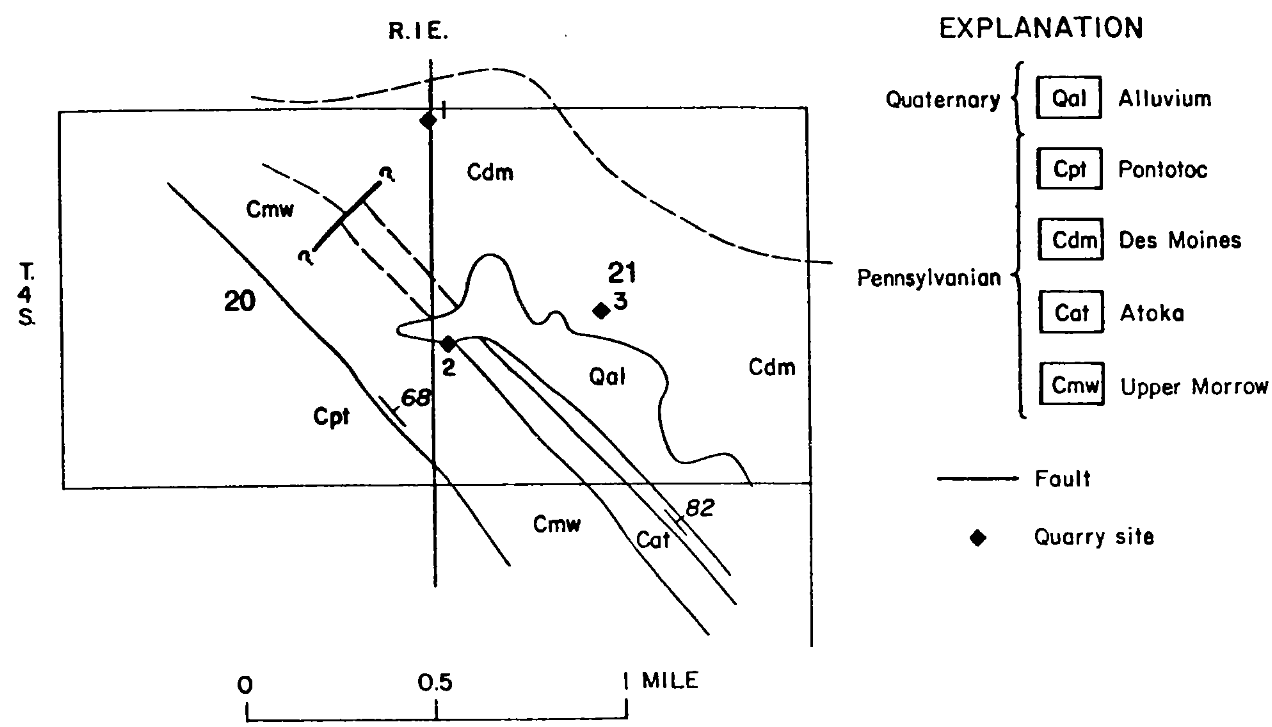

Figure 12. Geologic map of the West Ardmore area, Carter County, Oklahoma. See Figure 2 for location. Bitumen-bearing sandstones occur in Pennsylvanian strata. (After Shell Oil Company, 1957.)

bitumen content is 3–8%. Site 6 is a quarry about 0.25 mi long and 25–30 ft deep. The bitumen-bearing sandstone is Pennsylvanian in age and contains 6–17% bitumen. Site 7 is Springer sandstone, with an impregnated zone ~5 ft thick; bitumen content is not known.

Because of access and terrain problems, only a single core was taken in the Overbrook area. The total bitumen-impregnated interval was ~30 ft and was overlain by 20 ft of shale and siltstone. The bitumen-bearing zone consists of gray to brown fine-grained sandstone with abundant clay laminations and contains 2.9–8.0 wt.% bitumen (Appendixes II-3; III-3).

In-Place Bitumen.—Because of the lack of detailed geologic information, the estimate of in-place bitumen at the Overbrook site is based on field observations and data from the OGS No. 1 Overbrook. The assumptions used in making the estimate of in-place bitumen are given below.

1) The bitumen-impregnated outcrop area is approximately 2,640 ft by 1,320 ft (80 acres).

2) The bitumen content averages 5.8 wt.%.

3) The impregnated interval is 30 ft thick.

4) Specific gravities of the sandstone and bitumen are 2.65 g/cc and 1.017 g/cc, respectively.

The total in-place bitumen estimate for the Overbrook area, using the above assumptions, is 2.9 million barrels. If additional studies indicate greater areal extent of the bitumen-bearing sandstone, this area would be attractive for development owing to the relatively thin overburden (20 ft) and proximity to the production facilities at Overbrook Oil Field.

SUMMARY

The DOE–OGS effort to evaluate the tar-sand potential of several sites in Carter and Murray Counties consisted of a 20-hole coring program, determination of bitumen content, and calculation of in-place bitumen content.

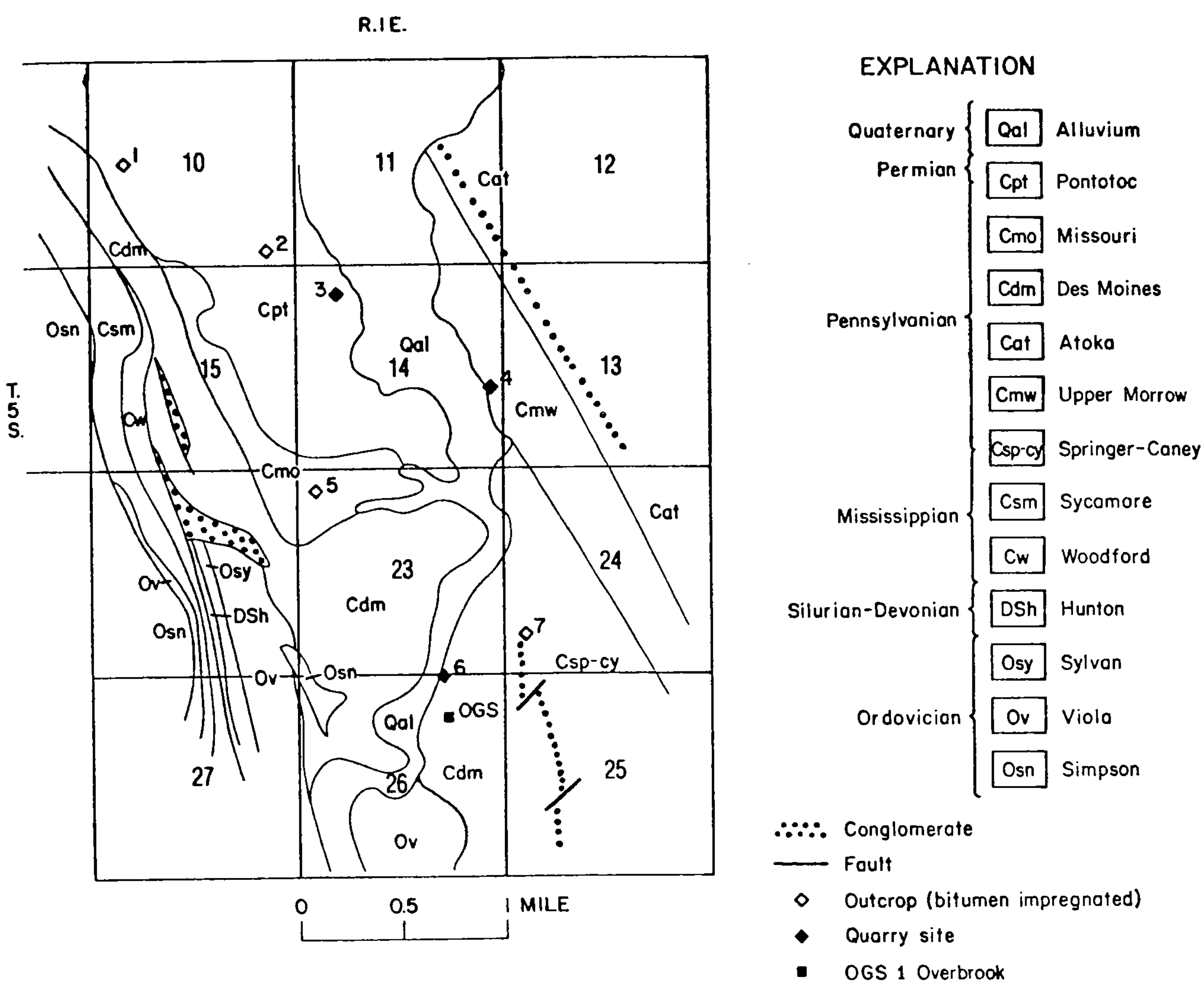

Figure 13. Geologic map of the Overbrook area, Carter County, Oklahoma. See Figure 2 for location. Most of the bitumen-impregnated sandstones in this area occur in Pennsylvanian and Permian strata. (After Shell Oil Company, 1957.)

TABLE 7.—Bitumen Estimates for Sulphur-Dougherty, Overbrook, and South Woodford Tar-Sand Deposits

Area	Bitumen content (10^6 bbls) Measured	Probable
Sulphur	33.8	12.6
Dougherty	—	3.6
Overbrook	—	2.9
South Woodford	8.0	2.4

Total measured bitumen, 41.8 million bbls
Total probable bitumen, 21.5 million bbls
Total probable resource base, 63.3 million bbls

Because of the good well control at the Sulphur Quarry area, the calculated volume of in-place bitumen is considered "measured" rather than "probable." Where well control is less abundant in the Sulphur area, the calculated bitumen is in the "probable" category. The estimates for in-place bitumen at the Dougherty Quarry and Overbrook areas are also "probable." The calculated bitumen at the South Woodford site is considered "measured" in the area defined by OGS cores and "probable" with reasonable extrapolations.

Table 7 is a summary of in-place calculations for both "measured" and "probable" bitumen content at the Sulphur-Dougherty, Overbrook, and South Woodford areas.

Thus, the potential for future tar-sand development at sites in Carter and Murray Counties appears to be quite high. The Sulphur and South Woodford areas offer the greatest possibilities for combined surface handling and *in situ* programs, and together they constitute a resource base approaching 42 million barrels.

Lack of detailed information makes it difficult to classify Dougherty and Overbrook potential as anything other than "probable." The assumptions made in evaluating these two sites are geologically reasonable and somewhat conservative, however, and future studies could significantly alter the tar-sand potential of these areas.

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Appendix I

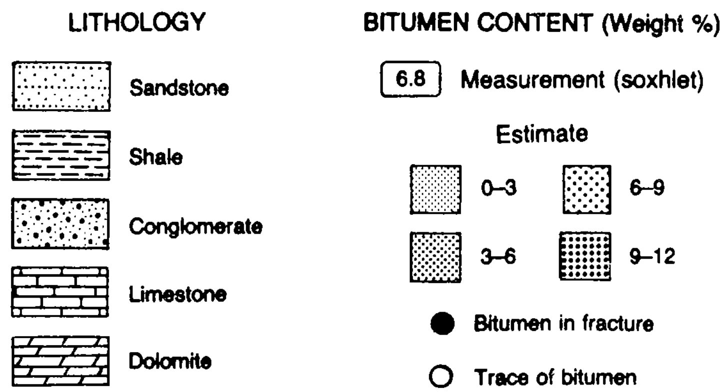
Soxhlet Extraction Procedure for Determining Bitumen Content

Core samples were disaggregated by hand or by mechanical crushing, and 30–50 grams of material was placed in a cellulose extraction thimble (43 × 123 mm). The thimble was plugged with glass wool and placed in a soxhlet device, where it was extracted for 24 hours with 350–400 mL of dichloromethane (glass distilled). The extraction flask containing the bitumen-solvent mixture was placed on a rotary evaporator, and the extract reduced to ~20 mL volume. The extract was quantitatively transferred to a tared sample vial. The extract was air-dried for a period of two weeks or until constant weight was attained. The bitumen weight was reported as weight percent of the initial sample.

Several of the core samples from the South Woodford area did not attain a stable weight after 7–8 weeks, indicating that this particular bitumen was less viscous than other tar-sand samples. This is evidence that the bitumen in the South Woodford area is probably more like a conventional crude oil than were other tar-sand deposits studied.

Appendix II-1

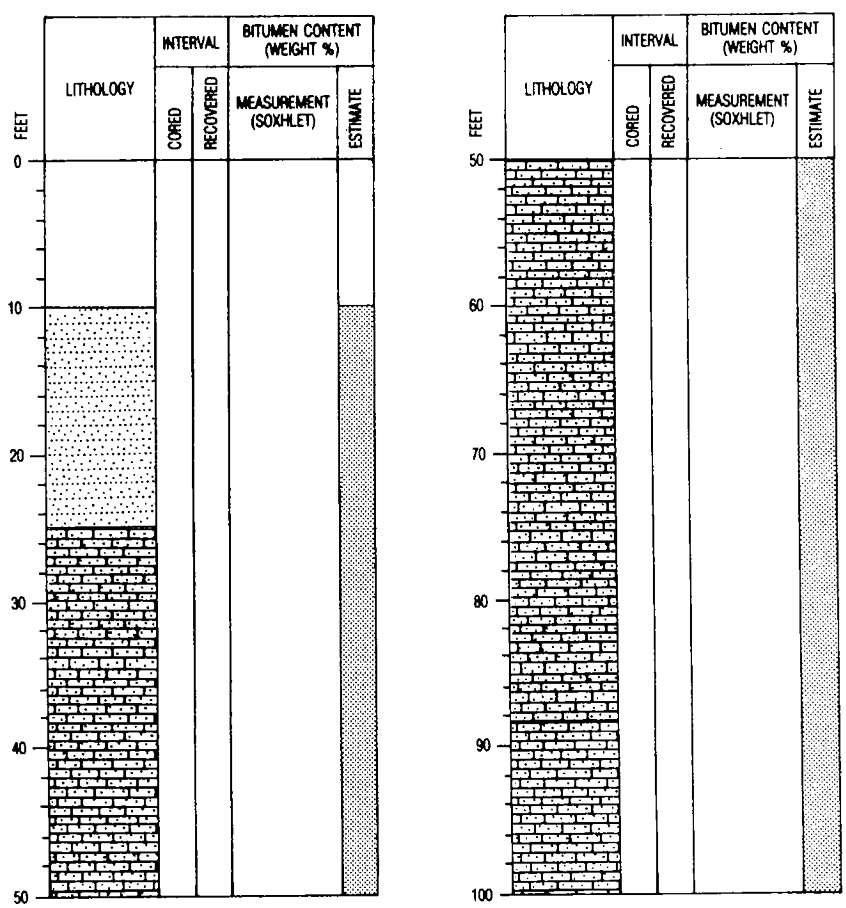
Lithologic Descriptions of Representative Cores from the Sulphur Deposit



PWS 1

(Borehole 1, Fig. 4)
Murray County, Oklahoma
SE¼SE¼NE¼NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 100.0 ft

(ft)	
0.0–10.0	Soil
10.0–25.0	White, fine- to very fine-grained, loose to friable sandstone, traces bitumen
25.0–100.0	Light gray to green, sandy limestone, traces bitumen



PWS 2

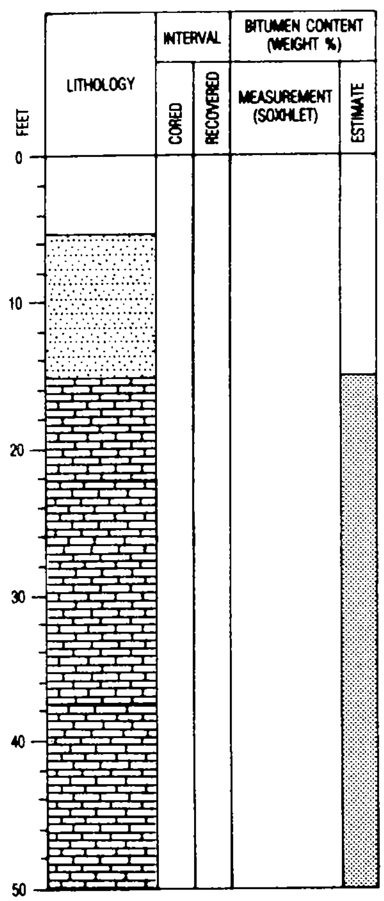
(Borehole 2, Fig. 4)

Murray County, Oklahoma

SE¼NE¼SE¼NE¼ sec. 21, T. 1 S., R. 3 E.

Total depth = 50.0 ft

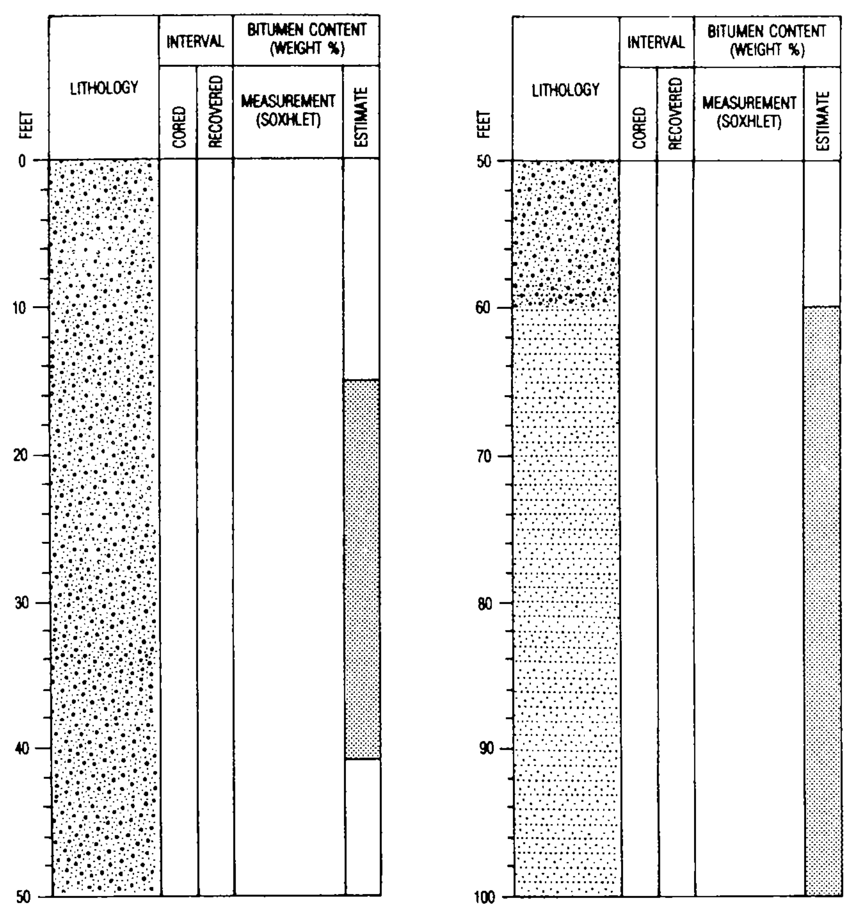
(ft)	
0.0–5.0	Soil
5.0–15.0	Weathered, fine- to very fine-grained, friable sandstone, clumps of grains with calcite cement, limonite concretions, no bitumen
15.0–50.0	Light-dark gray to greenish-black, often sandy, less dense limestone, brachiopod shells noted, very thin shale, light tan-brown-green with pyrite and quartz grains, traces bitumen

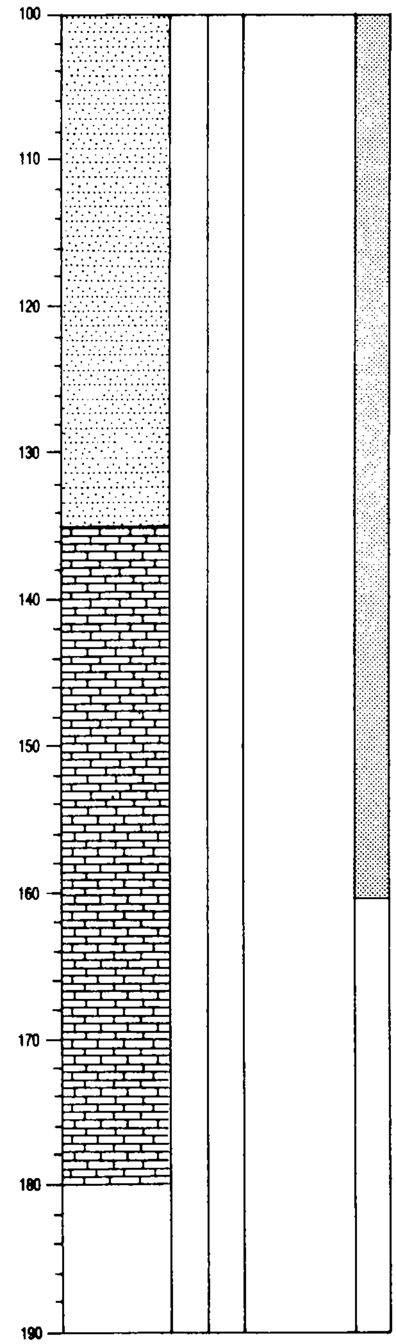


PWS 3

(Borehole 3, Fig. 4)
Murray County, Oklahoma
NW¼NE¼NE¼NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 180.0 ft

(ft)	
0.0–60.0	Limestone pebbles and cobbles; calcite cement, no matrix 0–0.5 ft; sand matrix, chunks sand grains cemented by carbonate, limestone pebbles and granules 5.0–15.0 ft; limestone pebble and cobble size, sizeable amount impregnated sand (mod. sat.), traces bitumen in limestone 15.0–40.0 ft; smaller masses of calcareous sand grains, less matrix 40.0–45.0 ft; increase in free sand grains ("matrix") 45.0–50.0 ft; loose sand 55.0–60.0 ft
60.0–135.0	Gray-tan, loose to very friable calcareous sandstone, fine- to very fine-grained, moderately well sorted, rounded, pitted and frosted; traces bitumen
135.0–180.0	Light to dark gray limestone, dense, often sandy; thin shale interbeds, green, slightly calcareous, with pyrite crystals; traces bitumen 135.0–160.0 ft; no bitumen 160.0–180.0 ft





PWS 4

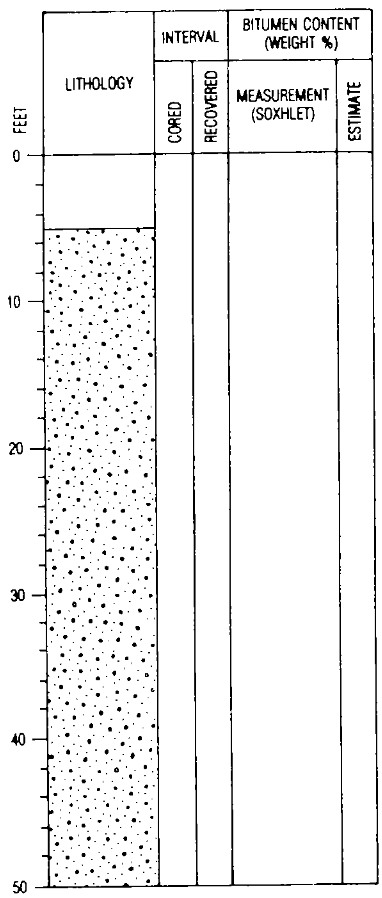
(Borehole 4, Fig. 4)

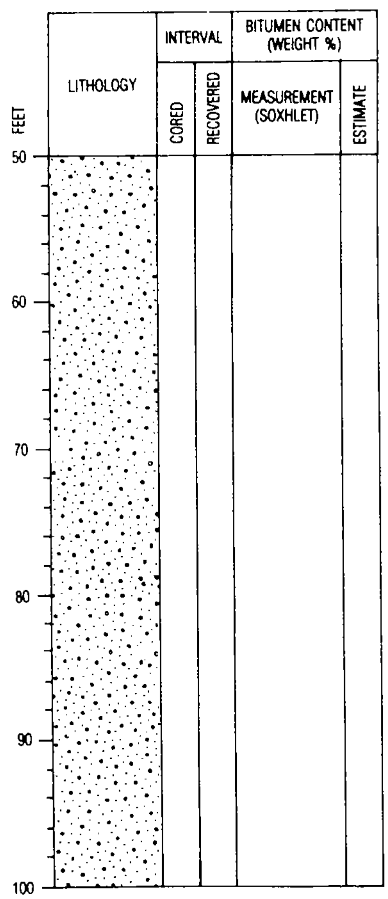
Murray County, Oklahoma

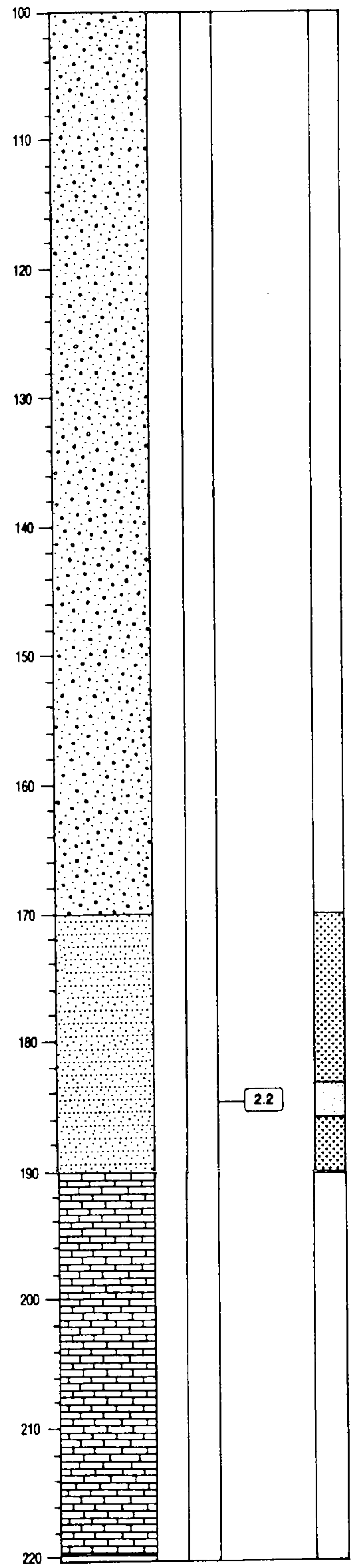
SE¼SE¼SE¼SE¼ sec. 16, T. 1 S., R. 3 E.

Total depth = 220.0 ft

(ft)	
0.0–5.0	Soil
5.0–170.0	Limestone cobble-pebble conglomerate, tan, light-dark gray, dense; sand matrix, carbonate cement common, traces bitumen throughout; matrix 40.0–50.0 ft; sand matrix 50.0–170.0 ft
170.0–190.0	Fine- to very fine-grained, rounded to subrounded, well sorted sandstone, some friable with carbonate cement, moderate bitumen, slight bitumen saturation last 5.0 ft
190.0–220.0	Limestone, sandy, gray-green, denser towards base; shale interbeds, green, calcareous, fissile



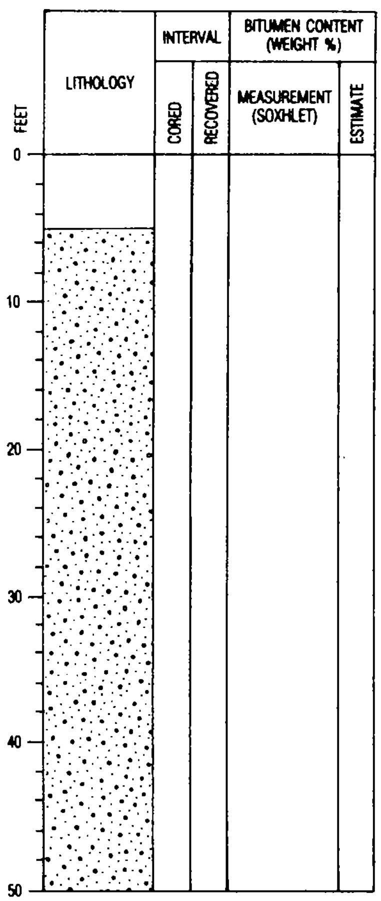


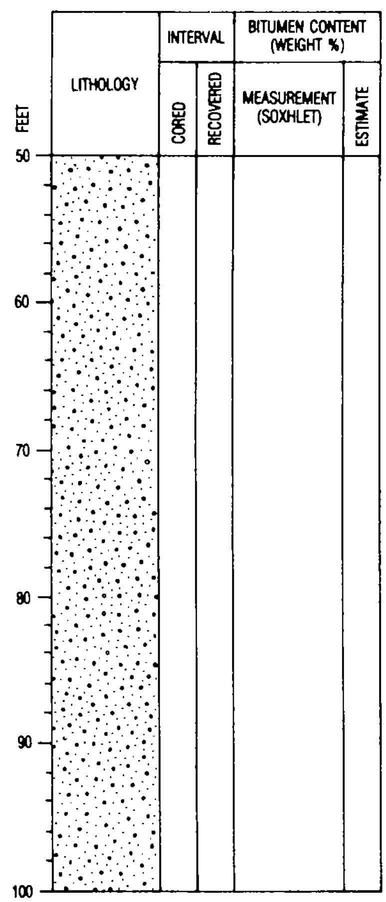


PWS 5

(Borehole 5, Fig. 4)
Murray County, Oklahoma
SE¼NE¼SE¼SE¼ sec. 16, T. 1 S., R. 3 E.
Total depth = 300.0 ft

(ft)	
0.0–5.0	Soil
5.0–200.0	Limestone pebbles and cobbles, sand matrix, initial 10.0 ft, tan, becoming light to medium gray, lumps bitumen throughout, granules of carbonate-cemented sands
200.0–220.0	Fine- to very fine-grained, well rounded, calcareous sandstone, moderate bitumen slight saturation last 5.0 ft
220.0–300.0	Limestone, green to light-dark gray, very sandy at top, more crystalline toward base; shale interbeds, green, calcareous, platy, pyrite noted, traces bitumen throughout





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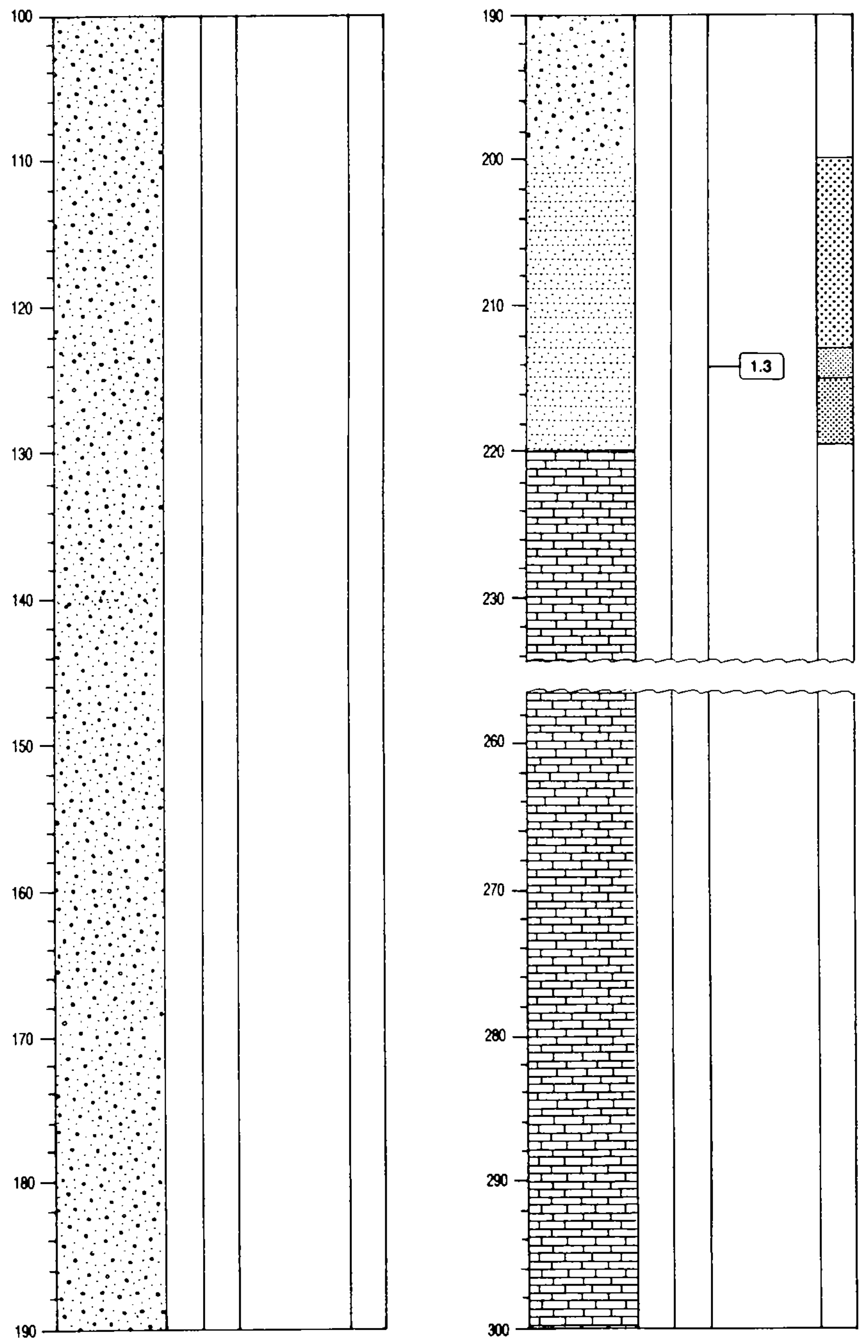
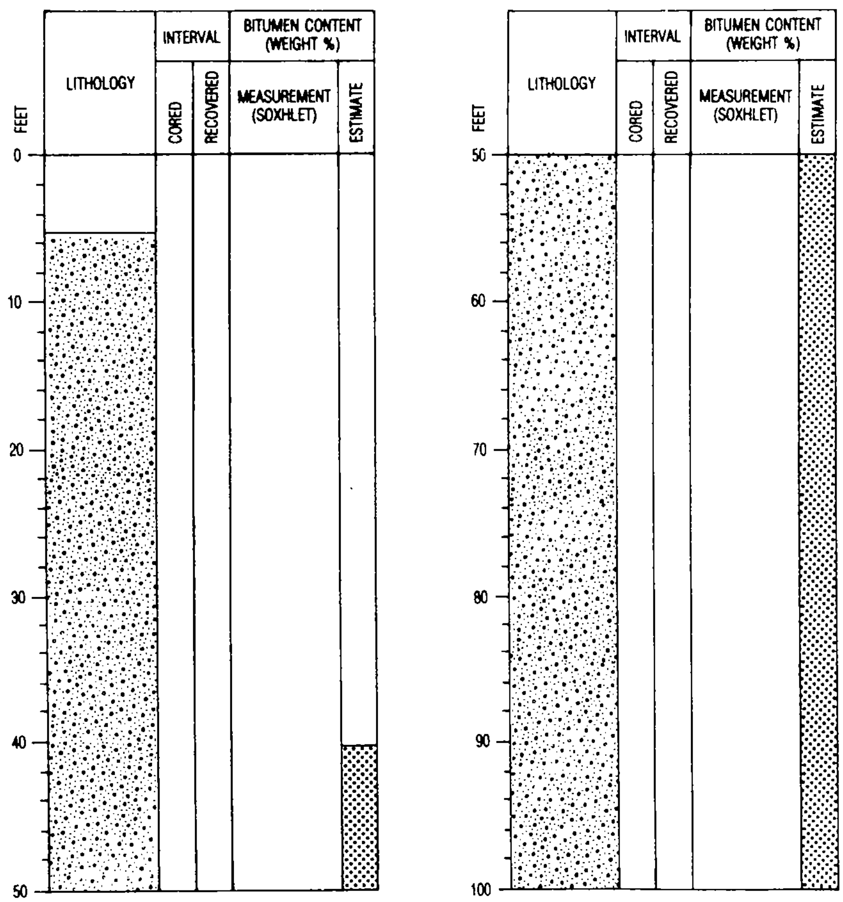
PWS 5 *(continued)*



PWS 6

(Borehole 6, Fig. 4)
Murray County, Oklahoma
NW¼SW¼NE¼NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 280.0 ft

(ft)	
0.0–5.0	Soil
5.0–190.0	Limestone, pebble-cobble conglomerate, tan, light-dark gray, dense, bitumen common (in form of saturated clumps of sand); moderate bitumen from 40.0 ft; increase in carbonate-cemented sand clumps with moderate bitumen saturation; increase in bitumen saturated clumps 55.0–65.0 ft
190.0–210.0	Fine- to very fine-grained, rounded-subrounded, some friable sandstone, moderate bitumen saturation
210.0–280.0	Limestone, sandy, becoming dense at bottom of hole, green-gray; shale interbeds, green, calcareous



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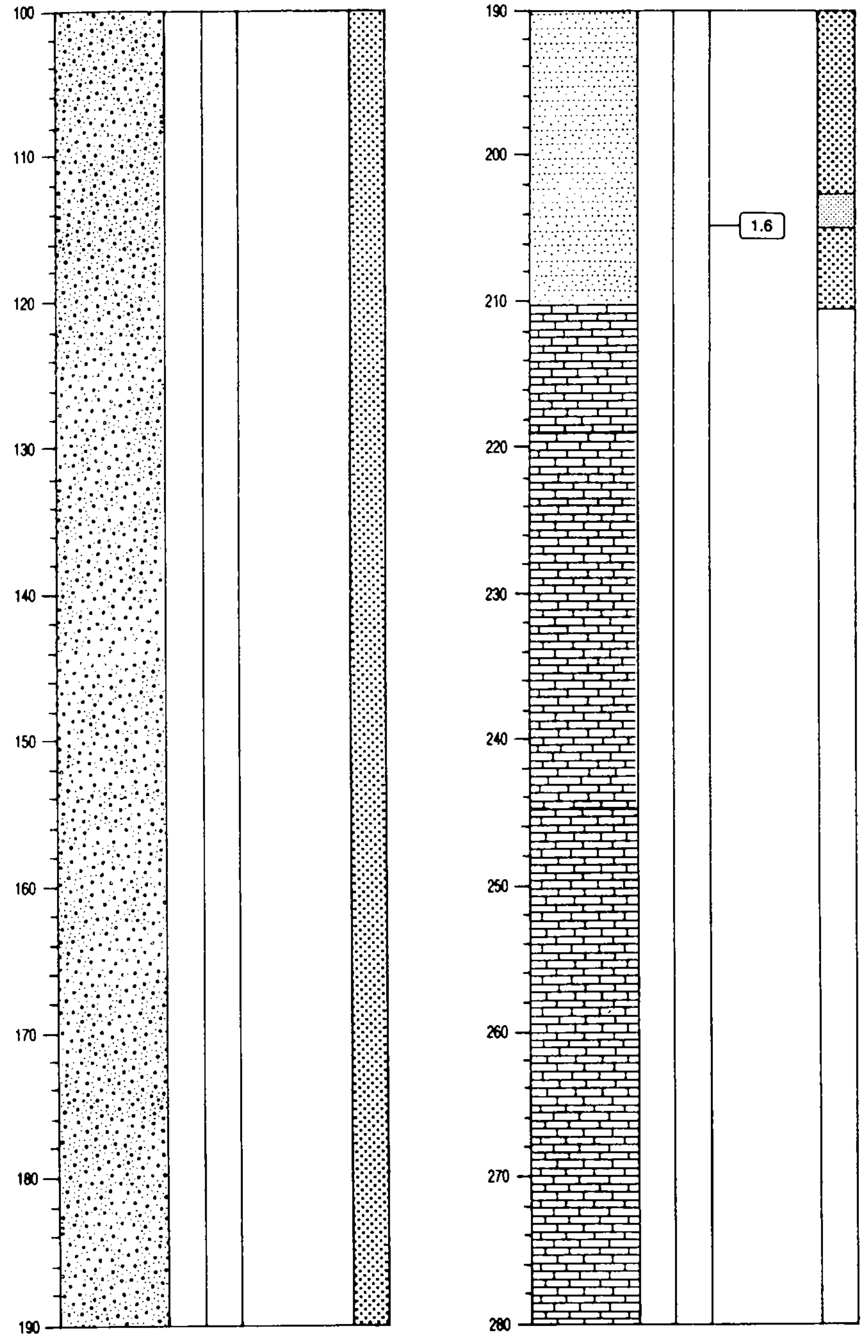
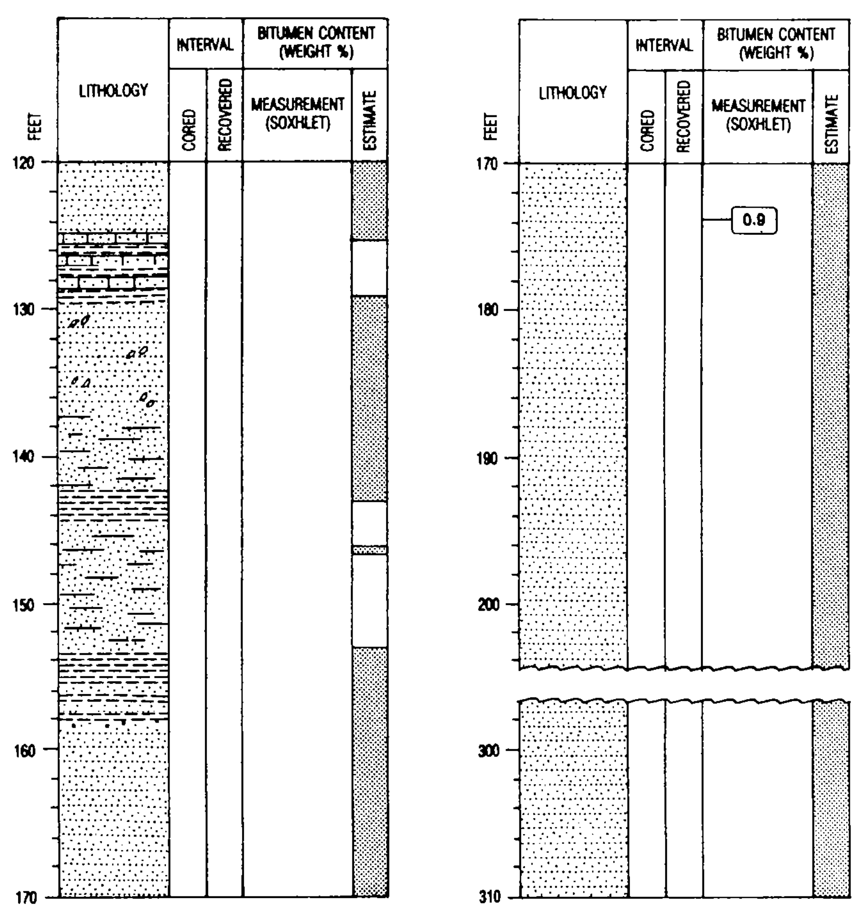
PWS 6 *(continued)*



PWS 7

(Borehole 7, Fig. 4)
Murray County, Oklahoma
2,450 ft FSL, 2,450 ft FWL, sec. 21, T. 1 S., R. 3 E.
Total depth = 310.0 ft

(ft)	
120.0–310.0	Cored, recovered 120.0–310.0 ft
120.0–125.0	Jumbled, fractured sandstone
125.0–129.0	Interbedded sandy limestone and shale
129.0–137.0	Fine sandstone with scattered grains of limestone
137.0–142.5	Fractured sandstone with shale stringers
142.5–145.0	Shale with some sandy zones
145.0–153.0	Sandstone with shale stringers
153.0–158.0	Gray shale with interbedded sandstone
158.0–158.5	Rounded limestone cobbles
158.5–310.0	Fine sandstone with trace of shale in fractures

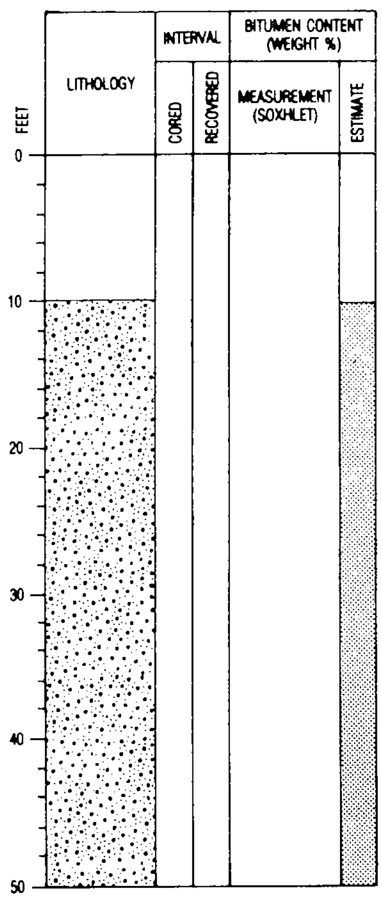


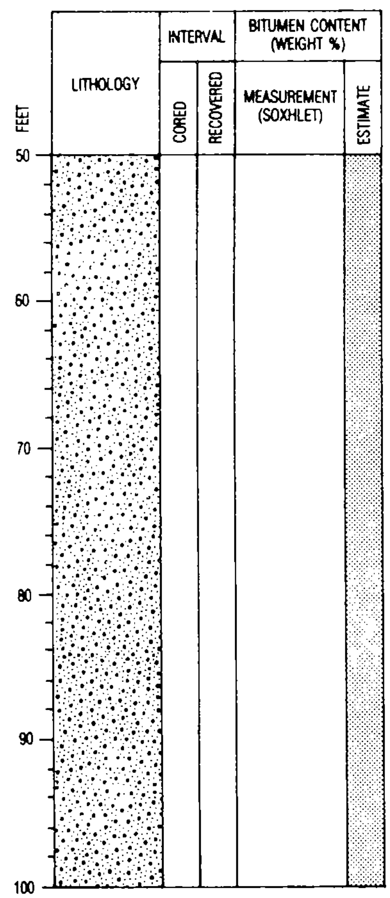
PWS 8A

(Borehole 8, Fig. 4)

Murray County, Oklahoma
NW¼SE¼NW¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 242.0 ft

(ft)	
0.0–10.0	Soil
10.0–101.0	Limestone cobble conglomerate, dense, sand matrix with carbonate cement; traces bitumen throughout
101.0–229.0	Fine- to very fine-grained sandstone, loose to friable with carbonate cement, well rounded, slight bitumen saturation, moderate saturation 136.0–153.0 ft (7%)
229.0–242.0	Limestone, sandy, denser at bottom of hole, dark green to gray





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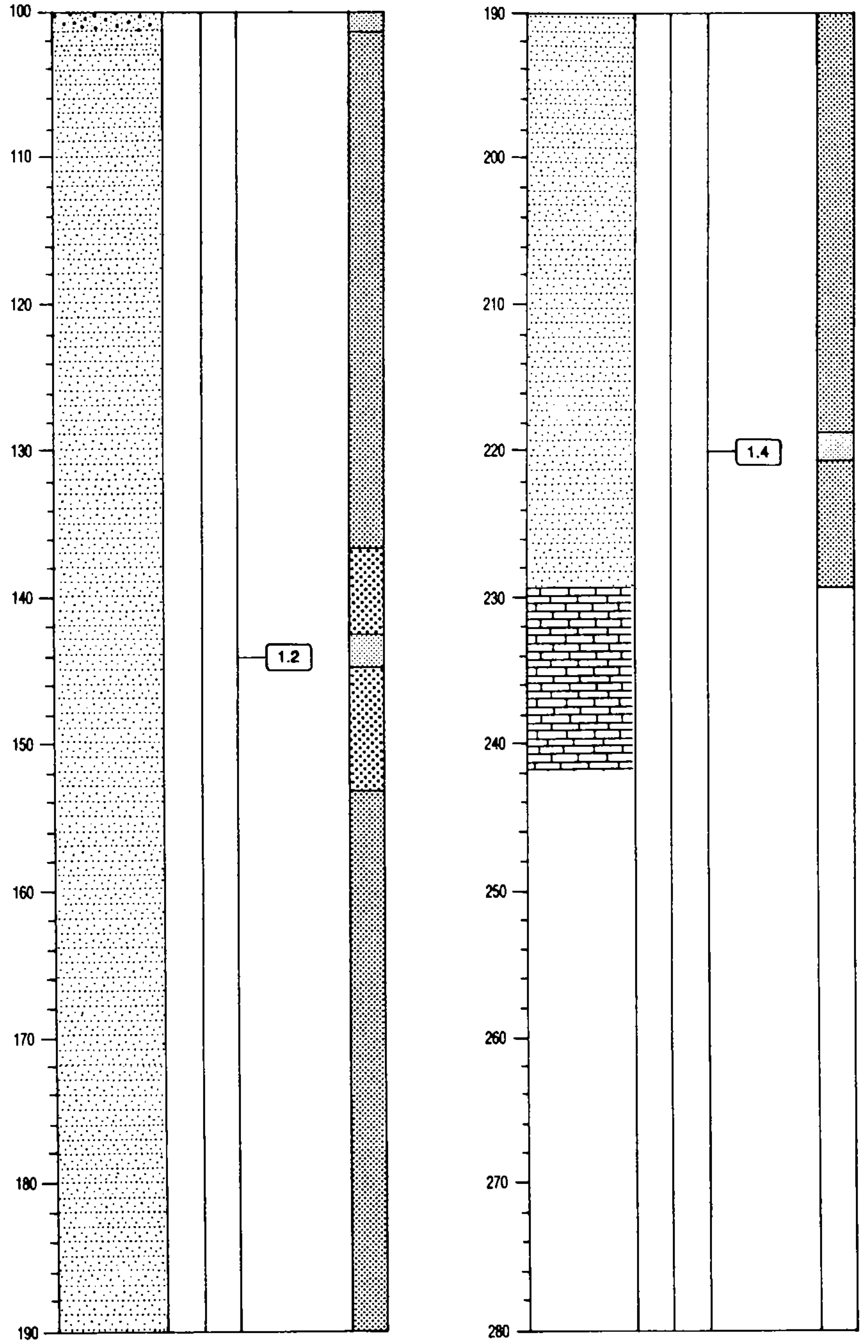
PWS 8A *(continued)*



PWS 9

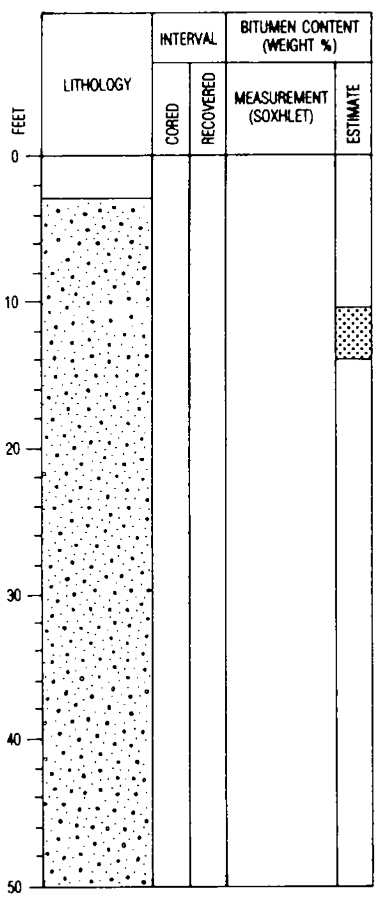
(Borehole 9, Fig. 4)

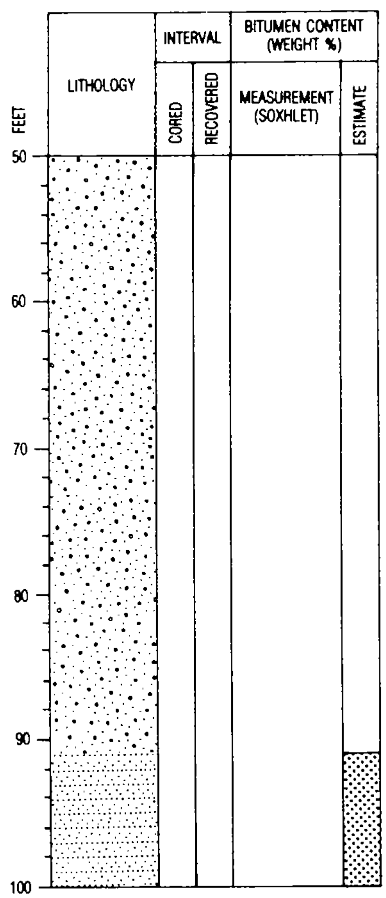
Murray County, Oklahoma

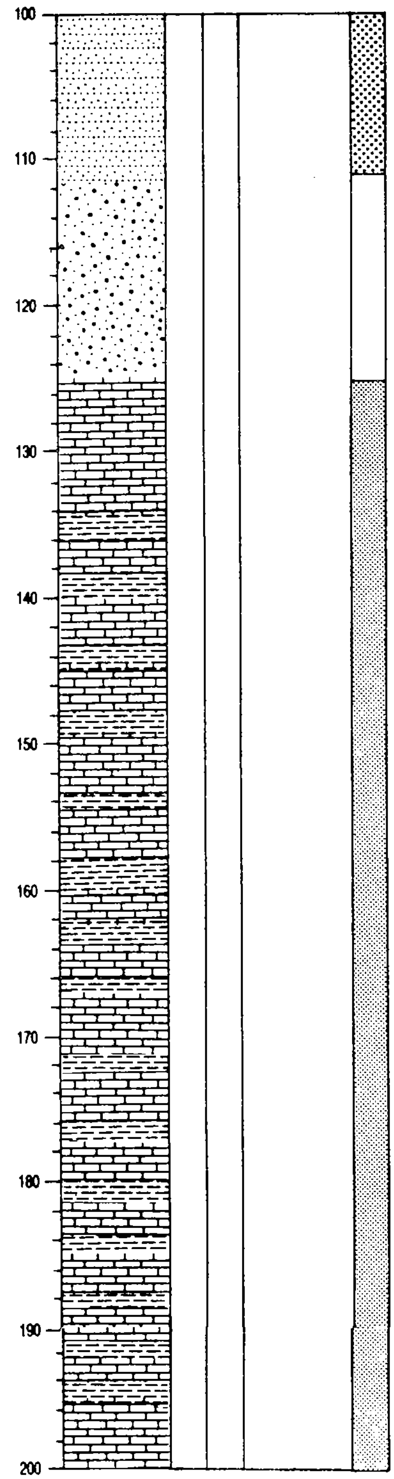
SE¼SE¼NW¼SW¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 200.0 ft

(ft)	
0.0–3.0	Soil
3.0–125.0	Limestone pebbles and cobbles, dense, light gray or tan, very sandy matrix, large amount fine-grained sand matrix, moderate saturation and carbonate cement 10.0–14.0 ft; at 20.0 ft less matrix; at 45.0 ft sand matrix increases; sandstone with carbonate cement, fine- to very fine-grained, fossiliferous with brachiopod shells; no bitumen 50.0–65.0 ft; sandstone, fine-grained, moderate saturation 91.0–111.0 ft
125.0–200.0	Limestone, medium to dark gray, dark green, often sandy, crystalline toward bottom of hole, darker toward bottom of hole; shale interbeds, green, calcareous, platy; traces bitumen



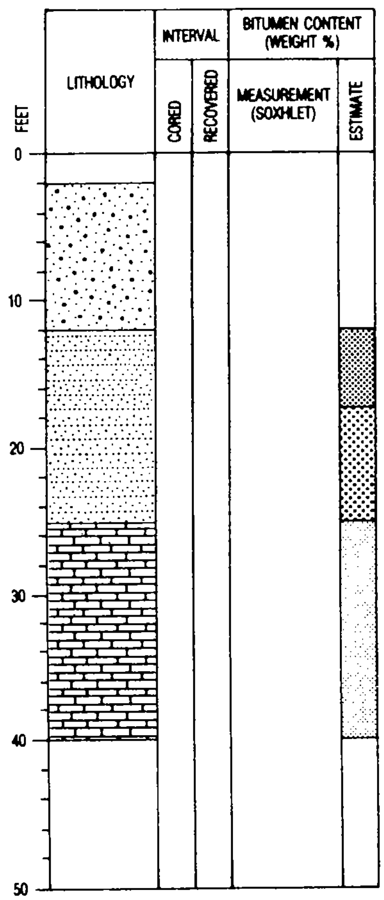




PWS 10

(Borehole 10, Fig. 4)
Murray County, Oklahoma
C NW¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 40.0 ft

(ft)	
0.0–2.0	Soil
2.0–12.0	Limestone pebble and cobble conglomerate, sandy matrix, light tan, white, light gray
12.0–25.0	Fine- to very fine-grained, well rounded, silica cement; slight saturation top 5.0 ft, else moderate saturation
25.0–40.0	Limestone, sandy, medium to dark gray or green; shale, green, fissile, calcareous; traces bitumen throughout

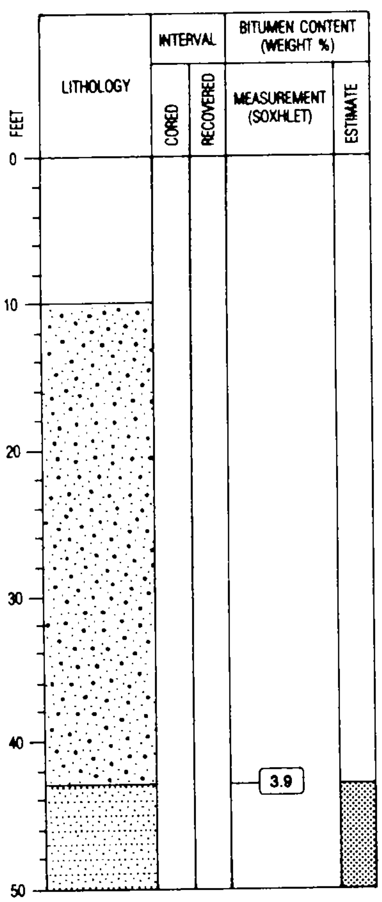


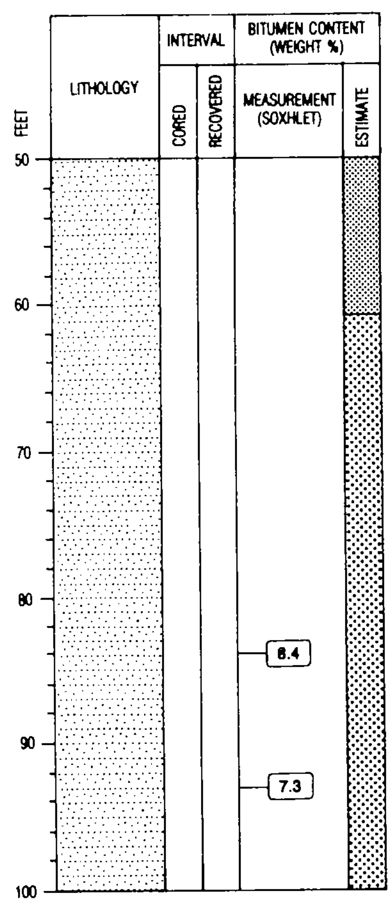
PWS 11

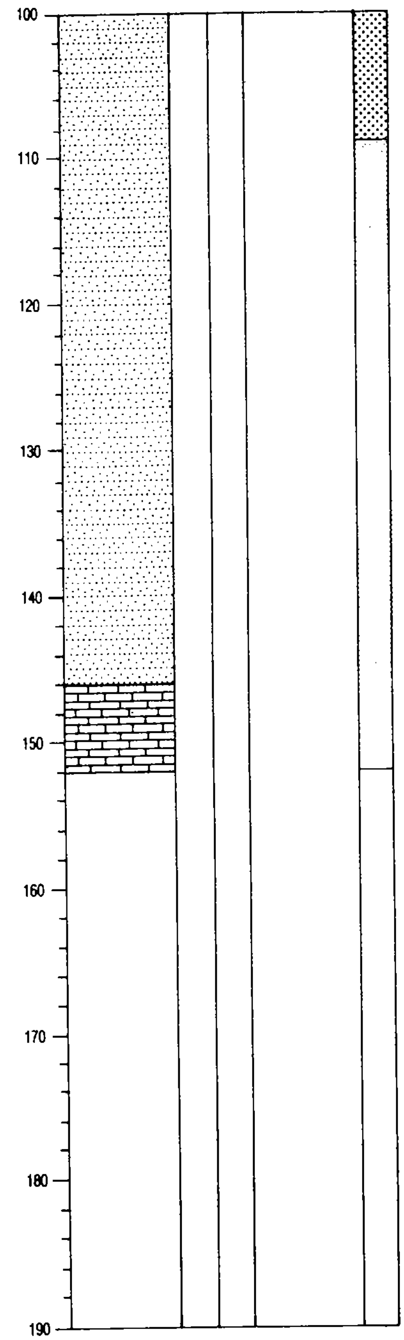
(Borehole 11, Fig. 4)

Murray County, Oklahoma
330 ft N of C SW¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 152.0 ft

(ft)	
0.0–10.0	Soil
10.0–43.0	Limestone pebble-cobble conglomerate, sand matrix with carbonate cement, dense, light gray tan; sandstone fine-grained, no bitumen 15.0–20.0 ft
43.0–146.0	Fine- to very fine-grained sandstone, friable with carbonate cement, slight saturation 43.0–60.0 ft; moderate saturation 60.0–108.0 ft; traces bitumen 108.0–146.0 ft
146.0–152.0	Limestone, sandy becomes dense at bottom of hole, light gray, traces bitumen





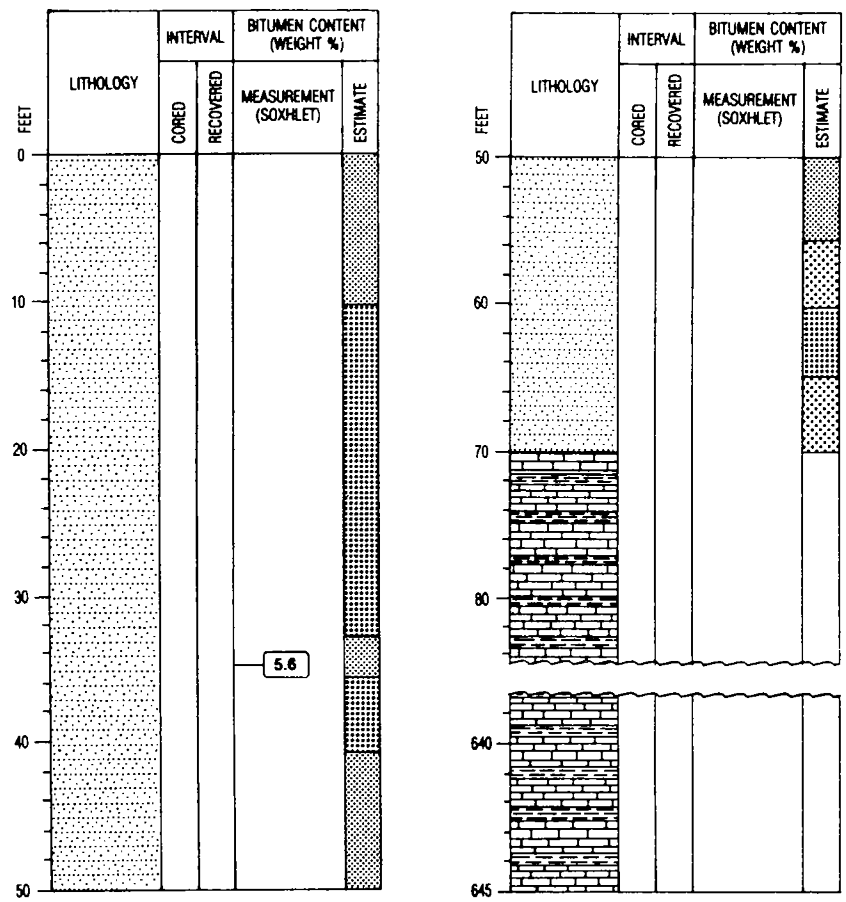


PWS 13

(Borehole 13, Fig. 4)

Murray County, Oklahoma
SW¼SE¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 645.0 ft

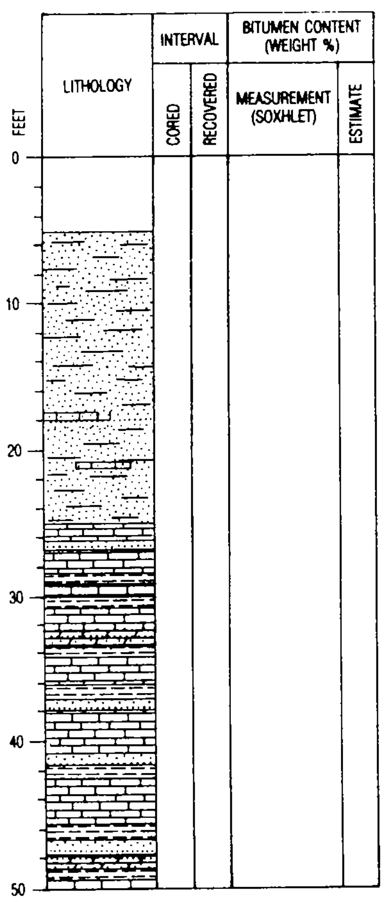
(ft)	
0.0–70.0	Fine- to very fine-grained sandstone, rounded to subrounded, loose to friable; loose, slight saturation 0–10.0 ft; excellent saturation 10.0–40.0 ft; slight saturation 40.0–55.0 ft; moderate saturation 55.0–60.0 ft; excellent saturation 60.0–65.0 ft; moderate saturation 65.0–70.0 ft
70.0–380.0	Limestone, sandy, green; dense toward base, medium dark gray, light brown; shale, green, calcareous; at 260.0 ft light-medium green, light-medium gray, white-gray, sandy texture; no bitumen
380.0–645.0	Limestone, finely crystalline, dark gray to dark green; numerous thin shale layers, green, calcareous; at 500.0 ft color is tan; no bitumen

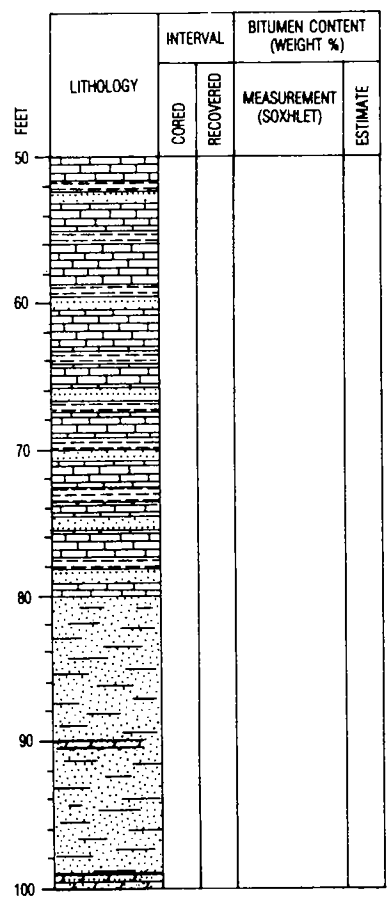


PWS 14

(Borehole 14, Fig. 4)
Murray County, Oklahoma
SE¼SW¼NW¼NW¼ sec. 22, T. 1 S., R. 3 E.
Total depth = 275.0 ft

(ft)	
0.0–5.0	Soil
5.0–25.0	Fine-grained sandstone with stringers of shale and limestone
25.0–80.0	Limestone with interbedded shale, fine-grained sandstone, and fine-grained sandy dolomite
80.0–145.0	Fine-grained sandstone with shale stringers and some fine-grained sandy dolomite
145.0–270.0	Interbedded limestone and green shale with scattered layers of fine-grained sandstone





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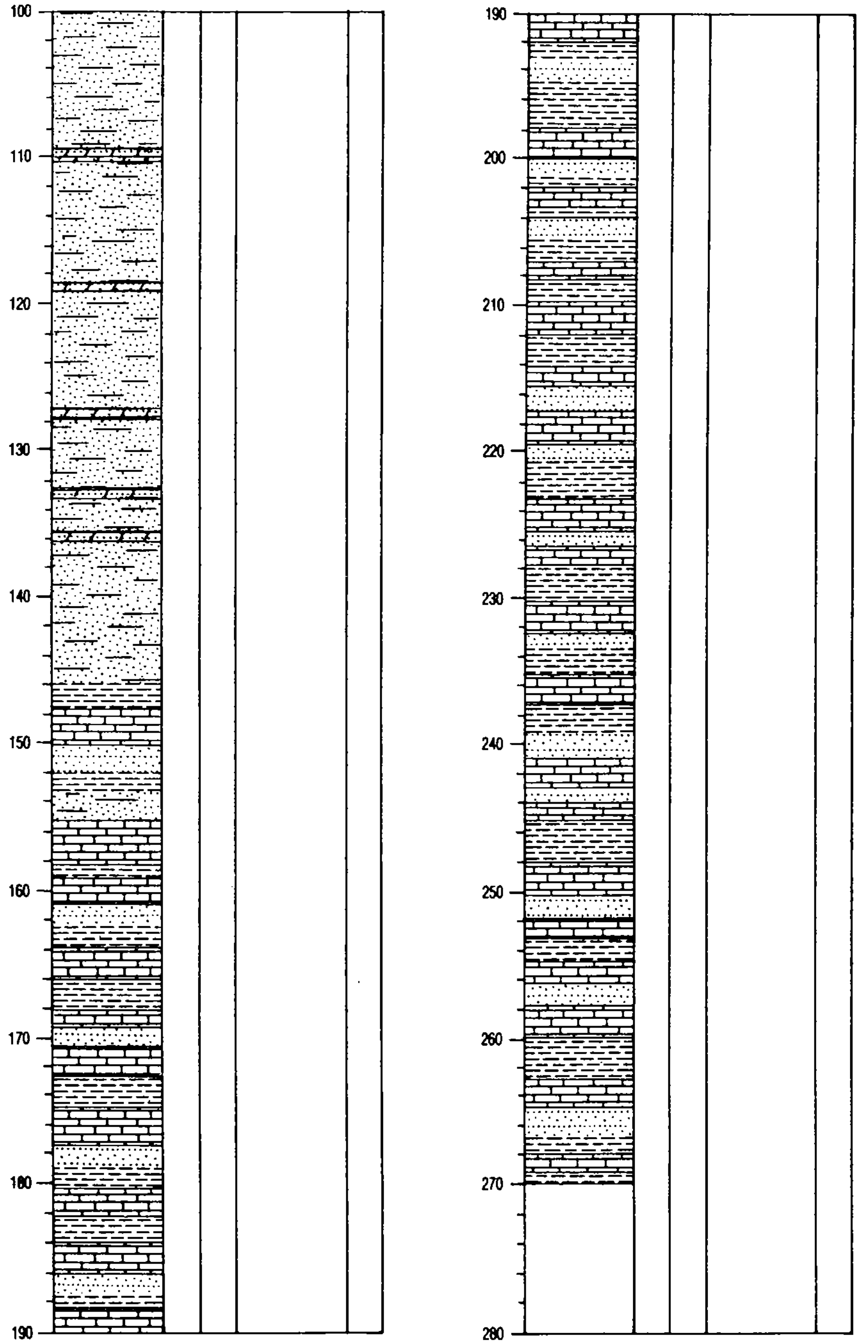
PWS 14 *(continued)*



PWS 16

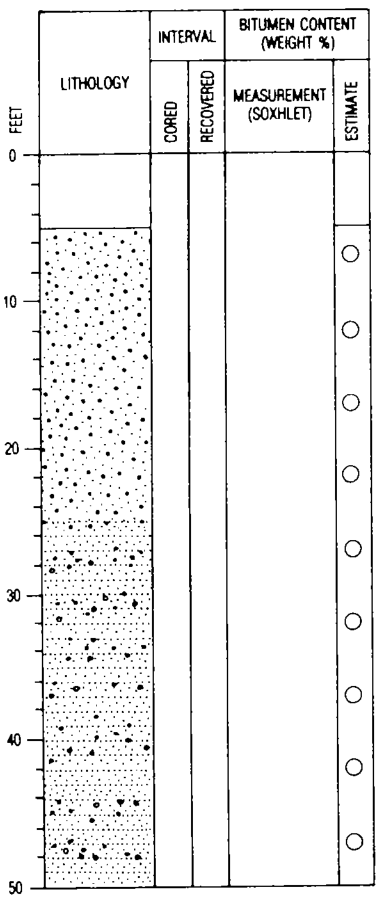
(Borehole 16, Fig. 4)

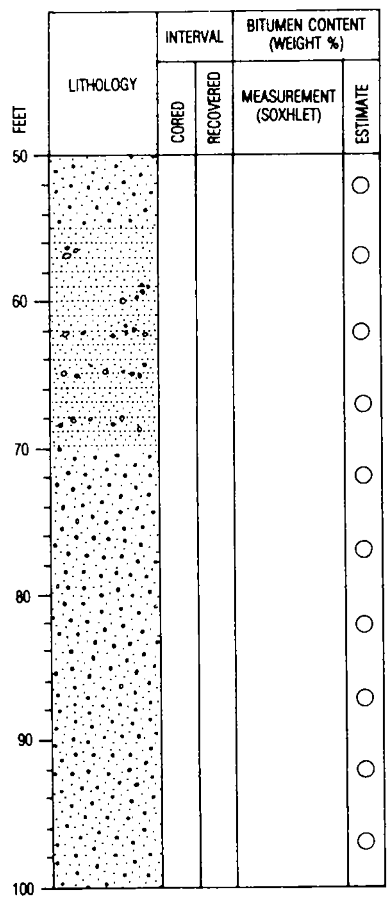
Murray County, Oklahoma

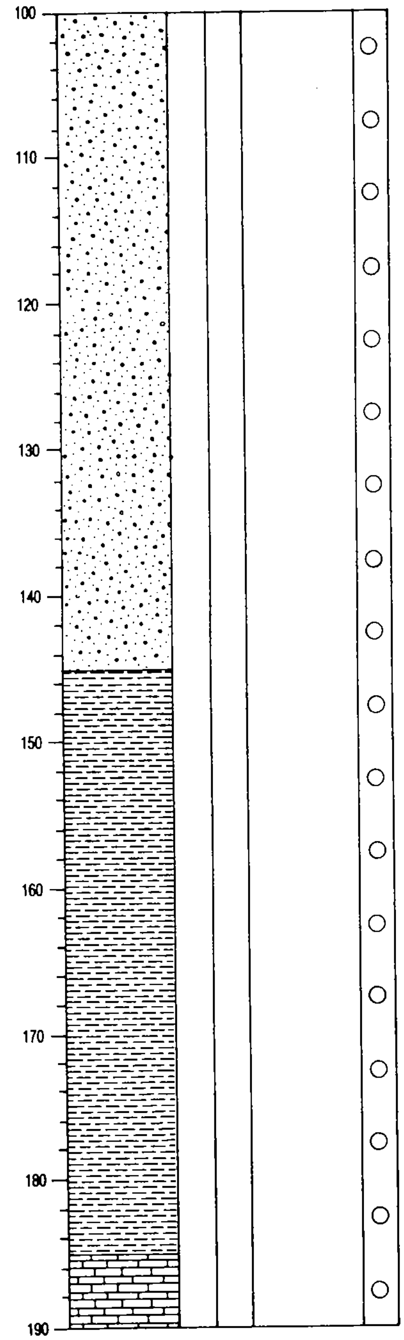
SE¼SW¼NE¼NE¼NW¼ sec. 21, T. 1 S., R. 3 E.

Total depth = 660.0 ft

(ft)	
0.0–5.0	Soil
5.0–145.0	Limestone pebble-cobble conglomerate, very sandy matrix; loose, friable sand layers 25.0–50.0 ft, 55.0–70.0 ft; pyritic, traces bitumen
145.0–210.0	Shale, 145.0–185.0 ft, green, calcareous; limestone 185.0–210.0 ft; gray, light tan, sandy, traces bitumen
210.0–310.0	Apparent thrust fault; fine- to very fine-grained sandstone, calcareously cemented, slight saturation, moderate saturation 300.0–310.0 ft
310.0–500.0	Green calcareous shale interbedded with white to gray limestone, sandy, pyritic; traces bitumen
500.0–610.0	Limestone, dark gray to black, tan, sandy; shale beds common, slightly fossiliferous; traces bitumen







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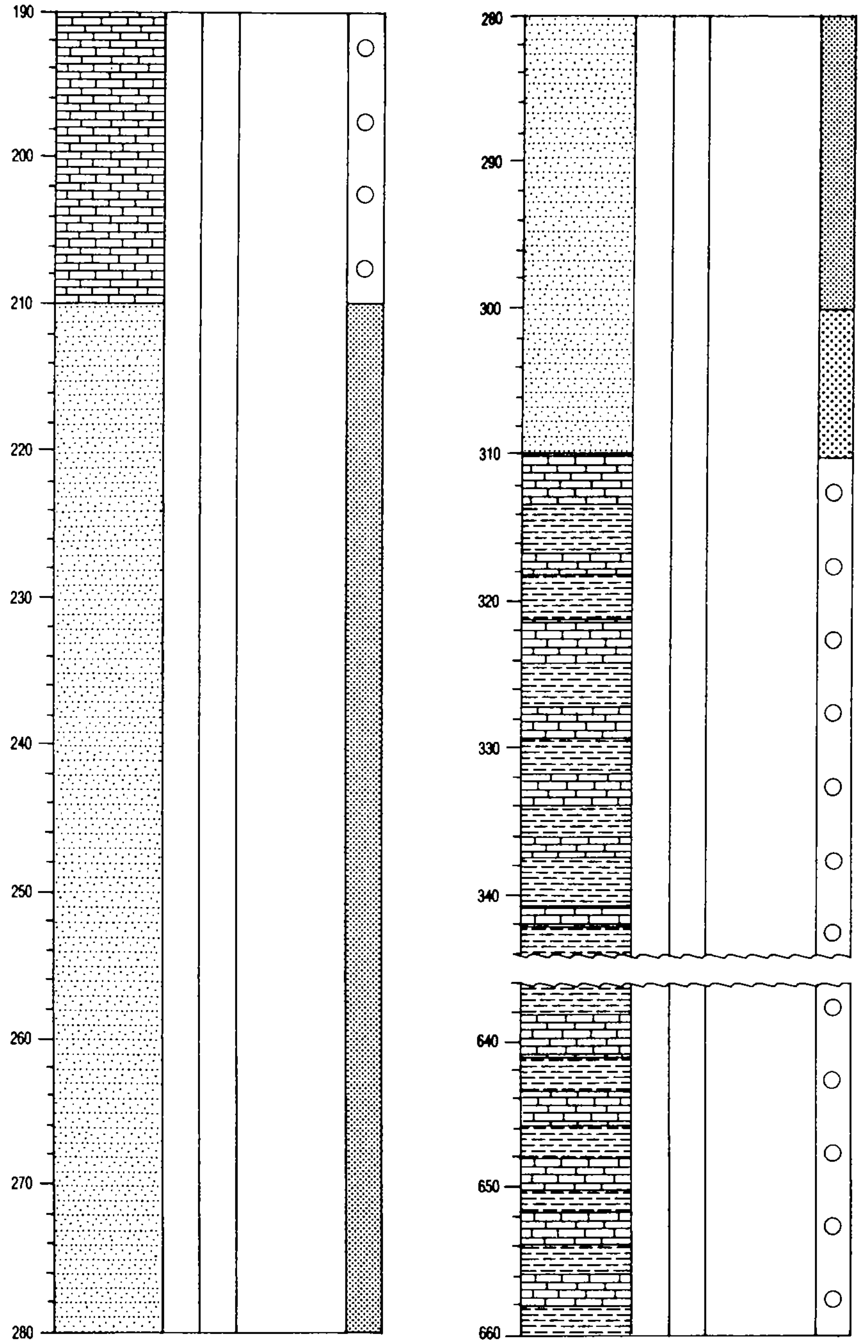
PWS 16 *(continued)*



PWS 17

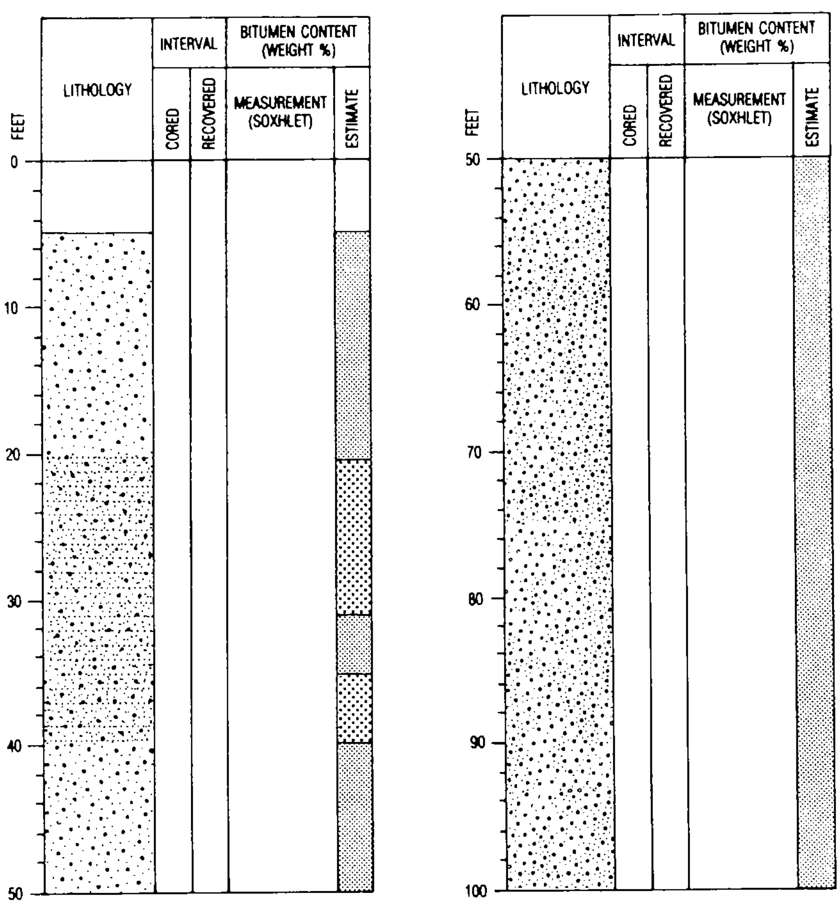
(Borehole 17, Fig. 4)

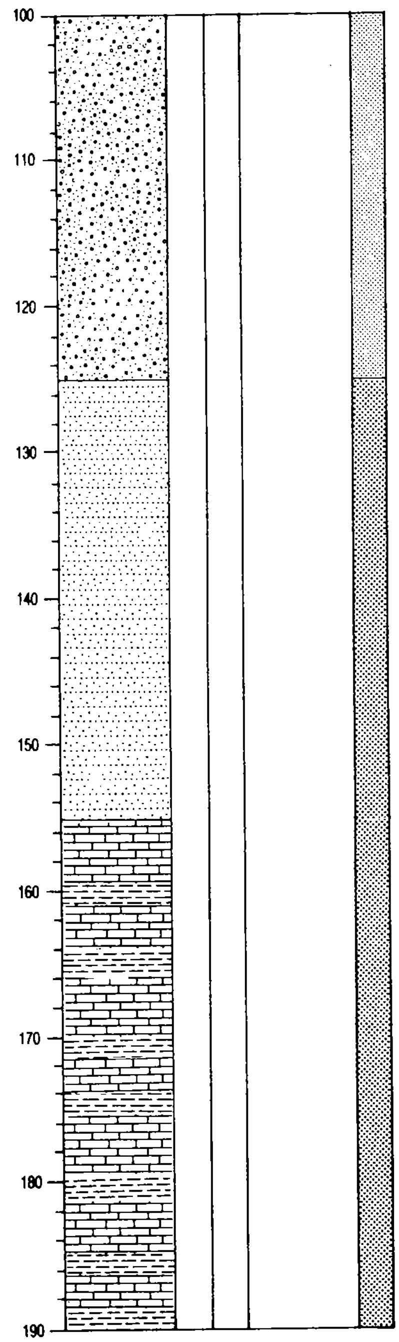
Murray County, Oklahoma

SW¼SW¼NE¼SW¼SE¼ sec. 16, T. 1 S., R. 3 E.

Total depth = 568.0 ft

(ft)	
0.0–5.0	Soil
5.0–125.0	Limestone pebble-cobble conglomerate, sandy matrix, tan, light to medium gray; traces bitumen throughout, moderate saturation at 20.0–30.0 ft, 35.0–40.0 ft
125.0–155.0	Fine- to very fine-grained sandstone, friable, with carbonate cement; slight saturation
155.0–300.0	Limestone, green, gray, sandy, shale interbeds common, green, calcareous; possible slickensides at 215.0 ft; slight saturation 155.0–310.0 ft
300.0–450.0	Fine- to very fine-grained sandstone, well sorted, loose, tan to light brown; moderate saturation 310.0–375.0 ft. NOTE: 420.0–480.0 ft not sampled, contact estimated. Repeated Section
450.0–568.0	Limestone, white, very sandy; sandstone beds, friable, shale interbeds, green, calcareous, slight saturation





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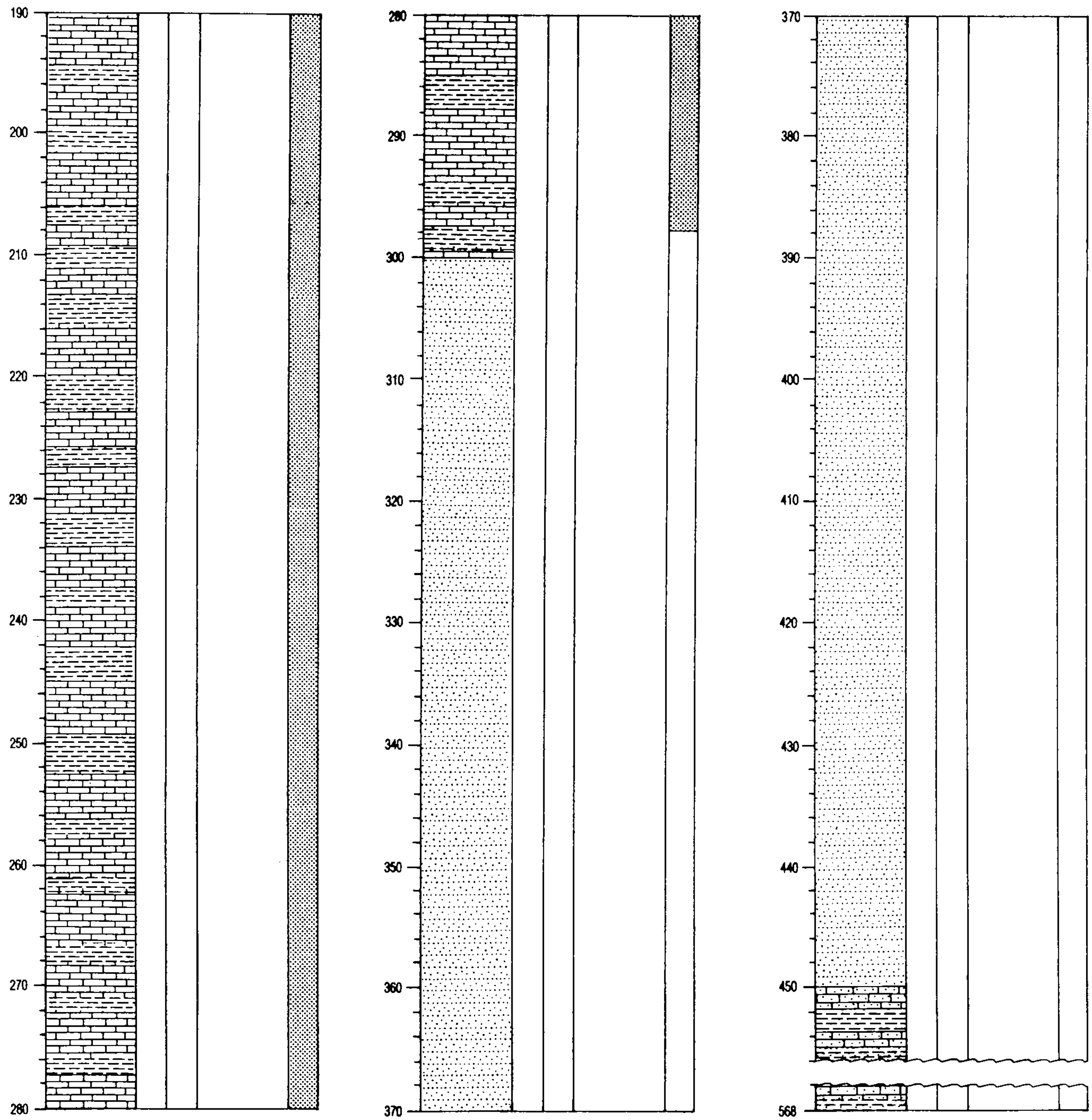
PWS 17 *(continued)*

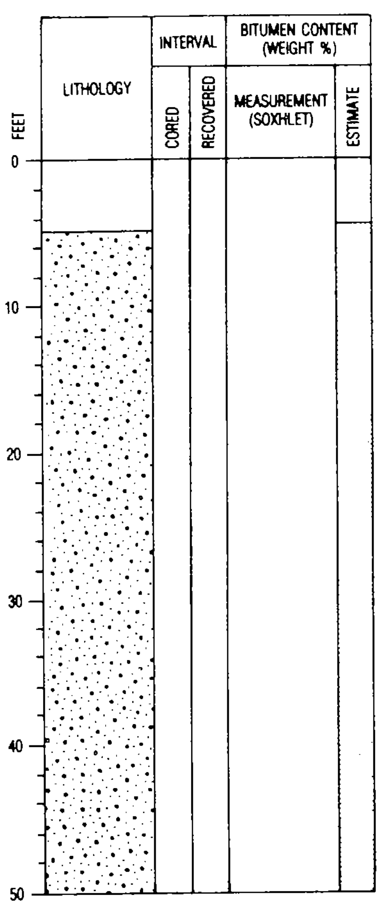


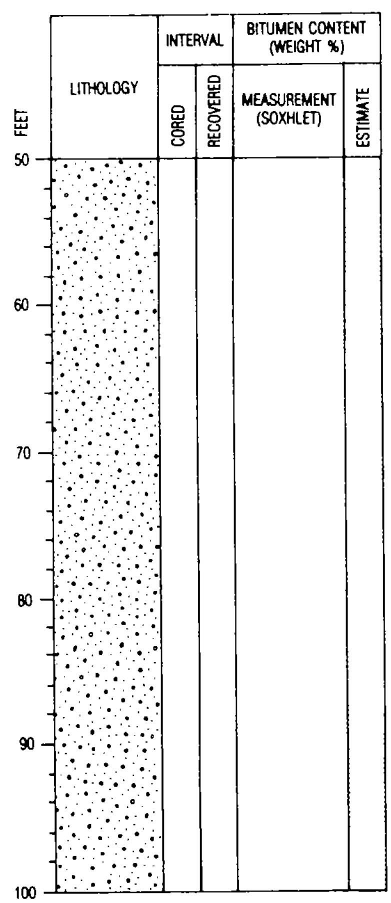
PWS 18

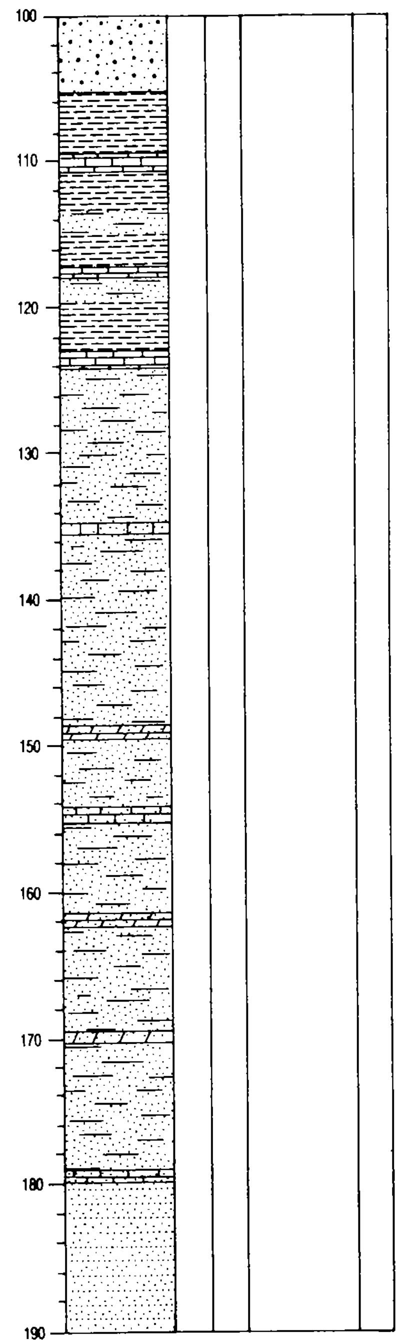
(Borehole 18, Fig. 4)

Murray County, Oklahoma
NW¼NE¼NW¼SE¼SE¼ sec. 16, T. 1 S., R. 3 E.
Total depth = 560.0 ft

(ft)	
0.0–5.0	Soil
5.0–105.0	Limestone pebble-cobble conglomerate, sandy matrix, tan, light to medium gray, dense; traces bitumen
105.0–125.0	Shale with interbedded limestone and sandstone
125.0–145.0	Fine-grained sandstone
145.0–180.0	Sandstone with stringers or interbeds of fine-grained sandy dolomite, limestone, and shale
180.0–260.0	Fine-grained sandstone
260.0–270.0	Green shale
270.0–295.0	Fine-grained sandstone, moderate saturation 270.0–280.0 ft
295.0–320.0	Sandstone with interbedded limestone and shale
320.0–335.0	Shale
335.0–360.0	Sandstone with shale stringers
360.0–440.0	Not sampled
440.0–560.0	Interbedded shale, limestone, and sandstone







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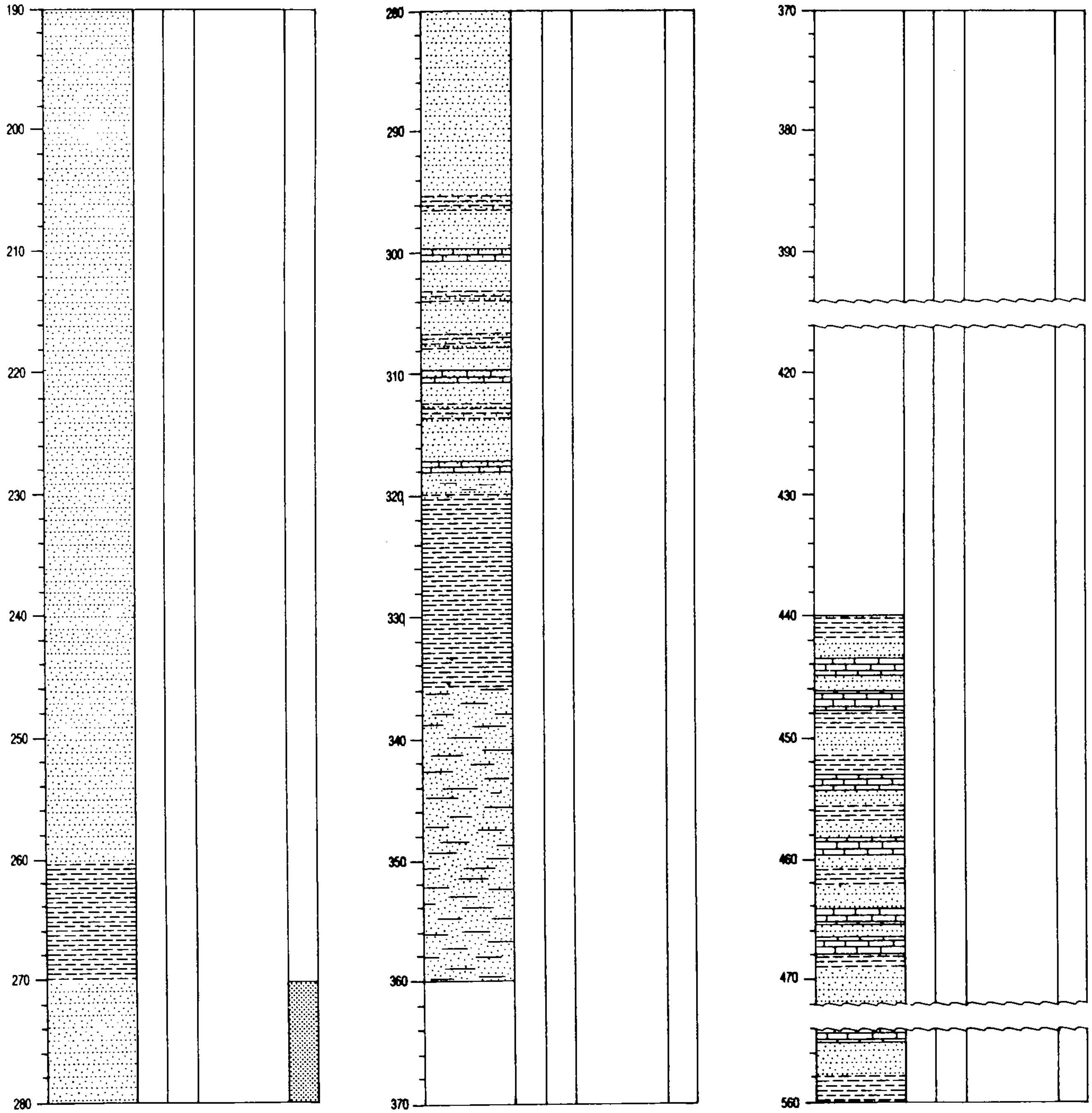
PWS 18 *(continued)*



PWS 19

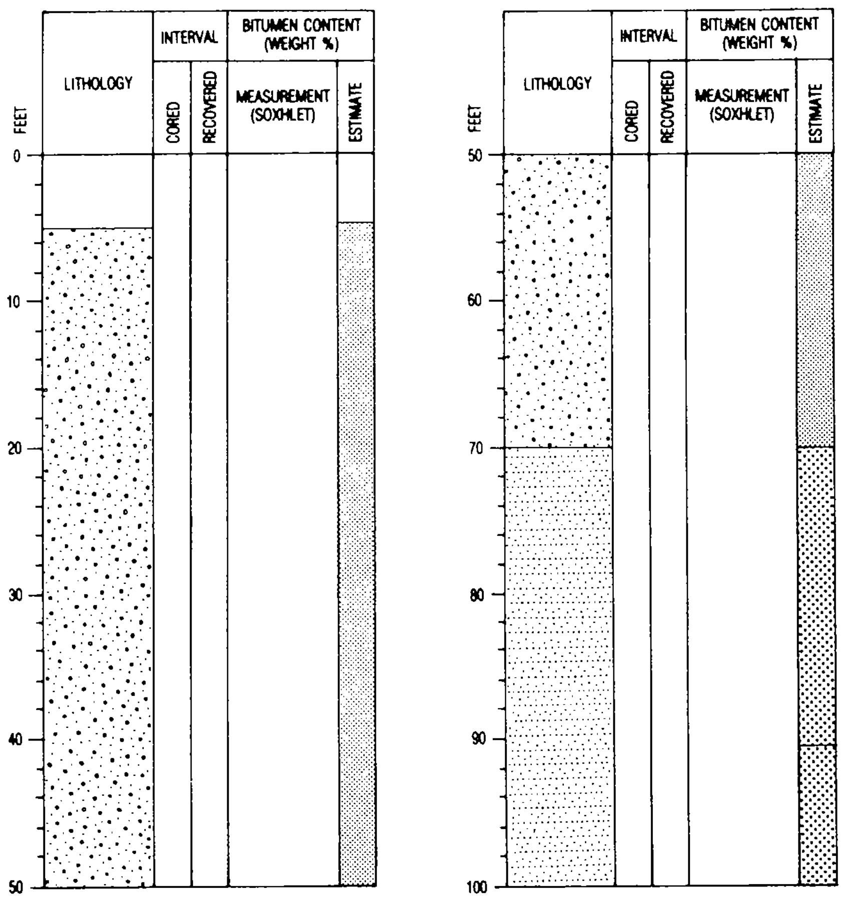
(Borehole 19, Fig. 4)

Murray County, Oklahoma

C NW¼SW¼SW¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 510.0 ft

(ft)	
0.0–5.0	Soil
5.0–70.0	Limestone pebble-cobble conglomerate, sand matrix, traces bitumen
70.0–180.0	Fine- to very fine-grained sandstone, tan, loose sand with numerous clumps of cemented grains 90.0–180.0 ft; moderate saturation 70.0–180.0 ft
180.0–410.0	Limestone, pale green, white, sandy, dense toward base; shale interbeds common, green calcareous; moderate saturation; at 320.0 ft shale 50–75%
410.0–510.0	Limestone, dense, finely crystalline, light-medium gray; no shale; traces bitumen



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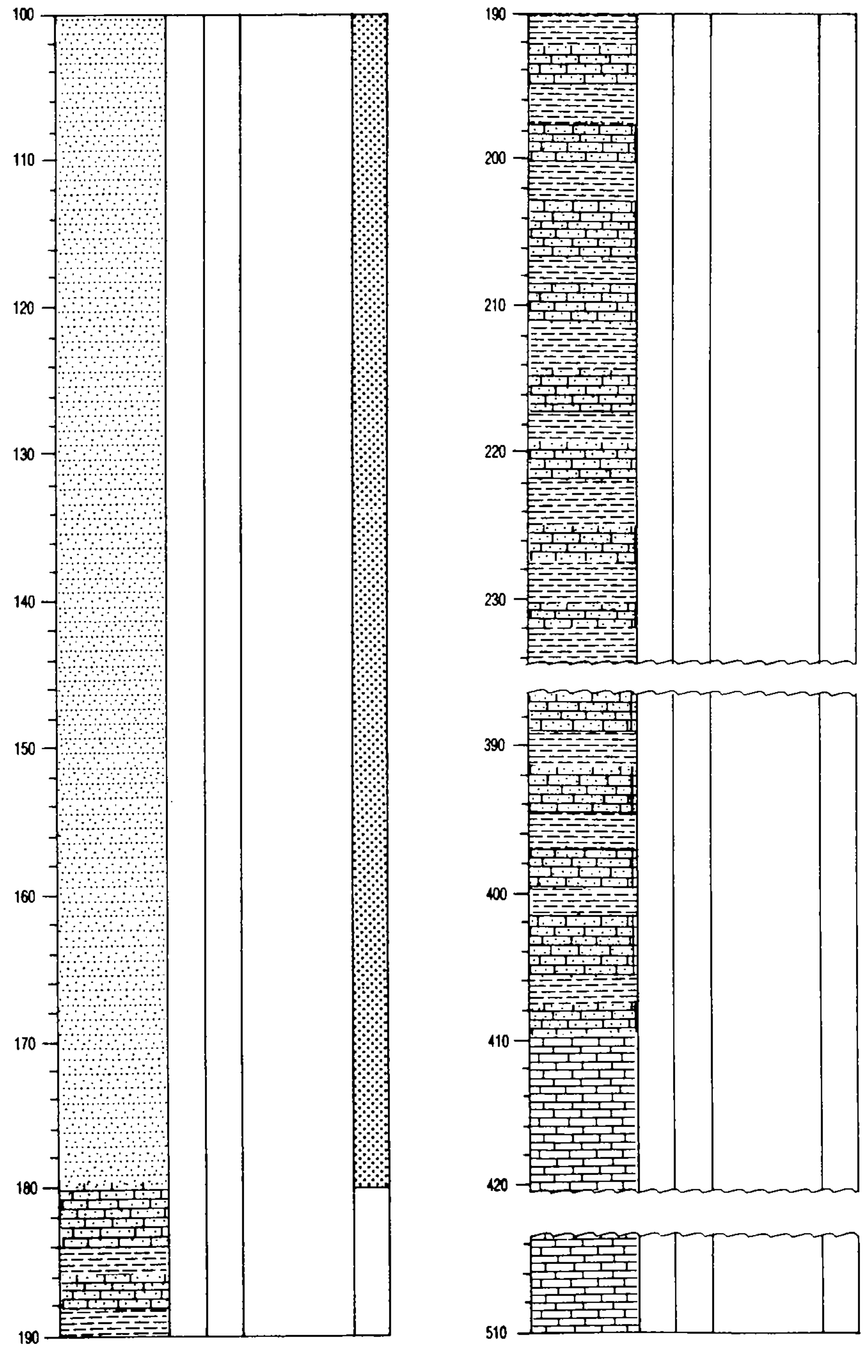
PWS 19 *(continued)*



PWS 22

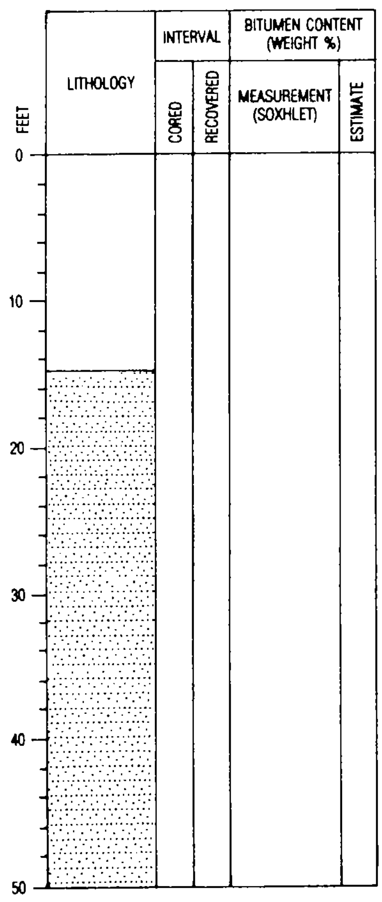
(Borehole 22, Fig. 4)

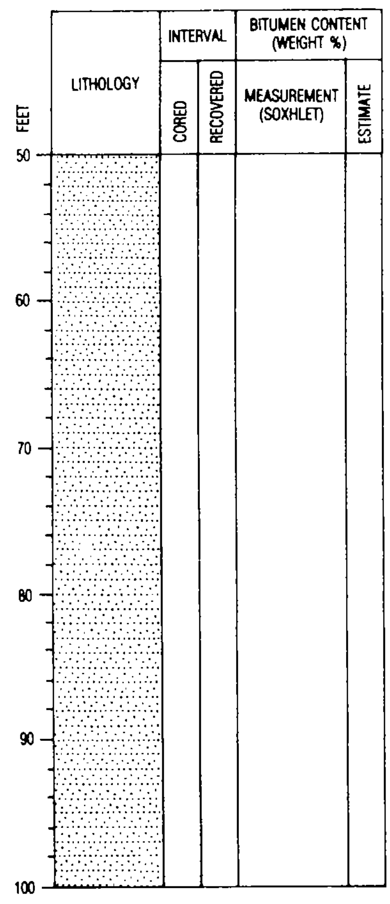
Murray County, Oklahoma

SW¼SW¼NW¼SE¼NE¼ sec. 21, T. 1 S., R. 3 E.

Total depth = 440.0 ft

(ft)	
0.0–15.0	Soil
15.0–120.0	Fine- to very fine-grained sandstone, rounded-subrounded, well sorted, tan, loose, clumps of carbonate-cemented sand, no bitumen or traces of bitumen in clumps; contains very thin layers of limestone, shale
120.0–350.0	Limestone, sandy, pale green; finely crystalline limestone; shale, green, calcareous, not as common here; tan color toward base; traces bitumen
350.0–440.0	Limestone, dense to finely crystalline, medium-gray; sand zones at 375.0–400.0 ft; 410.0–435.0 ft; no bitumen





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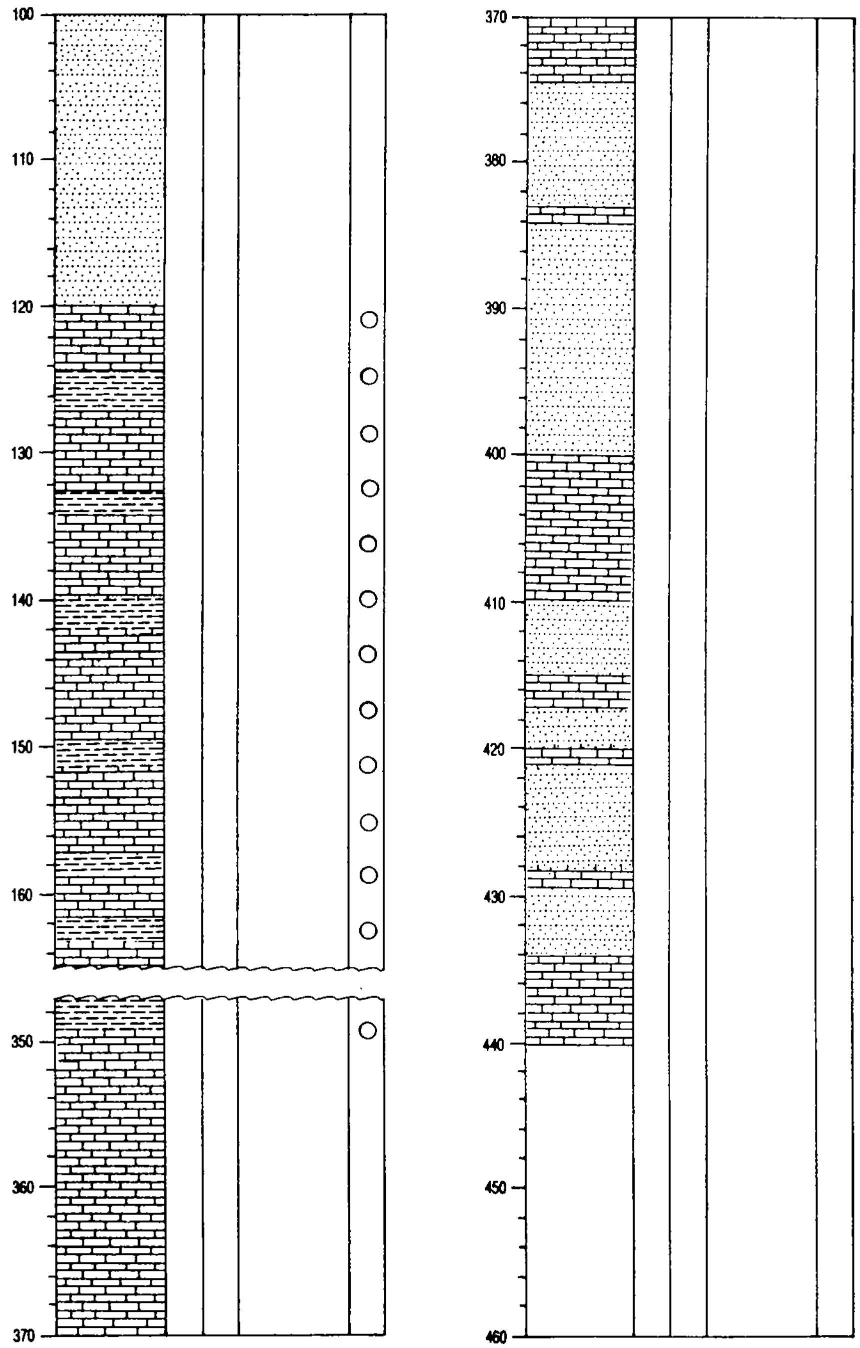
PWS 22 *(continued)*



PWS 23

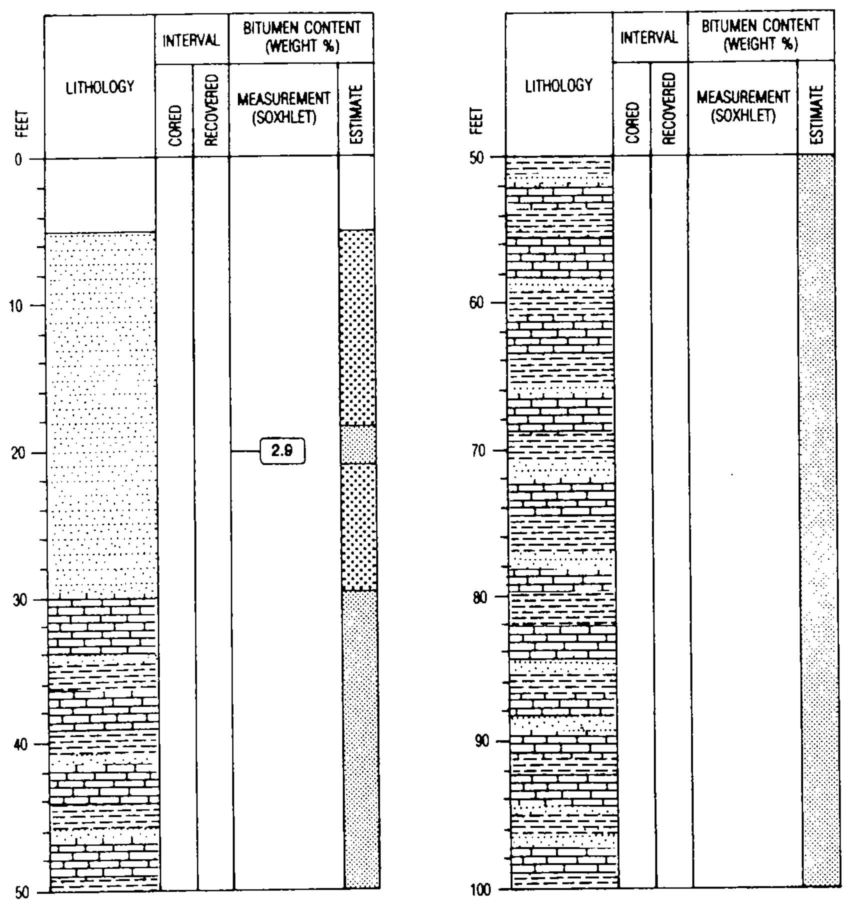
(Borehole 23, Fig. 4)

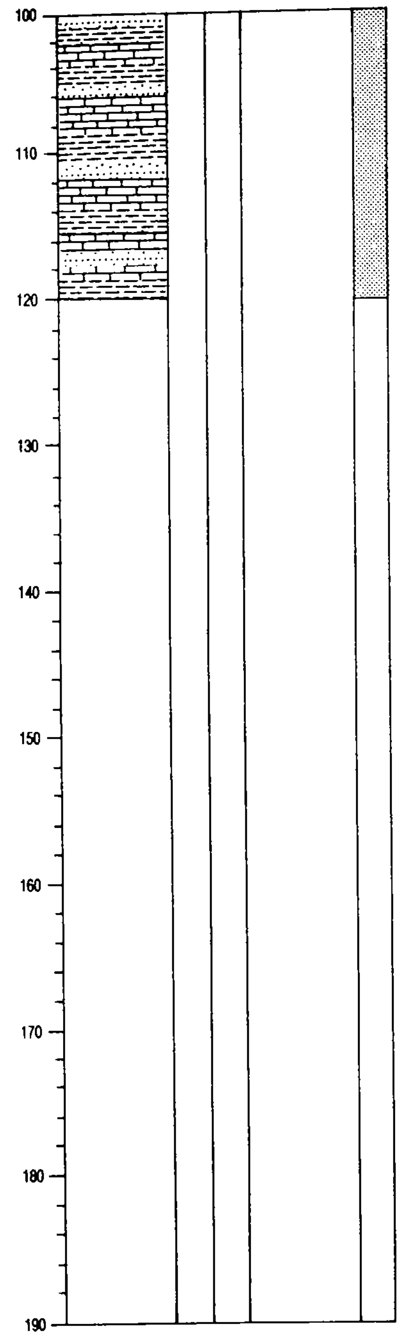
Murray County, Oklahoma

C NE¼SW¼NW¼NW¼ sec. 22, T. 1 S., R. 3 E.

Total depth = 120.0 ft

(ft)	
0.0–5.0	Soil
5.0–30.0	Fine- to very fine-grained sandstone, friable with carbonate cement, moderate saturation, 20.0–25.0 ft
30.0–120.0	Limestone, sandy, pale green to off-white; shale, green, calcareous, thin sand layers with slight saturation; traces bitumen throughout

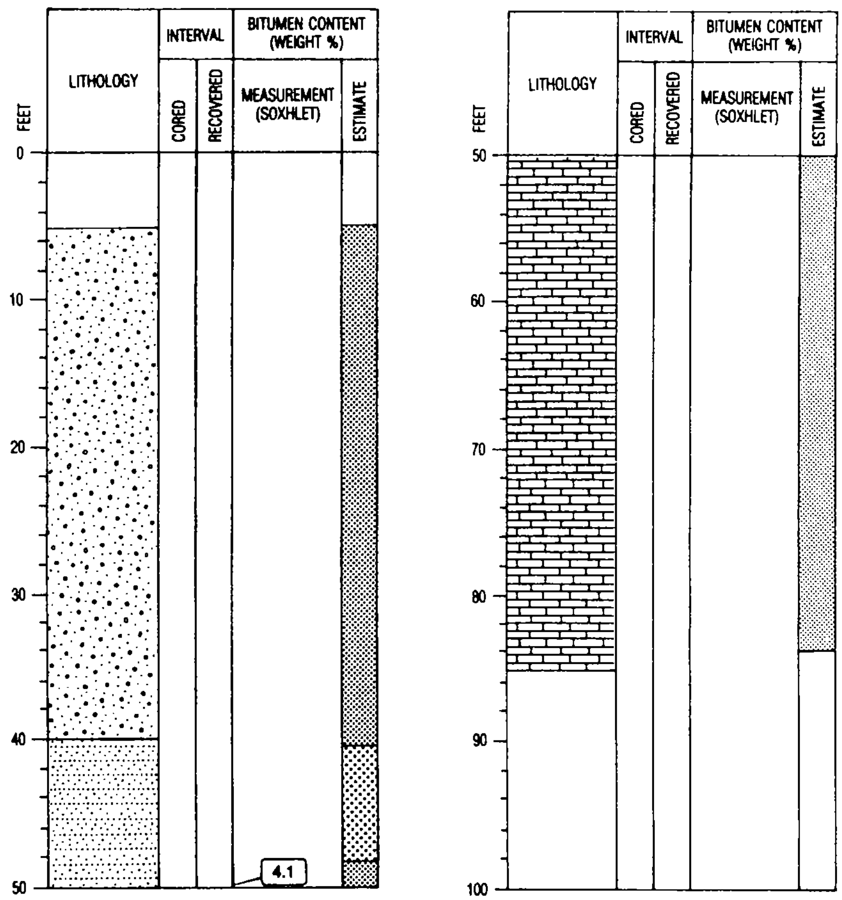




PWS 25

(Borehole 25, Fig. 4)
Murray County, Oklahoma
NW¼NW¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 85.0 ft

(ft)	
0.0–5.0	Soil
5.0–40.0	Limestone pebble-cobble conglomerate, dense, tan, light to medium gray; sand matrix, slight saturation
40.0–50.0	Fine- to very fine-grained sandstone, well sorted, loose; moderate saturation
50.0–85.0	Limestone, sandy, light brown to off-white; traces bitumen



PWS 26

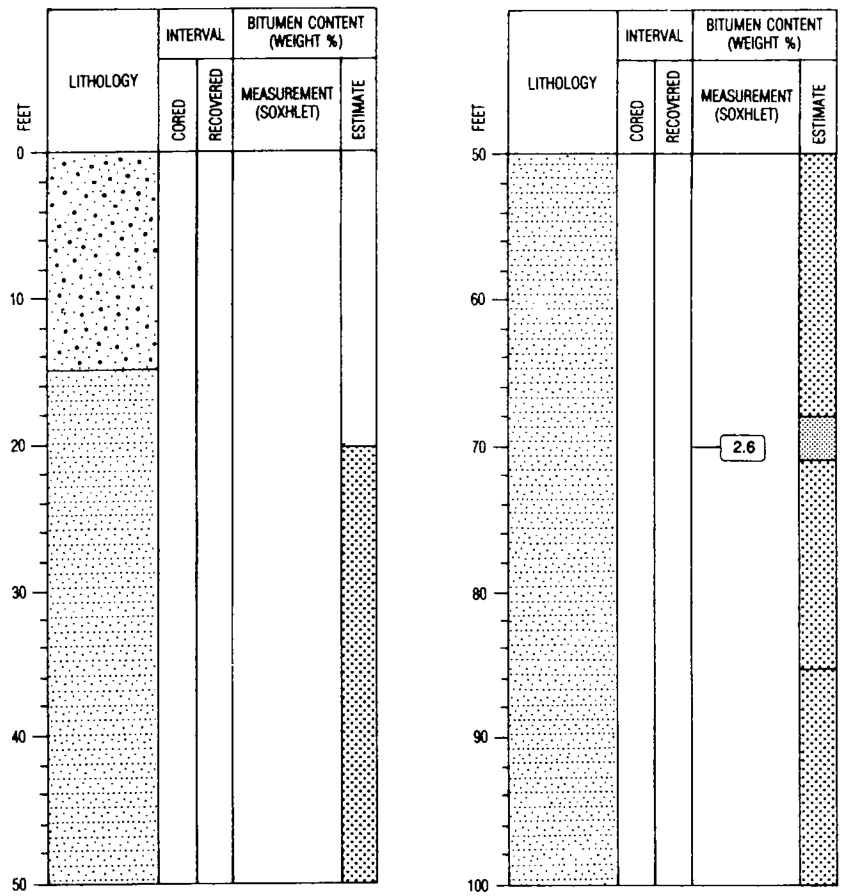
(Borehole 26, Fig. 4)

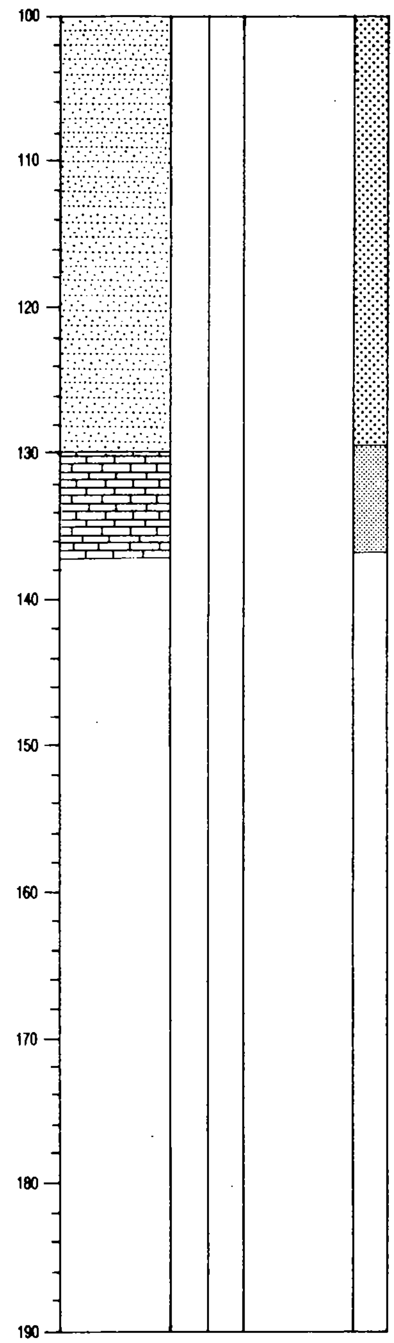
Murray County, Oklahoma

NE¼NE¼SW¼SW¼SW¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 137.0 ft

(ft)	
0.0–15.0	Limestone pebble-cobble conglomerate; no sand matrix, dense, tan, light to medium gray
15.0–130.0	Fine- to very fine-grained sandstone, well sorted, tan, loose; moderate saturation 20.0–85.0 ft; moderate saturation 85.0–130.0 ft
130.0–137.0	Limestone, sandy, pale green to off-white; traces bitumen

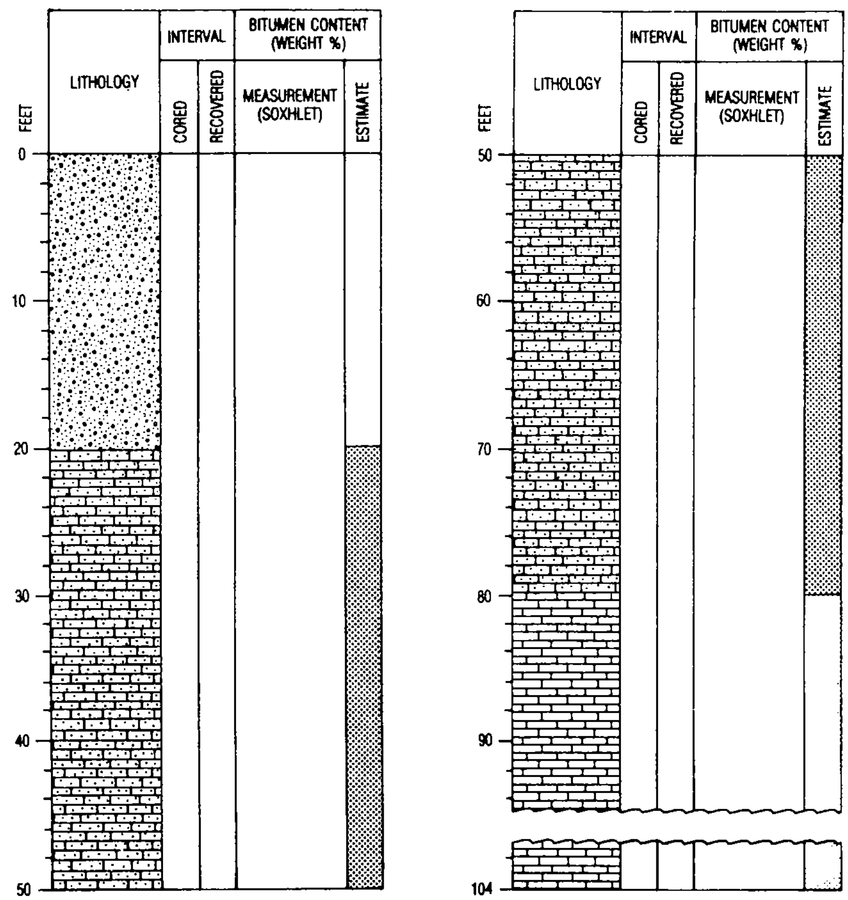




PWS 27

(Borehole 27, Fig. 4)
Murray County, Oklahoma
NE¼SW¼NE¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 104.0 ft

(ft)	
0.0–20.0	Limestone pebble-cobble conglomerate, tan to light brown, dense, no bitumen
20.0–80.0	Limestone, sandy, light to medium gray, finely crystalline toward base; sandier toward base; slight saturation
80.0–104.0	Limestone, sandy, medium to dark gray; no shale; traces bitumen



PWS 28

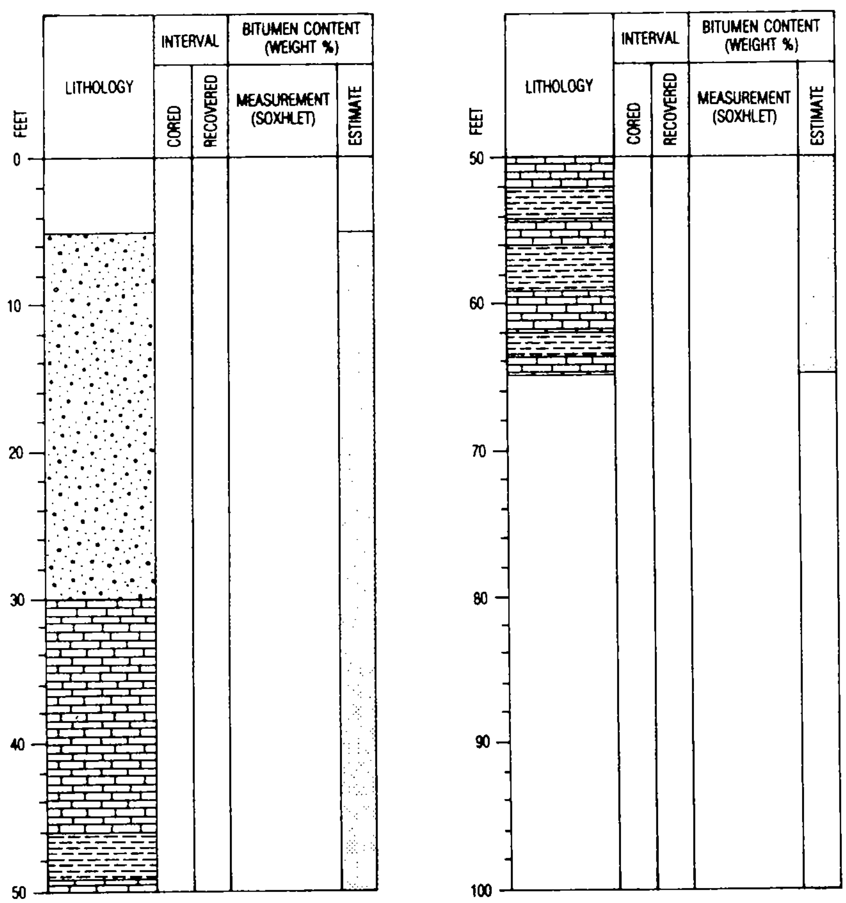
(Borehole 28, Fig. 4)

Murray County, Oklahoma

NE¼SE¼NE¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 65.0 ft

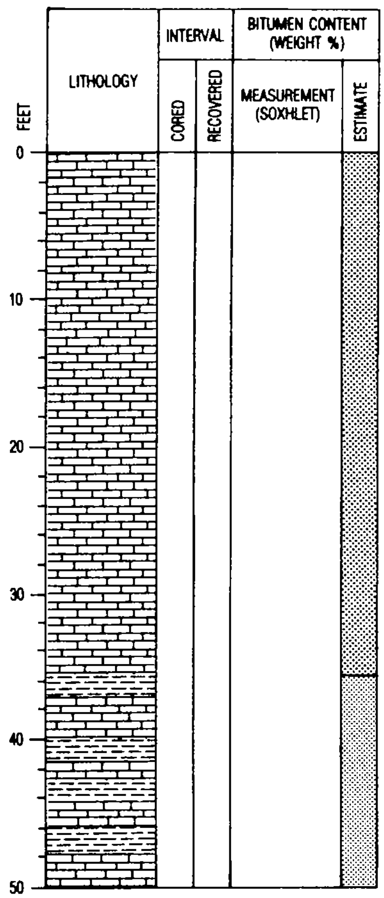
(ft)	
0.0–5.0	Soil
5.0–30.0	Limestone pebble-cobble conglomerate, light tan, light gray, dense, sandy, traces bitumen
39.0–45.0	Limestone, finely crystalline, light to medium gray, traces bitumen
45.0–65.0	Limestone, sandy, medium gray; shale, green, calcareous, 70%; traces bitumen



PWS 29

(Borehole 29, Fig. 4)
Murray County, Oklahoma
SW¼SE¼NW¼NE¼NW¼ sec. 22, T. 1 S., R. 3 E.
Total depth = 50.0 ft

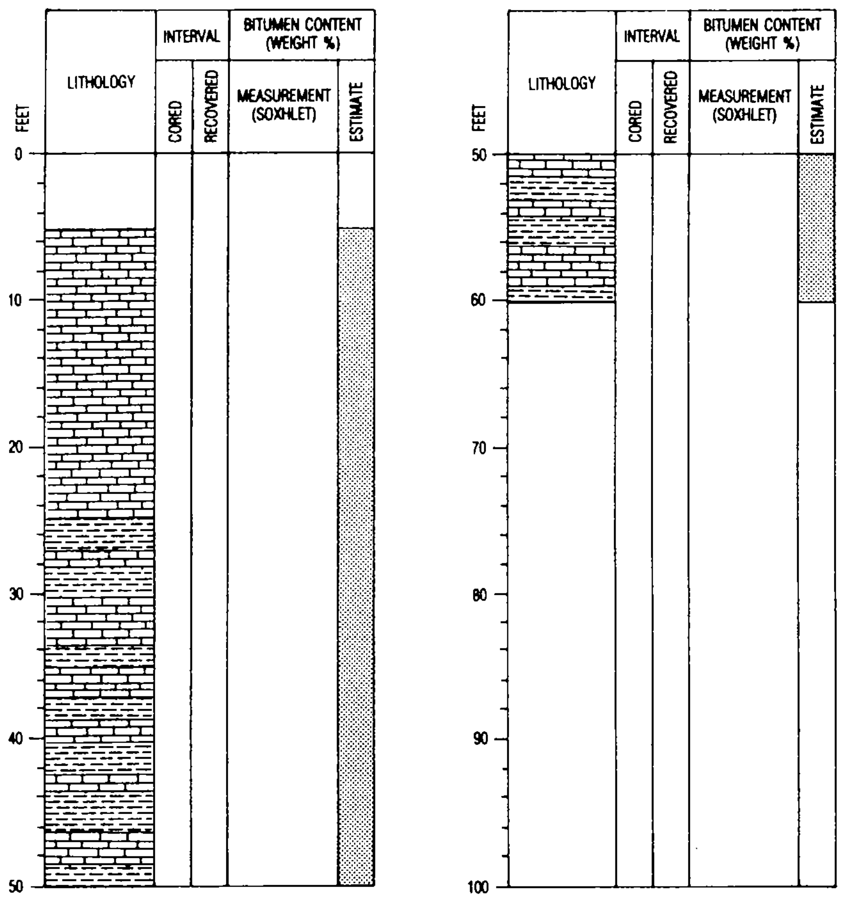
(ft)	
0.0–35.0	Limestone, sandy to finely crystalline, light brown at top, medium to dark gray, slight saturation
35.0–50.0	Limestone, sandy, light gray; shale, green, calcareous, traces bitumen



PWS 30

(Borehole 30, Fig. 4)
Murray County, Oklahoma
NE¼SE¼SE¼NW¼NW¼ sec. 22, T. 1 S., R. 3 E.
Total depth = 60.0 ft

(ft)	
0.0–5.0	Soil
5.0–20.0	Limestone, sandy, tan to light gray, traces bitumen
20.0–60.0	Limestone, sandy, grayish; shale, green calcareous, traces bitumen



D 1

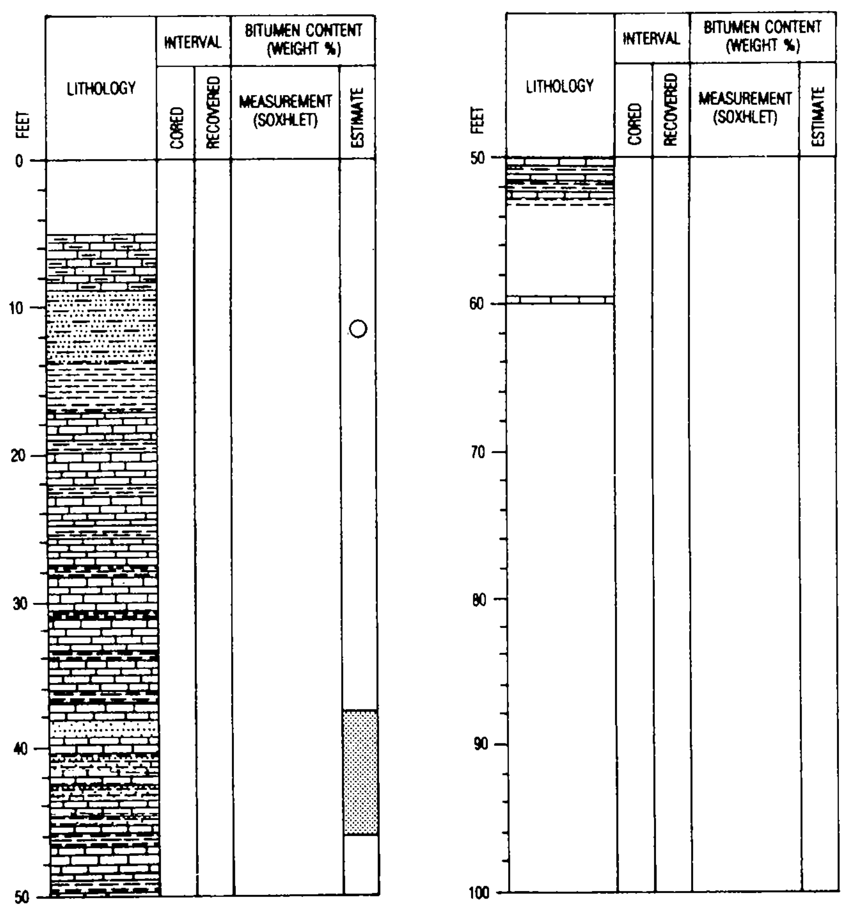
(Borehole 31, Fig. 4)

Murray County, Oklahoma

490 ft FNL, 2,150 ft FWL, sec. 22, T. 1 S., R. 3 E.

Total depth = 60.0 ft

(ft)	
0.0–5.0	Drilled
5.0–52.5	Cored, recovered 5.0–52.5 ft
5.0–9.0	Brown crystalline limestone and mud
9.9–14.0	Fine sandstone with trace of shale
14.0–16.5	Gray shale
16.5–18.0	Green shale with fractured limestone
18.0–22.5	Gray-green shale with thin limestone layers
22.5–37.5	Highly fractured green-gray shale and limestone
37.5–40.5	Fractured limestone with sandstone stringers
40.5–45.0	Gray-green calcareous shale with sandstone stringers
45.0–52.5	Gray-brown limestone and gray-brown shale
52.5–60.0	Cored, recovered 59.5–60.0 ft
59.5–60.0	Gray-brown fine crystalline limestone

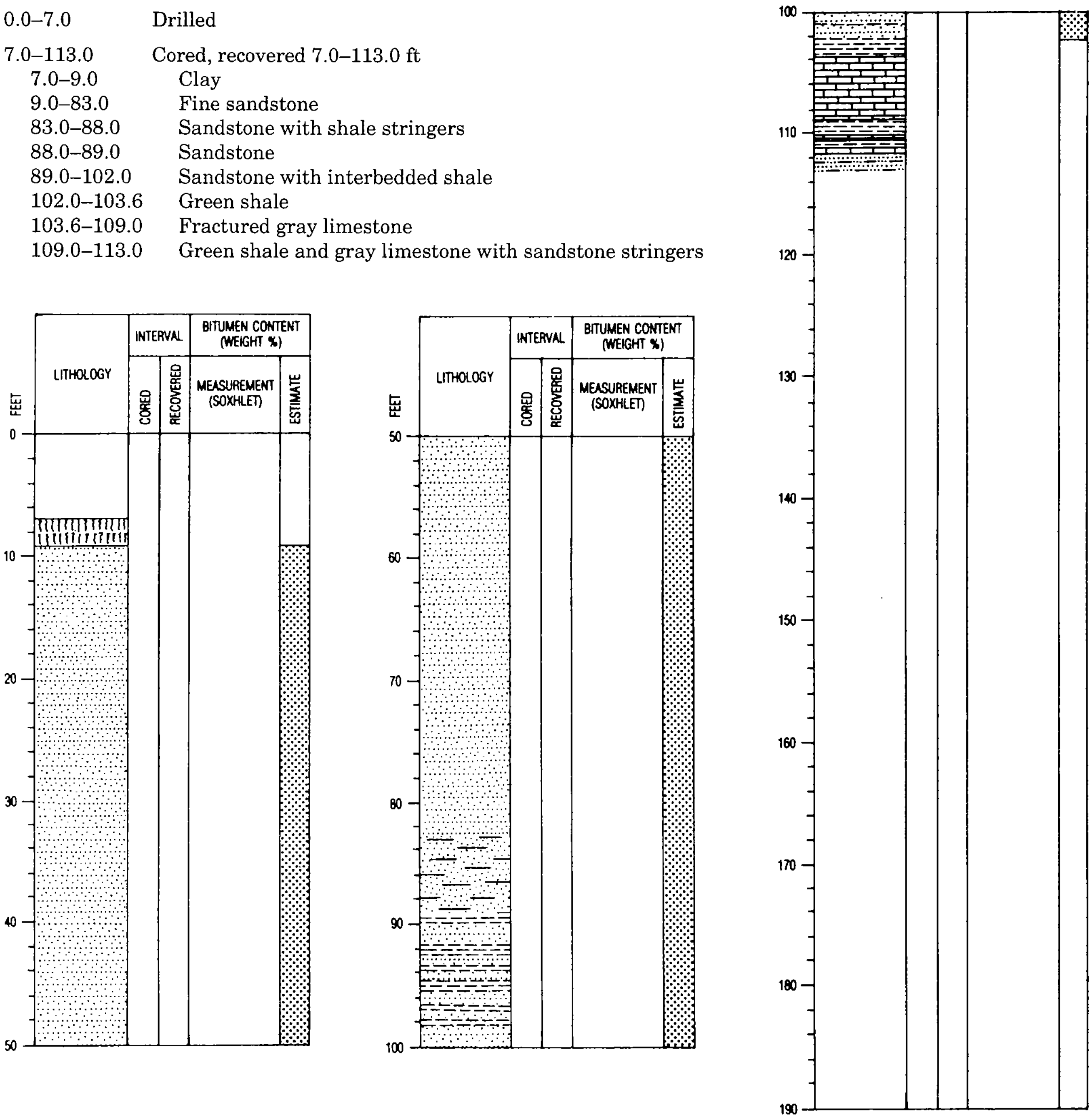


D 2

(Borehole 32, Fig. 4)

Murray County, Oklahoma
1,150 ft FNL, 2,450 ft FWL, sec. 22, T. 1 S., R. 3 E.
Total depth = 113.0 ft

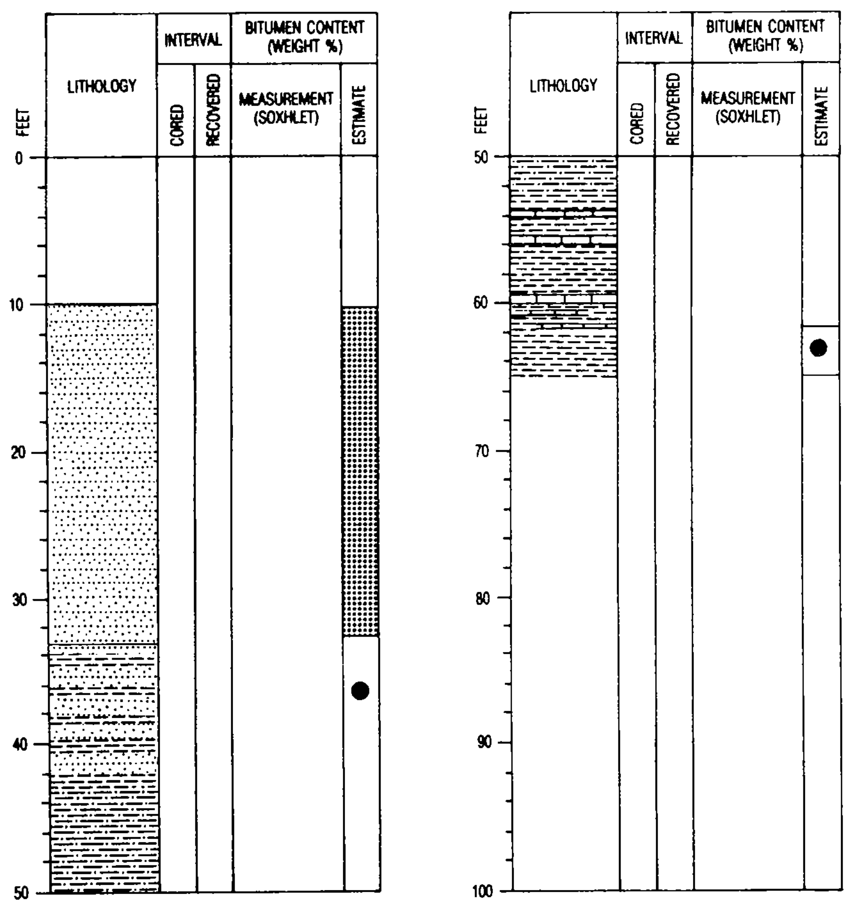
(ft)	
0.0–7.0	Drilled
7.0–113.0	Cored, recovered 7.0–113.0 ft
7.0–9.0	Clay
9.0–83.0	Fine sandstone
83.0–88.0	Sandstone with shale stringers
88.0–89.0	Sandstone
89.0–102.0	Sandstone with interbedded shale
102.0–103.6	Green shale
103.6–109.0	Fractured gray limestone
109.0–113.0	Green shale and gray limestone with sandstone stringers



D 3

(Borehole 33, Fig. 4)
Murray County, Oklahoma
1,185 ft FNL, 2,150 ft FWL, sec. 22, T. 1 S., R. 3 E.
Total depth = 65.0 ft

(ft)	
0.0–10.0	Drilled
10.0–65.0	Cored, recovered 10.0–65.0 ft
10.0–33.0	Fine-grained sandstone, well rounded and well sorted
33.0–42.0	Jumbled fine sandstone and green calcareous shale
42.0–52.5	Green calcareous shale with laminae of fine glauconitic sandstone
52.5–62.5	Green calcareous shale with lenses of fractured limestone
62.5–65.0	Gray shale



D 4

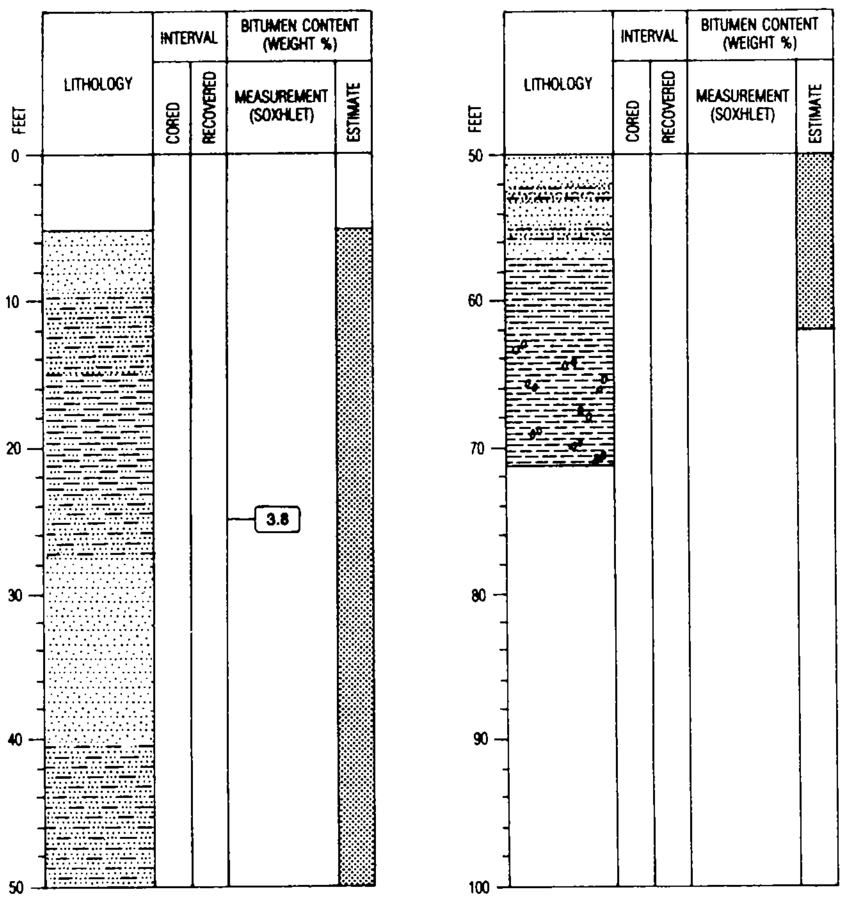
(Borehole 34, Fig. 4)

Murray County, Oklahoma

1,150 ft FNL, 1,500 ft FWL, sec. 22, T. 1 S., R. 3 E.

Total depth = 71.5 ft

(ft)	
0.0–5.0	Drilled
5.0–71.5	Cored, recovered 5.0–71.5 ft
5.0–9.0	Fine sandstone, well sorted and rounded
9.0–15.0	Sandstone with shale stringers
15.0–22.0	Gray shale and siltstone with sandstone stringers
22.0–24.0	Fractured tan, fine-grained sandstone with shale stringers
24.0–28.0	Sandstone with shale stringers
28.0–40.0	Fine sandstone
40.0–57.0	Fine sandstone with shale stringers
57.0–58.0	Green shale with sandstone stringers
58.0–62.0	Fractured green shale with sandstone in fractures
62.0–71.5	Green shale with limestone pebbles

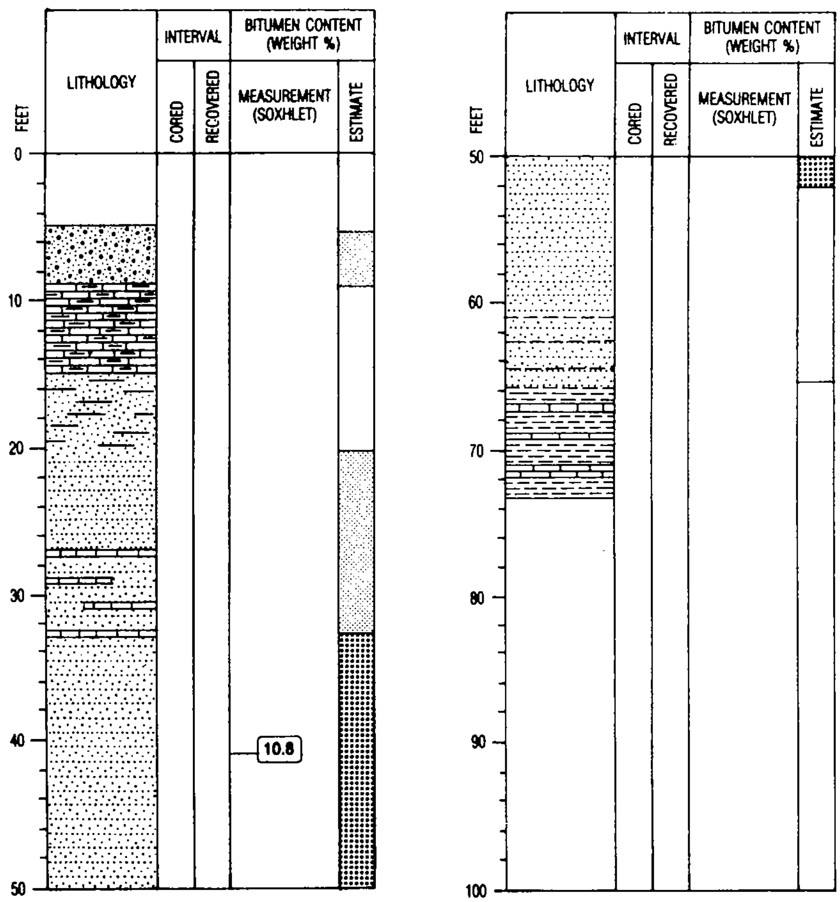


D 6

(Borehole 35, Fig. 4)

Murray County, Oklahoma
800 ft FSL, 1,500 ft FWL, sec. 15, T. 1 S., R. 3 E.
Total depth = 73.5 ft

(ft)	
0.0–5.0	Drilled
5.0–73.5	Cored, recovered 5.0–73.5 ft
5.0–9.0	Limestone conglomerate with sandy matrix
9.0–15.0	Very fine-grained argillaceous limestone
15.0–20.0	Argillaceous sandstone
20.0–61.0	Fine-grained sandstone with some limestone stringers
61.0–65.0	Fine sandstone with interbedded dark brownish-green shale
65.0–73.5	Green shale with thin layers of white to gray limestone

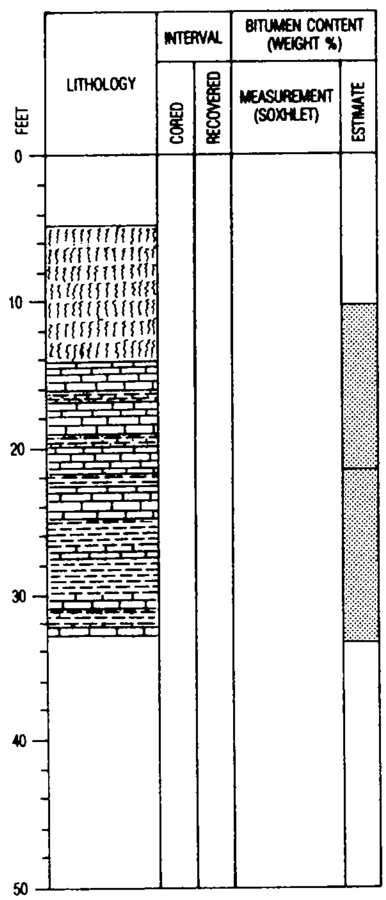


D 7

(Borehole 36, Fig. 4)

Murray County, Oklahoma
500 ft FNL, 2,500 ft FWL, sec. 22, T. 1 S., R. 3 E.
Total depth = 30.0 ft

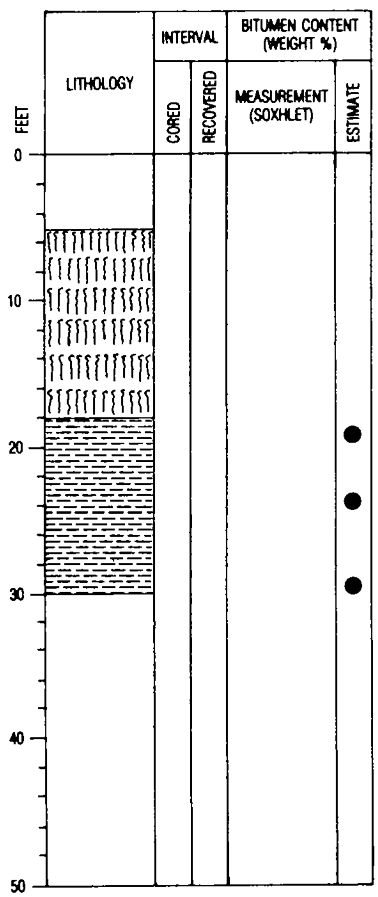
(ft)	
0.0–5.0	Drilled
5.0–14.0	Cored, recovered 5.0–14.0 ft
5.0–14.0	Clay
14.0–25.0	Cored, recovered 14.0–25.0 ft
14.0–25.0	Fractured limestone with shale stringers, shale and sandstone in fractures
25.0–33.0	Cored, recovered 25.0–33.0 ft
25.0–33.0	Green shale with limestone stringers



D 10

(Borehole 37, Fig. 4)
Murray County, Oklahoma
820 ft FNL, 2,500 ft FWL, sec. 22, T. 1 S., R. 3 E.
Total depth = 30.0 ft

(ft)	
0.0–5.0	Drilled
5.0–18.0	Cored, recovered 5.0–18.0 ft
5.0–18.0	Clay (soil)
18.0–30.0	Cored, recovered 18.0–30.0 ft
18.0–30.0	Green calcareous shale, bitumen stains in fractures



KM 1

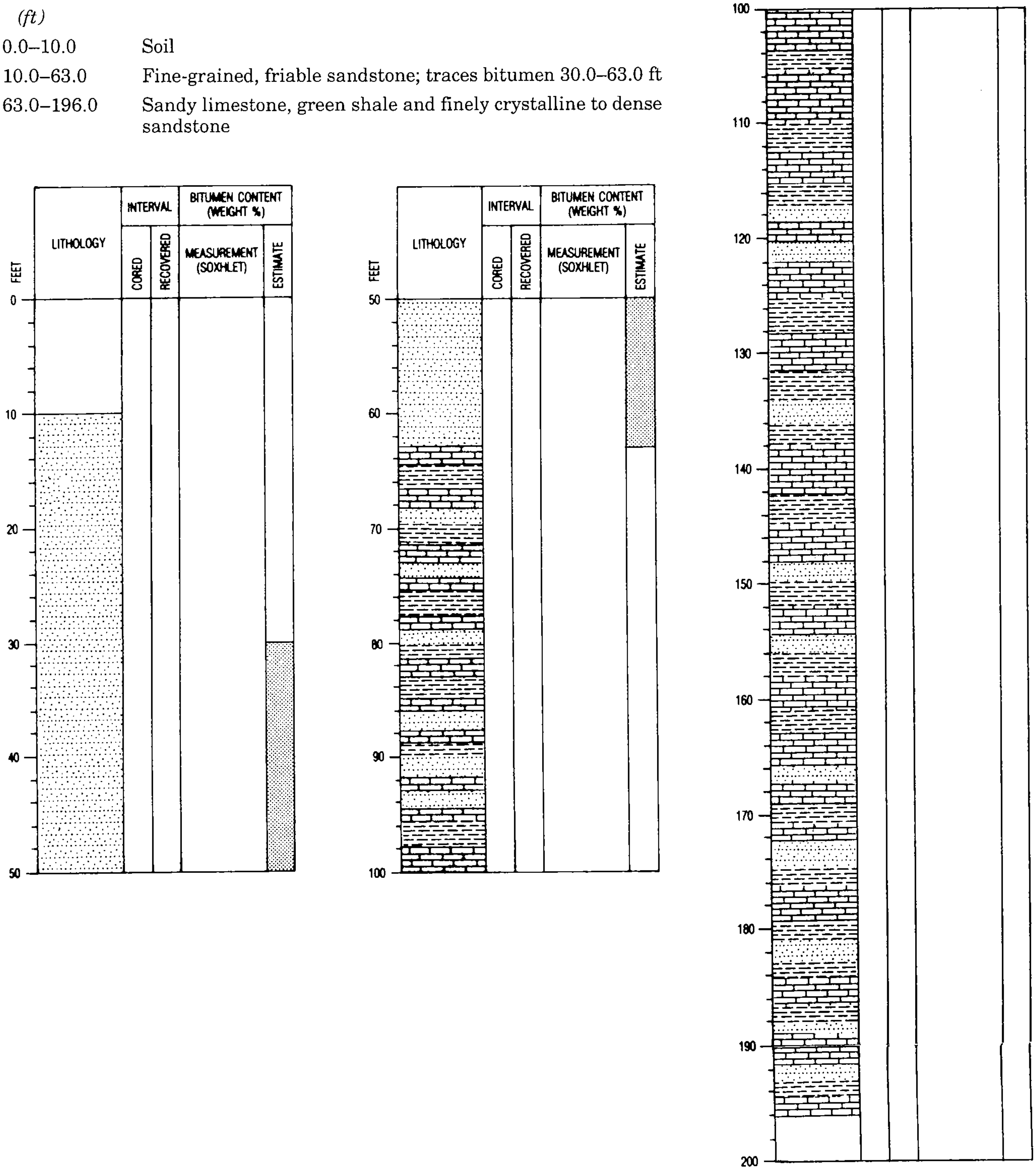
(Borehole 38, Fig. 4)

Murray County, Oklahoma

SE¼NE¼NE¼NE¼ sec. 21, T. 1 S., R. 3 E.

Total depth = 196.0 ft

(ft)	
0.0–10.0	Soil
10.0–63.0	Fine-grained, friable sandstone; traces bitumen 30.0–63.0 ft
63.0–196.0	Sandy limestone, green shale and finely crystalline to dense sandstone



KM 2A

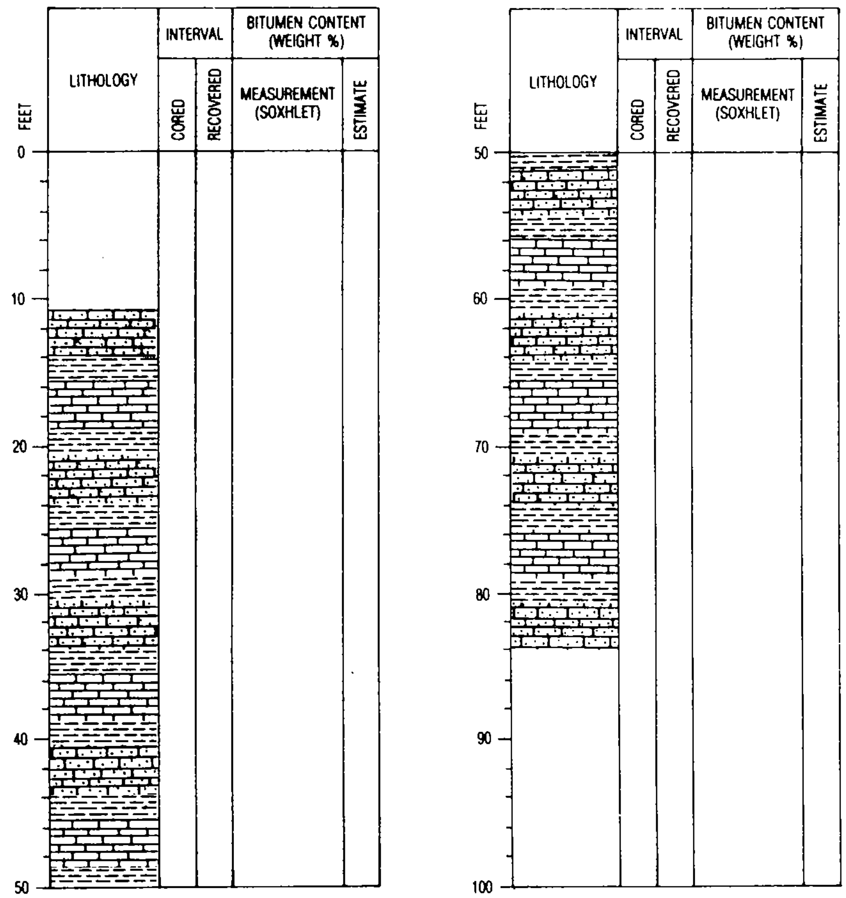
(Borehole 39, Fig. 4)

Murray County, Oklahoma

NE¼SW¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 84.0 ft

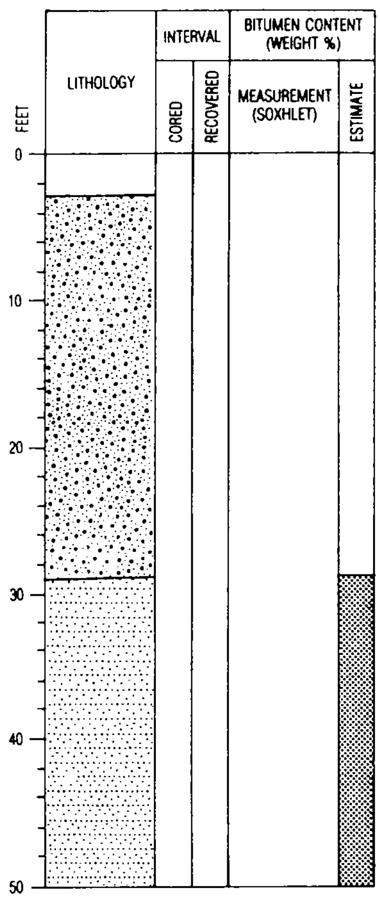
(ft)	
0.0–11.0	Soil
11.0–84.0	Sandy limestone, green shale and finely crystalline limestone

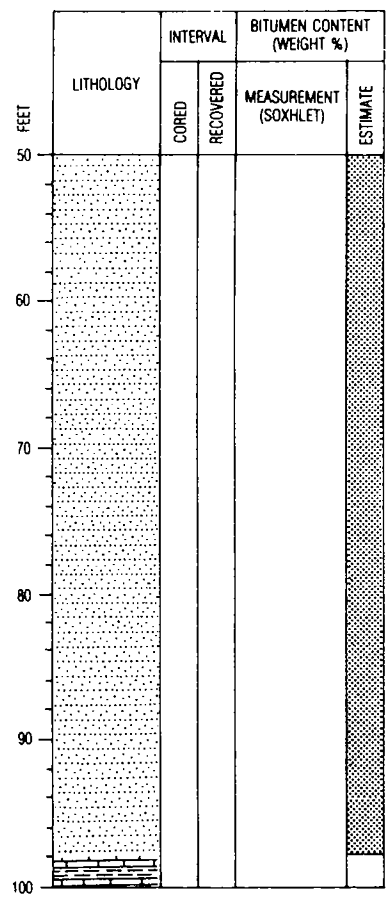


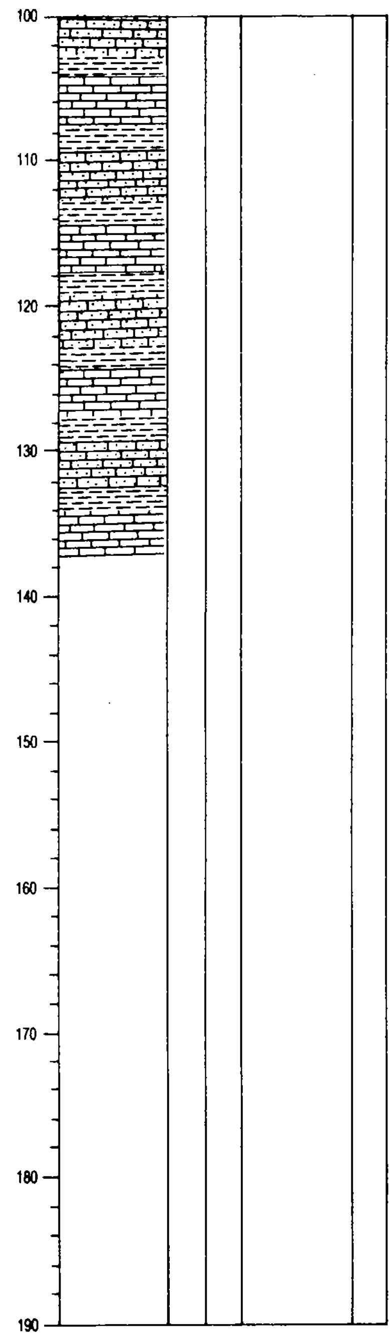
KM 3A

(Borehole 40, Fig. 4)
Murray County, Oklahoma
NE¼SW¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 137.0 ft

(ft)	
0.0–3.0	Soil
3.0–29.5	Conglomerate
29.5–98.0	Saturated asphaltic sandstone, moderate saturation
98.0–137.0	Limestone, shale, sandy limestone



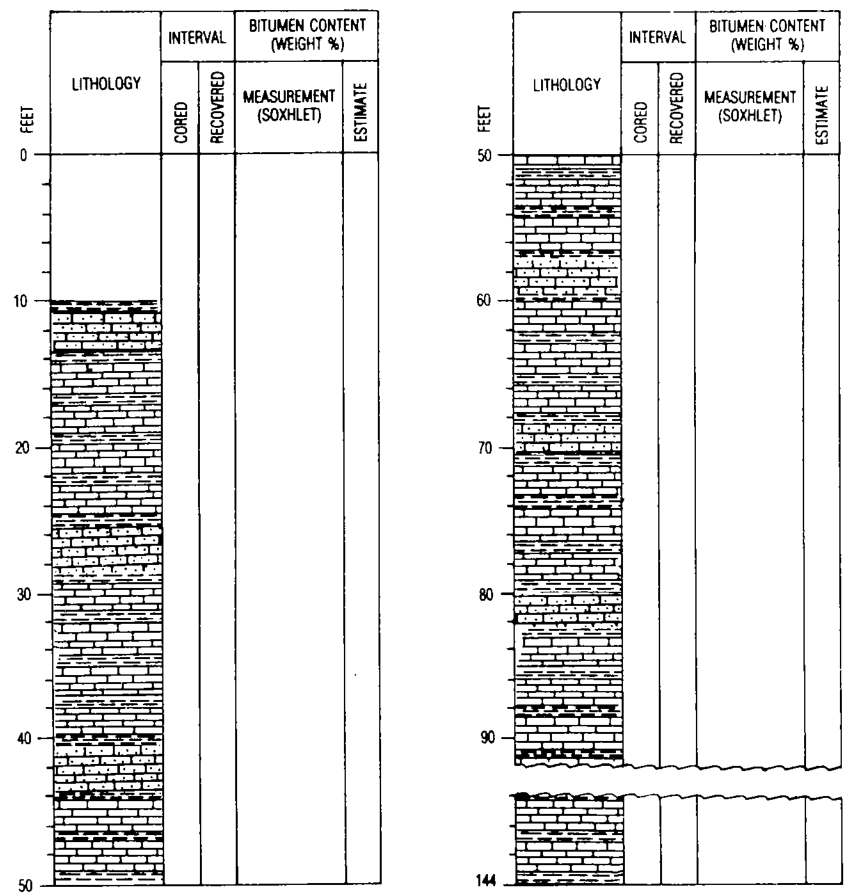




KM 4

(Borehole 41, Fig. 4)
Murray County, Oklahoma
SW¼NW¼NW¼NE¼ sec. 22, T. 1 S., R. 3 E.
Total depth = 144.0 ft

(ft)	
0.0–10.0	Soil
10.0–144.0	Sandy limestone, green shale, finely crystalline limestone

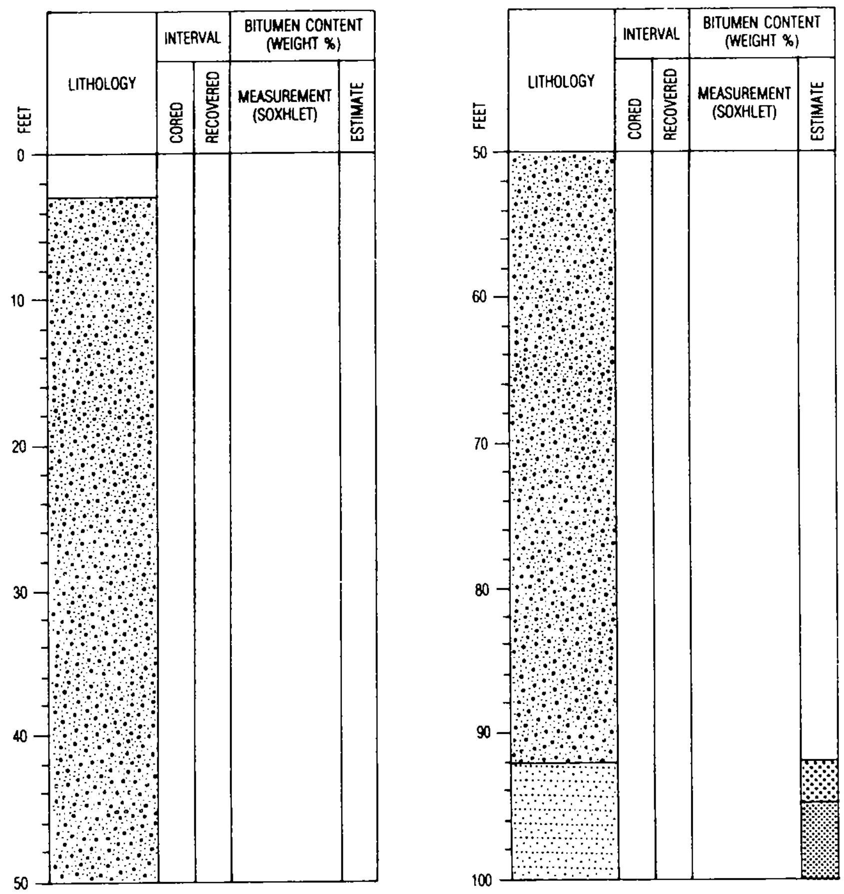


KM 5A

(Borehole 42, Fig. 4)

Murray County, Oklahoma
C SE¼SE¼ sec. 16, T. 1 S., R. 3 E.
Total depth = 292.0 ft

(ft)	
0.0–3.0	Soil
3.0–91.0	Limestone conglomerate, sandy matrix
91.0–249.0	Fine saturation, light to moderate bitumen stain throughout, good saturation 91.0–93.0 ft
249.0–292.0	Limestone, shale, and sandy limestone



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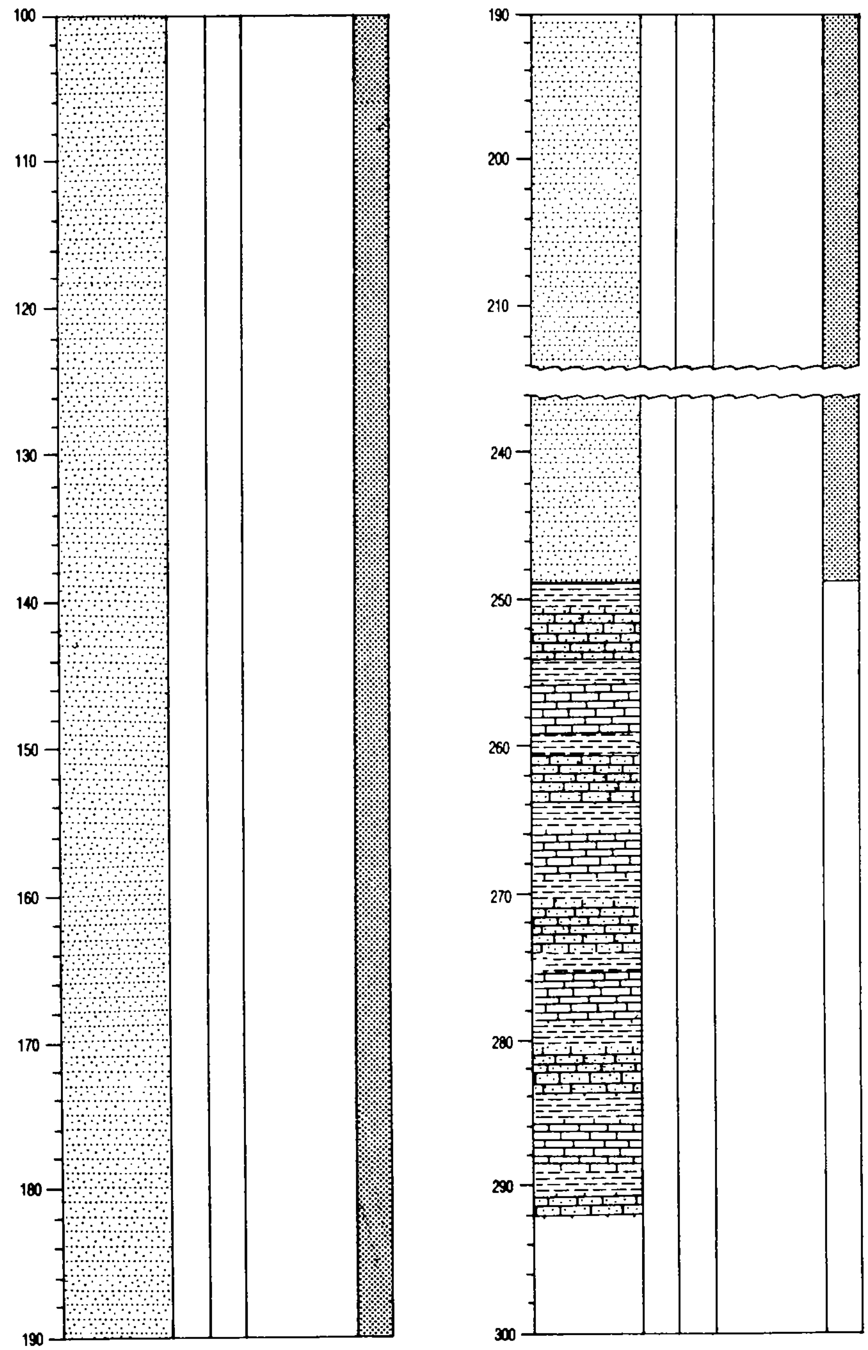
KM 5A *(continued)*



KM 6A

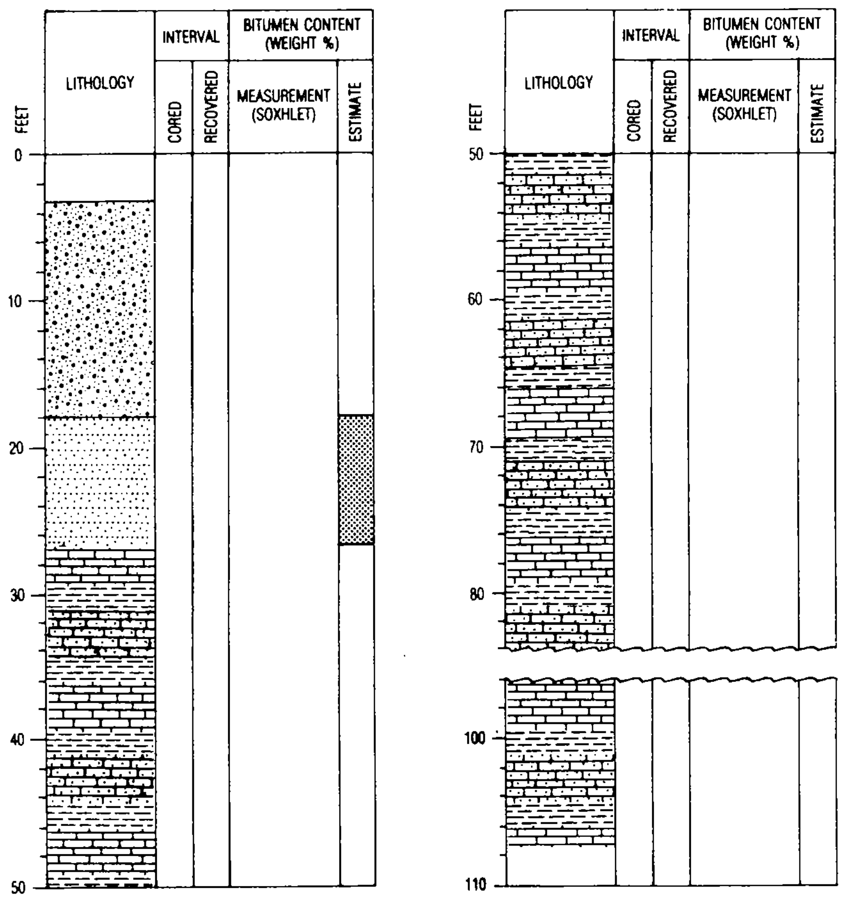
(Borehole 43, Fig. 4)

Murray County, Oklahoma

NE¼NE¼SW¼SE¼ sec. 15, T. 1 S., R. 3 E.

Total depth = 107.0 ft

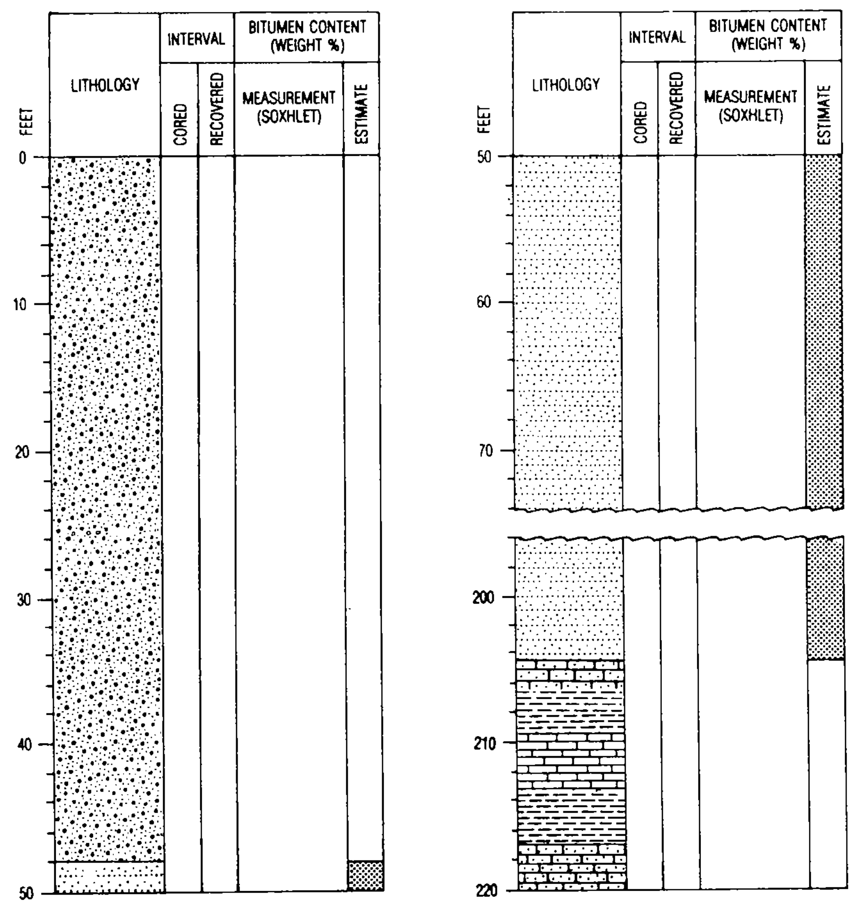
(ft)	
0.0–3.0	Soil
3.0–18.0	Limestone conglomerate, sandy matrix
18.0–26.5	Fine sandstone, bitumen saturated
26.5–107.0	Limestone, sandy limestone, and shale



KM 7

(Borehole 44, Fig. 4)
Murray County, Oklahoma
NE¼NE¼SW¼NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 220.0 ft

(ft)	
0.0–48.0	Limestone conglomerate
48.0–205.0	Fine sandstone, fair to good bitumen saaturation 48.0–68.0 ft, light to mediuim saturation 68.0–205.0 ft
205.0–220.0	Limestone, shale, and sandy limestone

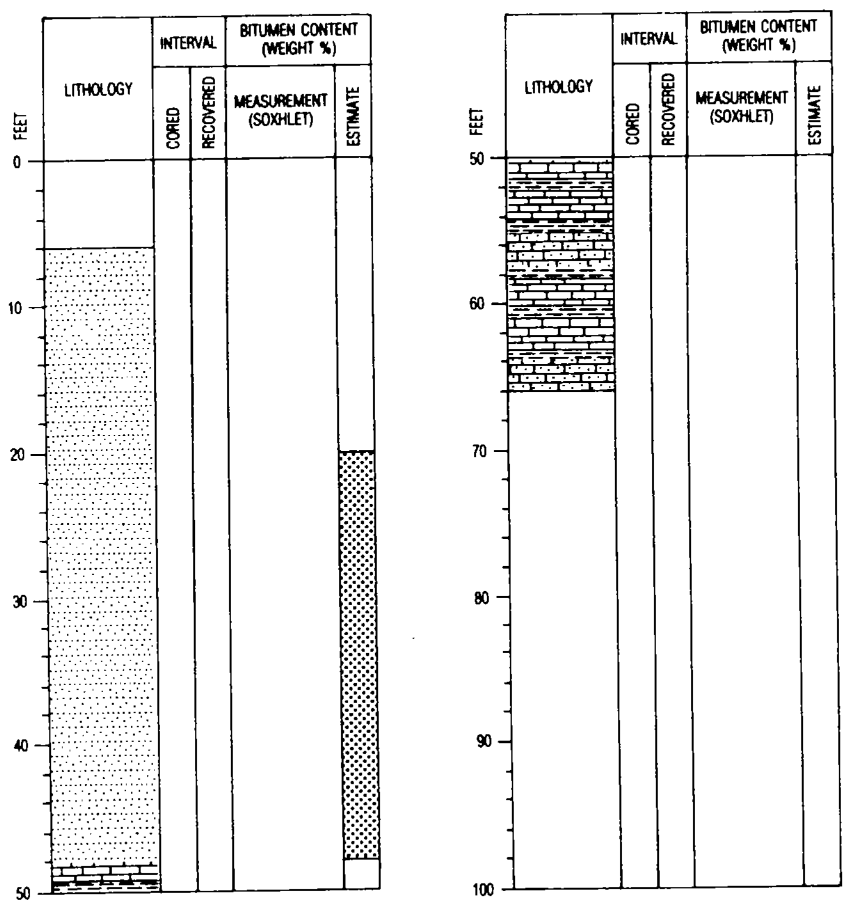


KM 8

(Borehole 45, Fig. 4)

Murray County, Oklahoma
NW¼SW¼SE¼NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 66.0 ft

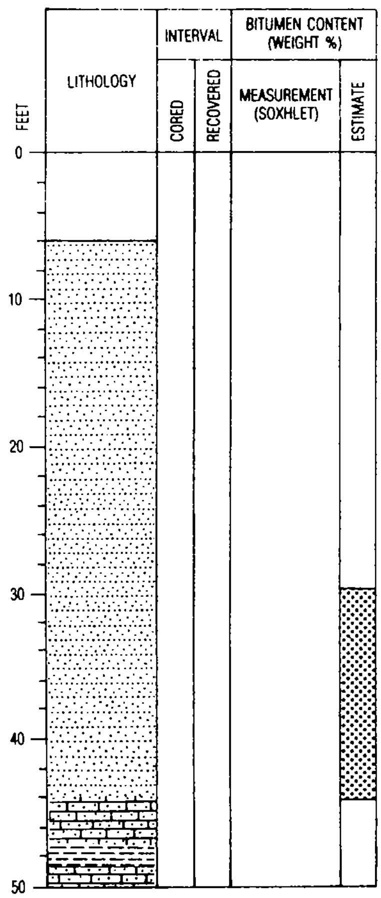
(ft)	
0.0–6.0	Soil
6.0–48.5	Fine white sandstone, fair to good saturation 20.0–48.5 ft
48.5–66.0	Limestone, shale, and sandy limestone

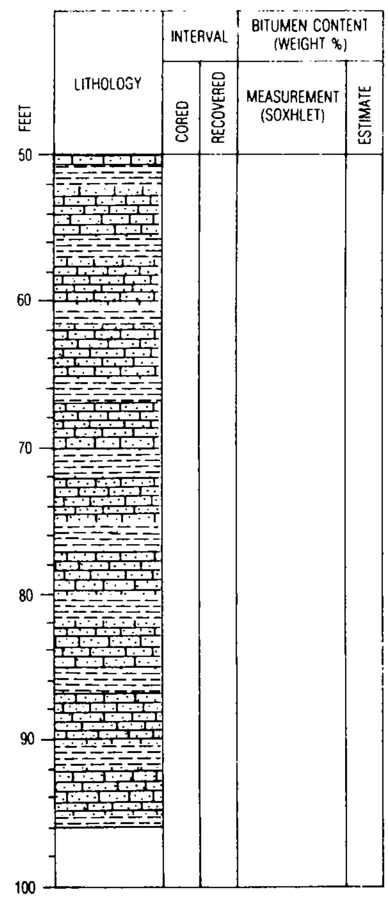


KM 9

(Borehole 46, Fig. 4)
Murray County, Oklahoma
C of E Line, SE¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 96.0 ft

(ft)	
0.0–6.0	Soil
6.0–44.0	Calcareous sandstone, moderate saturation 30.0–44.0 ft
44.0–96.0	Green shale and sandy limestone



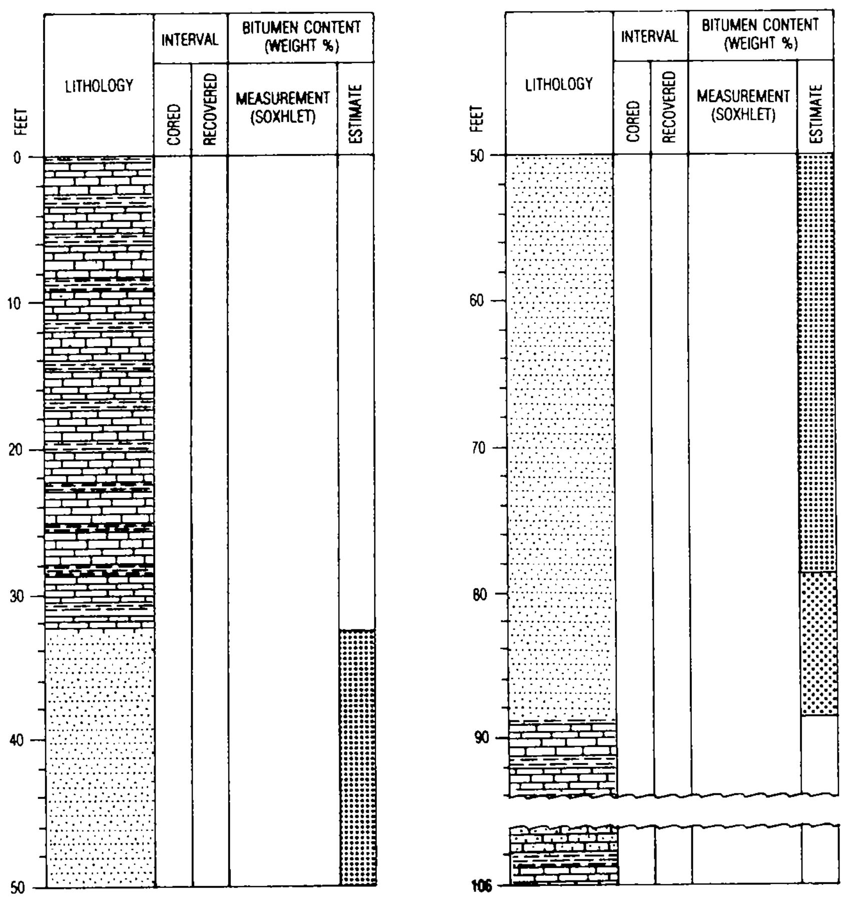


KM 10

(Borehole 47, Fig. 4)

Murray County, Oklahoma
C of S Line, SE¼SE¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 106.0 ft

(ft)	
0.0–33.0	Limestone with green shale
33.0–89.0	Fine sandstone, excellent saturation 33.0–79.0 ft, good saturation 79.0–89.0 ft
89.0–106.0	Limestone, shale, and sandy limestone



KM 11

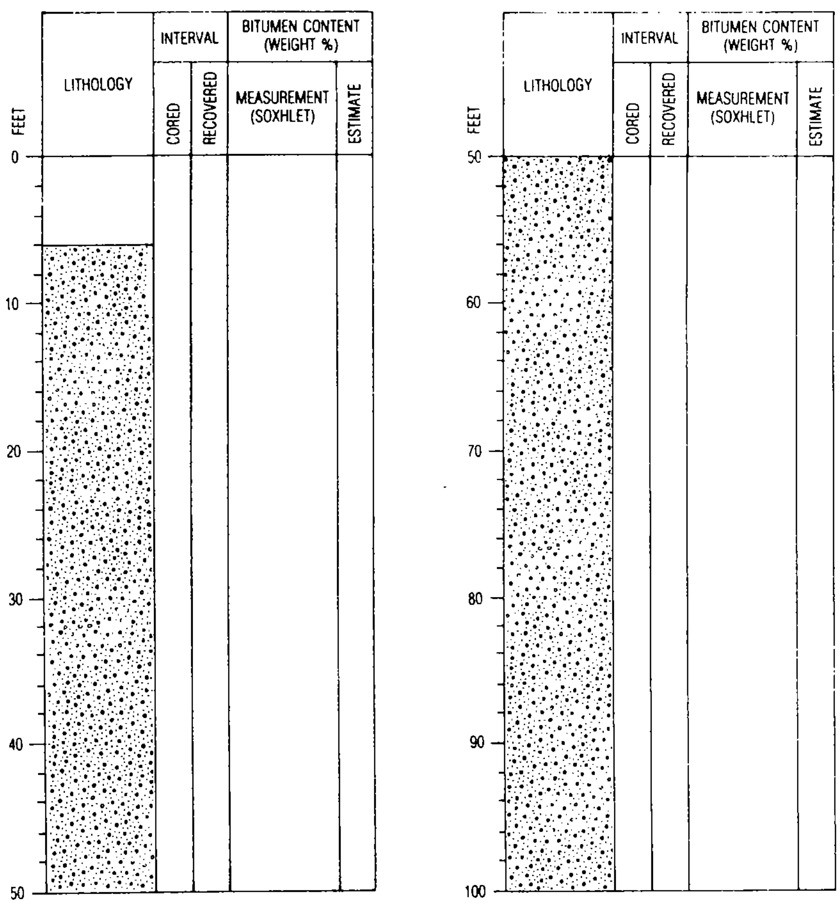
(Borehole 48, Fig. 4)

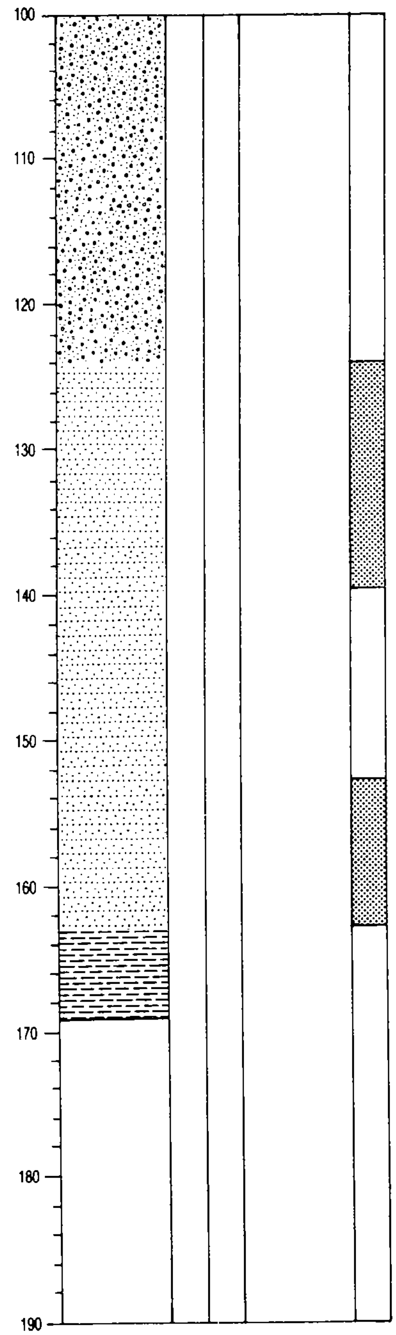
Murray County, Oklahoma

C of W Line, SW¼NW¼NE¼ sec. 21, T. 1 S., R. 3 E.

Total depth = 169.0 ft

(ft)	
0.0–6.0	Soil
6.0–124.0	Limestone conglomerate
124.0–163.0	Fine sandstone, fair to good saturation 124.0–140.0 ft and 153.0–163.0 ft
163.0–169.0	Green shale

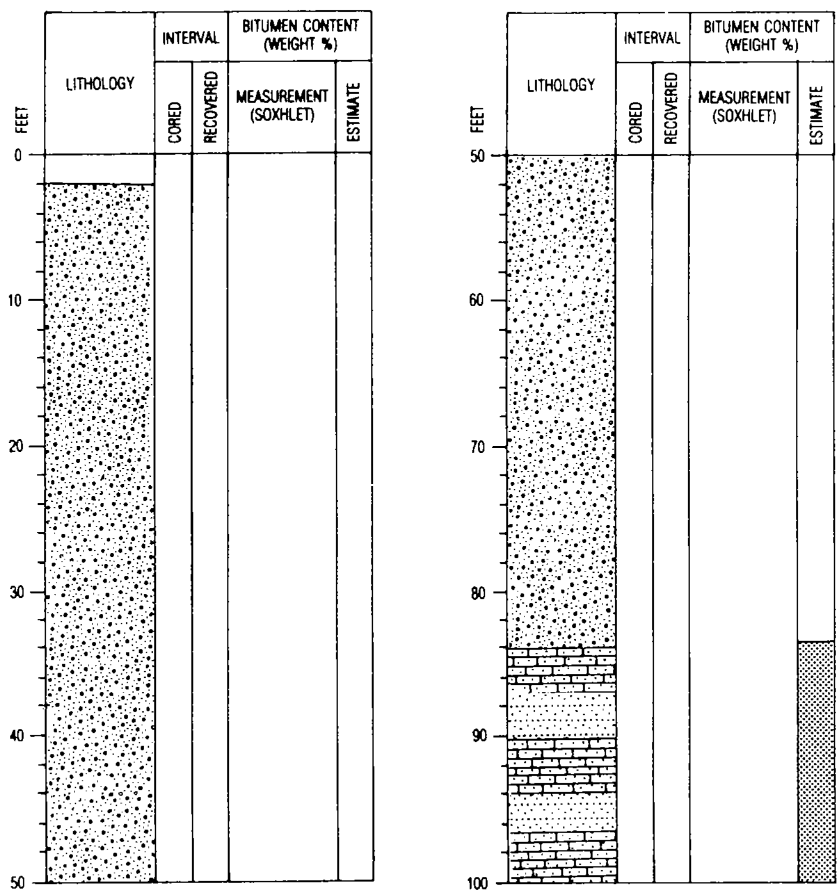




KM 12

(Borehole 49, Fig. 4)
Murray County, Oklahoma
NW¼NW¼NW¼SE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 324.0 ft

(ft)	
0.0–2.0	Soil
2.0–84.0	Conglomerate
84.0–155.0	Sandy limestone and calcareous sandstone, asphalt saturated
155.0–309.0	Sandstone, moderate saturation
309.0–324.0	Green shale and sandy limestone



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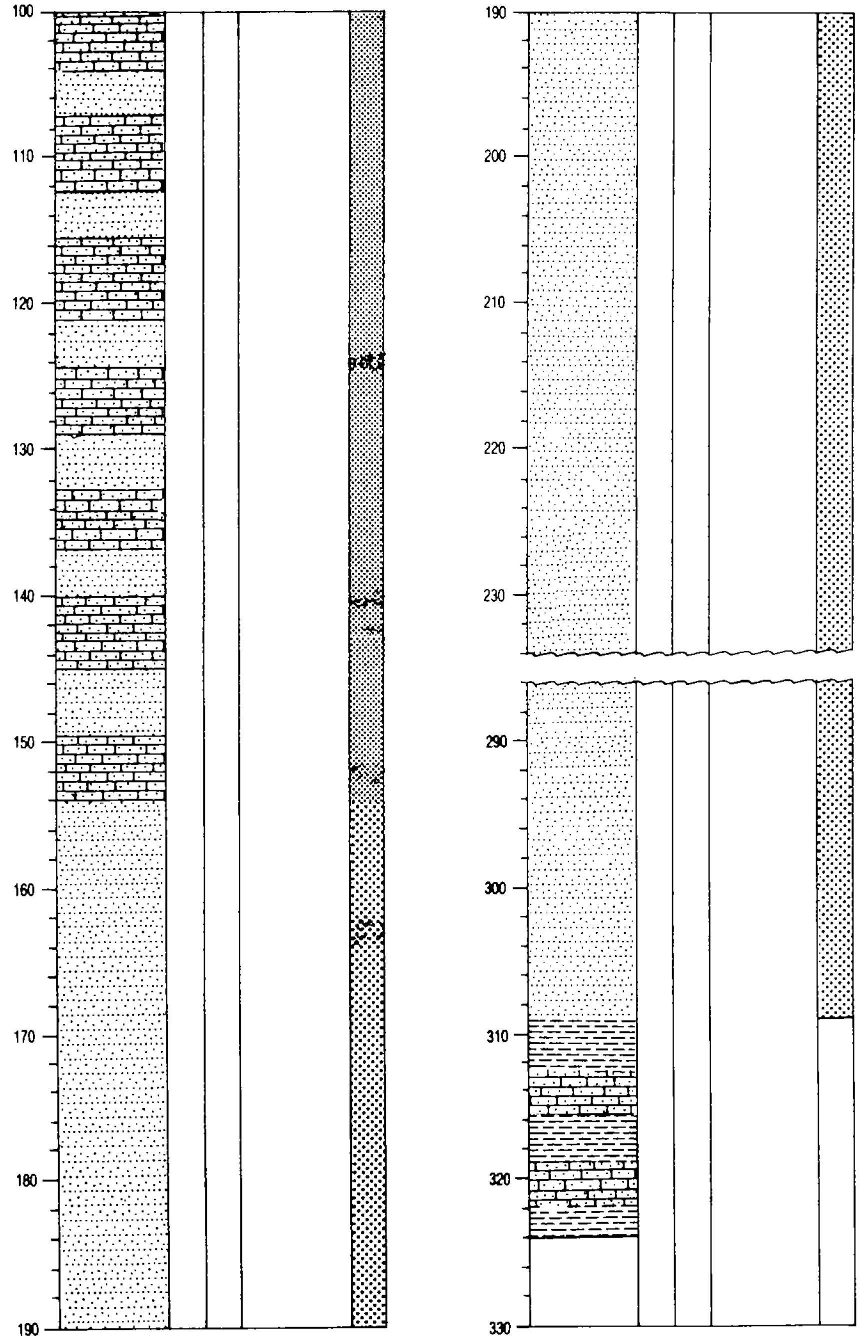
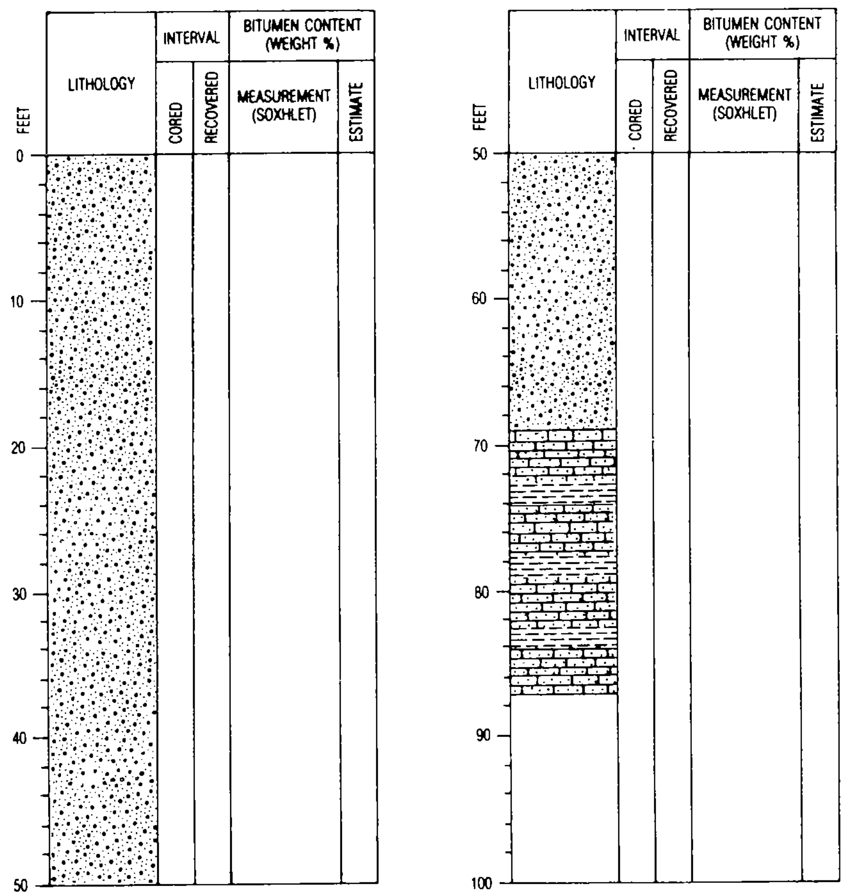
KM 12 *(continued)*



KM 13

(Borehole 50, Fig. 4)
Murray County, Oklahoma
C of N Line, NE¼SE¼SW¼ sec. 15, T. 1 S., R. 3 E.
Total depth = 87.0 ft

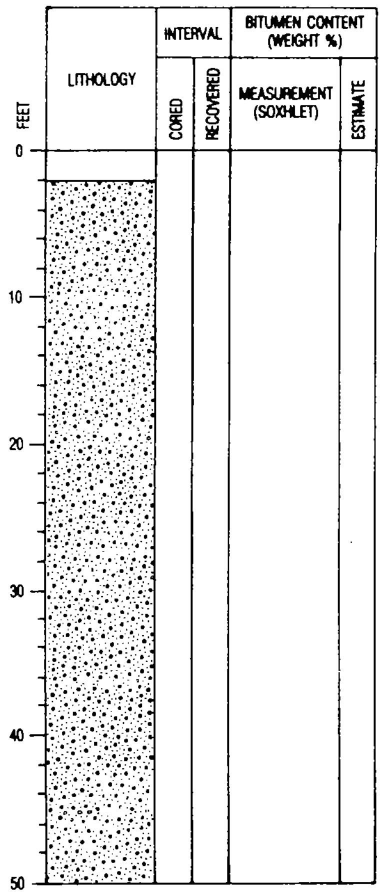
(ft)	
0.0–69.0	Limestone conglomerate, sandy matrix
69.0–87.0	Sandy limestone and shale

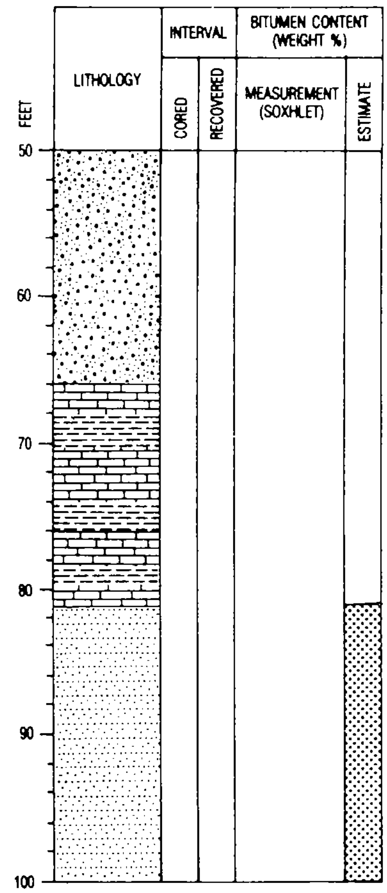


KM 14

(Borehole 51, Fig. 4)
Murray County, Oklahoma
C of N½NE¼ sec. 21, T. 1 S., R. 3 E.
Total depth = 246.4 ft

(ft)	
0.0–2.0	Soil
2.0–66.0	Limestone conglomerate, sandy matrix
66.0–81.0	Limestone with green shale
81.0–242.0	Fine sandstone, fair to good saturation 81.0–106.0 ft, medium to light bitumen stain 106.0–242.0 ft
242.0–246.4	Limestone, shale, and sandy limestone





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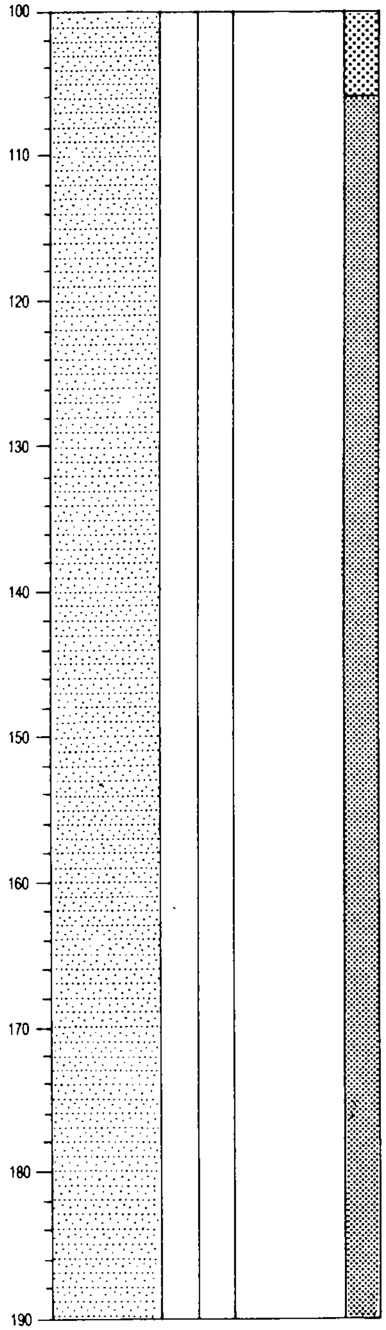
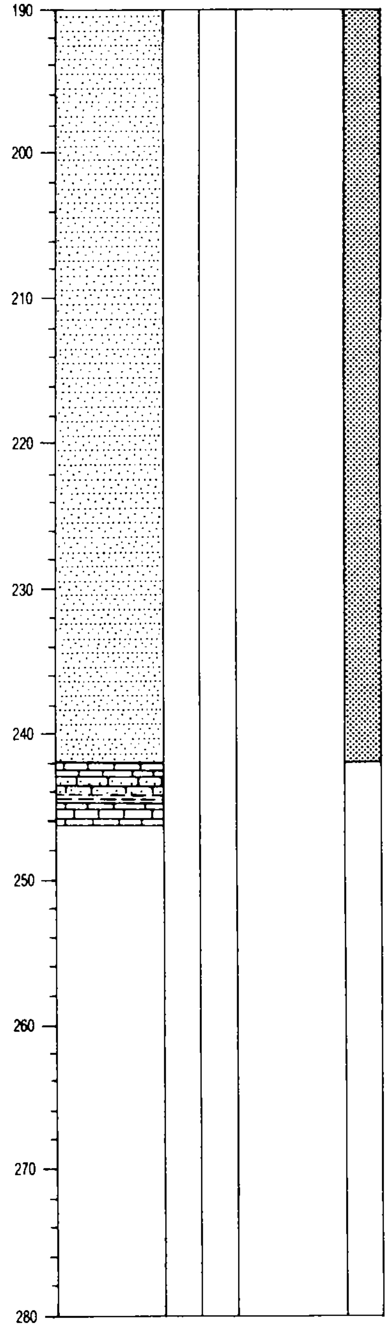
KM 14 *(continued)*





OGS 1 Jumas

(Borehole OGS 2, Fig. 4)

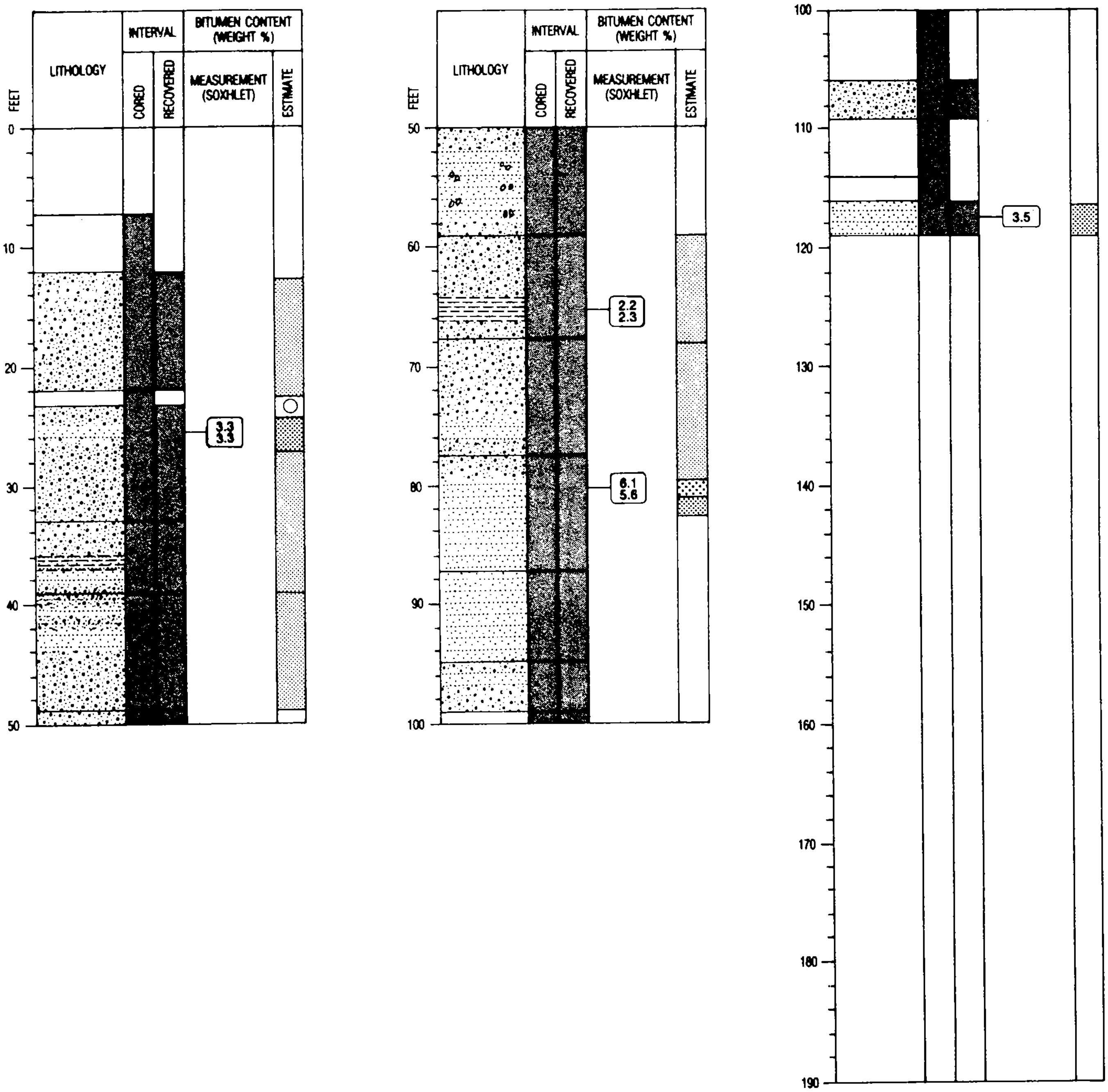
Murray County, Oklahoma

1,800 ft FSL, 1,550 ft FWL, sec. 15, T. 1 S., R. 3 E.

Total depth = 120.0 ft

(ft)	
0.0–7.3	Drilled
7.3–22.0	Cored, recovered 12.0–22.0 ft
12.0–22.0	Pebble and cobble limestone conglomerate with calcareous sandy matrix (bitumen in matrix)
22.0–33.0	Cored, recovered 23.0–33.0 ft
23.0–24.7	Conglomerate as above
24.7–25.8	Fine-grained bitumen-bearing sandstone
25.8–33.0	Limestone conglomerate with bitumen in sandy matrix
33.0–39.0	Cored, recovered 33.0–39.0 ft
33.0–36.6	Limestone conglomerate
36.6–37.3	Calcareous gray sandy shale and silty sandstone
37.3–39.0	Gray silty sandstone with limestone pebbles, some bitumen
39.0–49.0	Cored, recovered 39.0–49.0 ft
39.0–41.7	Gray calcareous sandstone with limestone and chert clasts, some bitumen
41.7–43.8	Fine-grained gray calcareous sandstone, some bitumen
43.8–44.0	Bitumen-bearing sandstone and conglomerate
44.0–49.0	Conglomerate with bitumen in sandy matrix
49.0–59.0	Cored, recovered 49.0–59.0 ft
49.0–51.6	Conglomerate as above
51.6–58.0	Fine-grained gray calcareous sandstone with limestone pebbles
58.0–59.0	Limestone conglomerate
59.0–67.5	Cored, recovered 59.0–67.5 ft
59.0–65.8	Pebble-cobble limestone conglomerate with calcareous fine-grained sandstone matrix, bitumen in matrix
65.8–66.2	Gray, calcareous shale with bitumen-bearing sandstone zones
66.2–67.5	Conglomerate with bitumen in sandy matrix
67.5–77.3	Cored, recovered 67.5–77.3 ft
67.5–75.3	Conglomerate as above
75.3–76.3	Fine-grained gray calcareous sandstone
76.3–77.3	Limestone conglomerate with bitumen in sandy matrix
77.3–87.0	Cored, recovered 77.3–87.0 ft
77.3–79.0	Limestone conglomerate with good bitumen-bearing sandy matrix
79.0–87.0	Fine-grained gray calcareous sandstone with bitumen-rich zones
87.0–95.0	Cored, recovered 87.0–95.0 ft
87.0–95.0	Fine-grained gray slightly calcareous sandstone with some bitumen
95.0-99.0	Cored, recovered 95.0–99.0 ft
95.0–96.2	Sandstone with limestone clasts and shale stringers
96.2–99.0	Limestone conglomerate with calcareous sandy matrix
99.0–109.0	Cored, recovered 106.0–109.0 ft
106.0–109.0	Limestone conglomerate as above
109.0–114.0	Cored, no recovery
114.0–119.0	Cored, recovered 116.0–119.0 ft
116.0–119.0	Fine-grained tan sandstone with scattered bitumen

OGS 1 Jumas

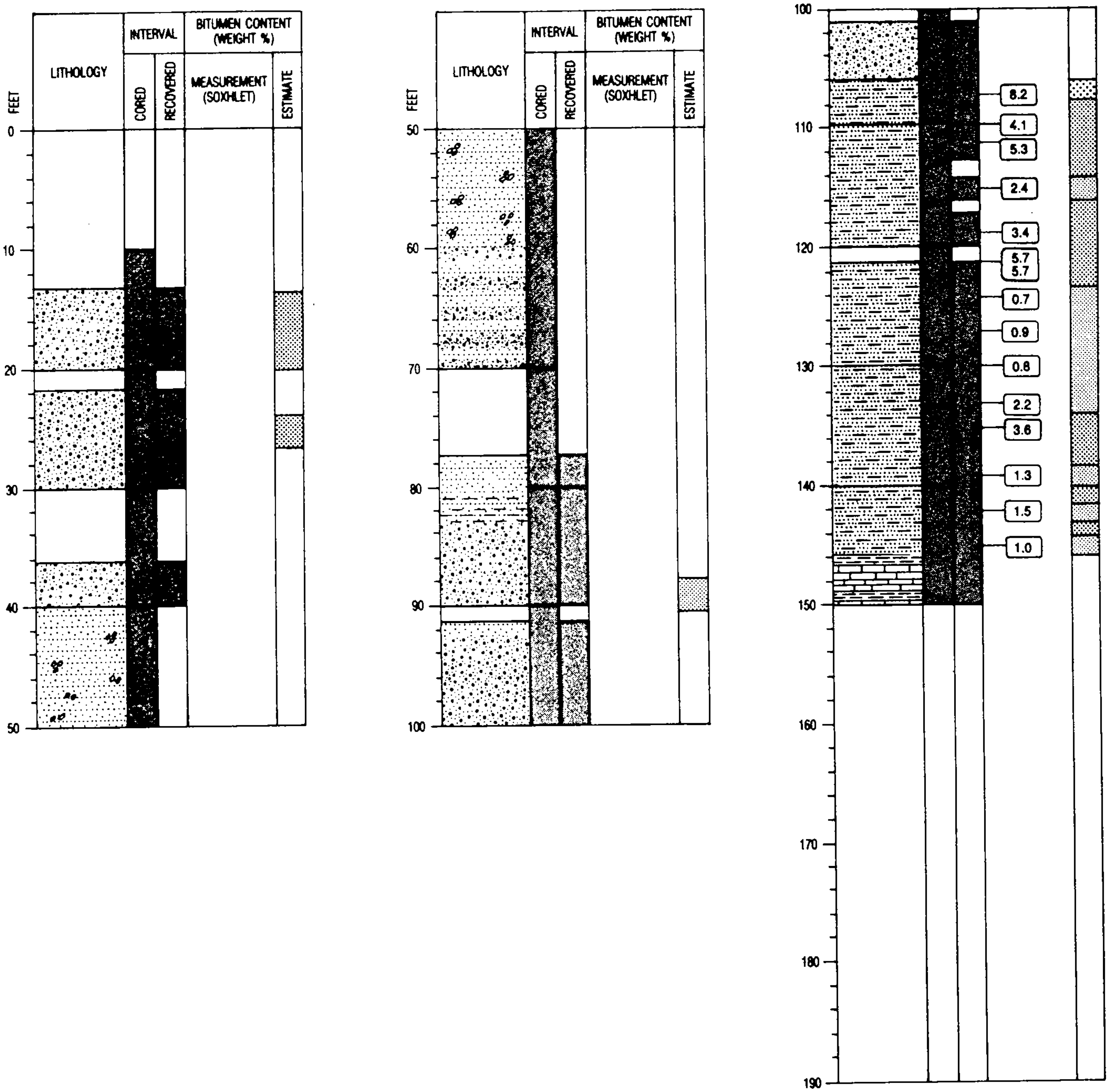

FEET
LITHOLOGY
INTERVAL
CORED
RECOVERED
BITUMEN CONTENT (WEIGHT %)
MEASUREMENT (SOXHLET)
ESTIMATE
0
10
20
30
40
50
3.2
3.3
60
70
80
90
100
2.2
2.3
6.1
5.6
110
120
130
140
150
160
170
180
190
3.5

OGS 3 Jumas

(Borehole OGS 3, Fig. 4)
Murray County, Oklahoma
1,800 ft FSL, 1,800 ft FWL, sec. 15, T. 1 S., R. 3 E.
Total depth = 150.0 ft

(ft)	
0.0–10.0	Drilled
10.0–20.0	Cored, recovered 13.8–20.0 ft
13.8–20.0	Limestone conglomerate with fine-grained bitumen-bearing sandy matrix
20.0–30.0	Cored, recovered 21.8–30.0 ft
21.8–30.0	Conglomerate as above
30.0–40.0	Cored, recovered 36.3–40.0 ft
36.3–40.0	Conglomerate as above
40.0–70.0	Cored, no recovery
40.0–70.0	Description from samples:
30.0–60.0	Fine-grained sandstone with scattered bitumen, some limestone
60.0–70.0	Limestone conglomerate with bitumen-bearing sandstone
70.0–80.0	Cored, recovered 77.8–80.0 ft
77.8–80.0	Fine-grained sandstone with scattered bitumen
80.0–90.0	Cored, recovered 80.0–90.0 ft
80.0–83.0	Interbedded fine-grained sandstone and green shale, scattered bitumen
83.0–90.0	Limestone conglomerate with bitumen-bearing sandy matrix
90.0–100.0	Cored, recovered 91.3–100.0 ft
91.3–92.0	Fine-grained sandstone with scattered bitumen
92.0–100.0	Limestone conglomerate with bitumen-bearing sandy and clayey matrix
100.0–110.0	Cored, recovered 101.0–110.0 ft
101.0–106.0	Limestone conglomerate as above
106.0–110.0	Fine-grained, well-rounded, well-sorted sandstone with good bitumen saturation; scattered shale stringers
110.0–120.0	Cored, recovered 112.5–120.0 ft
112.5–120.0	Sandstone as above
120.0–130.0	Cored, recovered 121.3–130.0 ft
121.3–130.0	Sandstone as above
130.0–140.0	Cored, recovered 130.0–140.0 ft
130.0–140.0	Sandstone as above
140.0–150.0	Cored, recovered 140.0–150.0 ft
140.0–145.5	Sandstone as above
145.5–150.0	Dark green shale interbedded with brown fractured limestone, some bitumen

OGS 3 Jumas

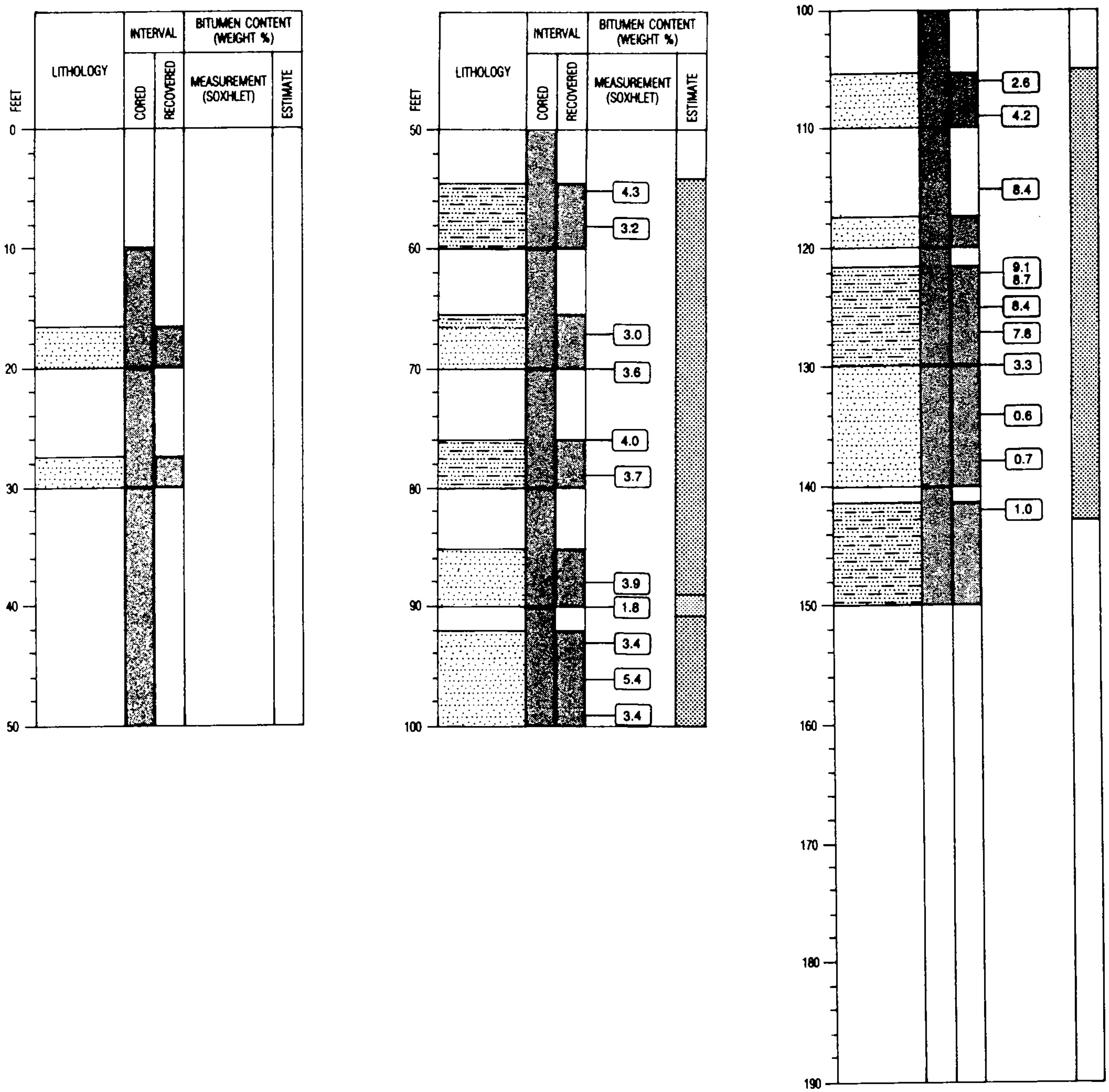

LITHOLOGY
INTERVAL
CORED
RECOVERED
BITUMEN CONTENT (WEIGHT %)
MEASUREMENT (SOXHLET)
ESTIMATE
FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
8.2
4.1
5.3
2.4
3.4
5.7
5.7
0.7
0.9
0.8
2.2
3.6
1.3
1.5
1.0

OGS 4 Kirby

(Borehole OGS 4, Fig. 4)
Murray County, Oklahoma
900 ft FSL, 750 ft FEL, sec. 15, T. 1 S., R. 3 E.
Total depth = 150.0 ft

(ft)	
0.0–10.0	Drilled
10.0–20.0	Cored, recovered 16.5–20.0 ft
16.5–20.0	Fine-grained quartz sandstone, rounded to well-rounded, well-sorted, well-indurated, with calcareous cement
20.0–30.0	Cored, recovered 27.75–30.0 ft
27.75–30.0	Fine-grained quartz sandstone with few stringers of fine sandy dolomite; sandstone well-rounded, well-sorted with hard white calcareous cement
30.0–50.0	Cored, no recovery
30.0–50.0	Description from cuttings: fine sandstone, poorly cemented, with bitumen stain
50.0–60.0	Cored, recovered 54.5–60.0 ft
54.5–60.0	Fine sandstone, poorly cemented, well-rounded, well-sorted, with occasional stringers of green or tan shale, moderately saturated throughout
60.0–70.0	Cored, recovered 65.5–70.0 ft
65.5–70.0	Fine sandstone as above, top 3 in. with tan shale stringers and shale in fractures, moderate to good saturation throughout
70.0–80.0	Cored, recovered 76.0–80.0 ft
76.0–80.0	Fine sandstone, well-rounded, well-sorted, few shale stringers and good saturation
80.0–90.0	Cored, recovered 85.5–90.0 ft
85.5–90.0	Fine sandstone with shale stringers; 88.0–90.0 ft, moderate to excellent saturation throughout
90.0–100.0	Cored, recovered 92.0–100.0 ft
92.0–100.0	Fine sandstone with numerous shale stringers, moderate to excellent saturation throughout
100.0–110.0	Cored, recovered 105.75–110.0 ft
105.75–110.0	As above
110.0–120.0	Cored, recovered 117.7–120.0 ft
117.7–118.0	Well-cemented sandstone with trace of bitumen
118.0–120.0	Fine sandstone with occasional shale stringers; excellent saturation
120.0–130.0	Cored, recovered 121.5–130.0 ft
121.5–127.5	As above
127.5–130.0	Fine sandstone with shale, moderate saturation
130.0–140.0	Cored, recovered 130.0–140.0 ft
130.0–140.0	Fine sandstone with numerous stringers of fine sandy dolomite and sandy shale, moderate to good saturation
140.0–150.0	Cored, recovered 141.5–150.0 ft
141.5–150.0	Fine sandstone interbedded with fine sandy dolomite, trace glauconite, with some green shale; portions very fractured; poor saturation throughout

OGS 4 Kirby

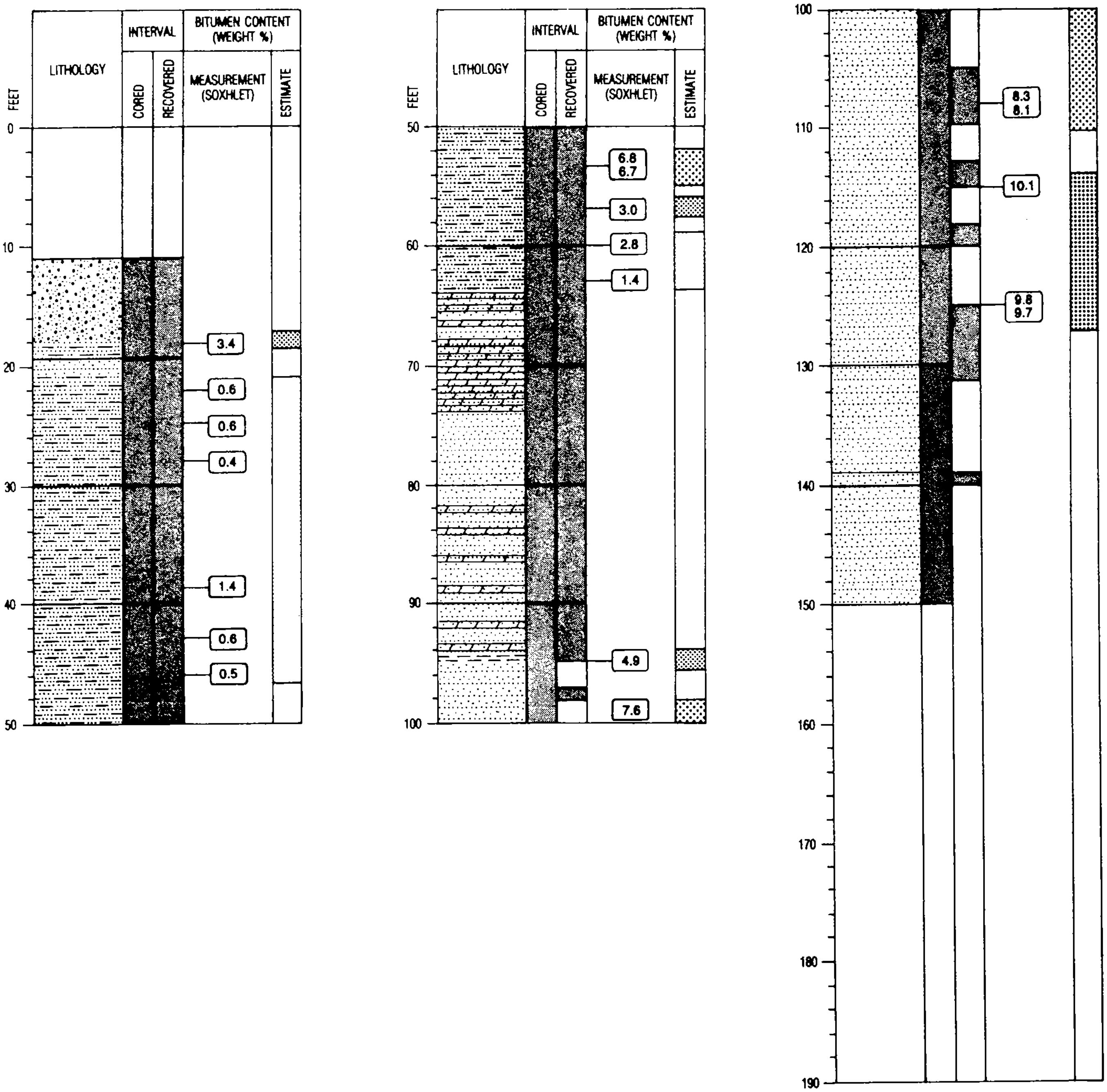

LITHOLOGY
INTERVAL
CORED
RECOVERED
BITUMEN CONTENT (WEIGHT %)
MEASUREMENT (SOXHLET)
ESTIMATE
FEET
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
4.3
3.2
3.0
3.6
4.0
3.7
3.9
1.8
3.4
5.4
3.4
2.6
4.2
8.4
9.1
8.7
8.4
7.8
3.3
0.6
0.7
1.0

OGS 3 Kirby

(Borehole OGS 5, Fig. 4)
Murray County, Oklahoma
775 ft FSL, 250 ft FEL, sec. 15, T. 1 S., R. 3 E.
Total depth = 150.0 ft

(ft)	
0.0–11.0	Drilled
11.0–19.5	Cored, recovered 11.0–19.5 ft
11.0–18.0	Pebble-cobble limestone and chert conglomerate with sandy matrix, trace bitumen in sand
18.0–19.5	Fine-grained sandstone, slightly calcareous, well-rounded, well-sorted with thin shale stringers, good saturation
19.5–30.0	Cored, recovered 19.5–30.0 ft
19.5–30.0	Fine-grained sandstone, well-rounded, well-sorted, with numerous thin stringers of green shale, moderate saturation
30.0–40.0	Cored, recovered 30.0–40.0 ft
30.0–33.5	As above
33.5–34.0	Fine-grained sandstone, well-rounded, well-sorted, with shale stringers, no saturation
34.0–36.0	Dark green sandy shale
36.0–40.0	Fine sandstone, slightly calcareous, well-rounded, well-sorted with numerous shale stringers, moderate saturation
40.0–50.0	Cored, recovered 40.0–50.0 ft
40.0–48.0	As above (36.0–40.0 ft)
48.0–50.0	Fine sandstone, slightly calcareous, well-rounded, well-sorted with occasional shale stringers, poor saturation
50.0–60.0	Cored, recovered 50.0–60.0 ft
50.0–51.75	As above (48.0–50.0 ft)
51.75–58.0	Fine-grained sandstone, well-rounded, well-sorted with abundant shale stringer, good to excellent saturation
58.0–59.25	Light gray fine-grained sandy dolomite with zones of fine-grained sandstone with excellent saturation
59.25–60.0	Fine sandstone, well-rounded, well-sorted with abundant shale stringers, good saturation
60.0–70.0	Cored, recovered 60.0–70.0 ft
60.0–61.0	As above (59.25–60.0 ft)
61.0–63.0	Fine sandstone, well-rounded, well-sorted with thin shale stringers, moderate to good saturation
63.0–68.0	Fine sandstone with interbedded fine-grained sandy dolomite; fractured, with good saturation in sandstone zones
68.0–70.0	Fine-grained sandy dolomite with bitumen in fractures
70.0–80.0	Cored, recovered 70.0–80.0 ft
70.0–72.0	As above (68.0–70.0 ft)
72.0–74.0	Fine-grained sandy dolomite with streaks of fine sandstone with good saturation
74.0–78.0	Extremely fractured fine to very fine calcareous sandstone with bitumen in fractures
78.0–80.0	Fine-grained sandstone, well-rounded, well-sorted, calcareous, fractured, moderate saturation
80.0–90.0	Cored, recovered 80.0–90.0 ft
80.0–90.0	Fine-grained sandstone, slightly calcareous, well-rounded, well-sorted with stringers of fine sandy dolomite; good to moderate saturation
90.0–100.0	Cored, recovered 93.0–100.0 ft
93.0–94.3	As above
94.3–94.7	Green shale with occasional fine white sandstone
94.7–100.0	Fine sandstone, well-rounded, well-sorted, good to excellent saturation
100.0–110.0	Cored, no recovery
110.0–120.0	Cored, recovered 111.0–120.0 ft
111.0–120.0	Fine sandstone, well-rounded, well-sorted, excellent saturation
120.0–130.0	Cored, recovered 126.0–130.0 ft
126.0–130.0	Fine sandstone as above with shale stringers, excellent saturation
130.0–140.0	Cored, recovered 138.5–140.0 ft
138.5–140.0	Fine sandstone as above, excellent saturation
140.0–150.0	Cored, no recovery
140.0–150.0	Description from cuttings: clean white sandstone, fine-grained as above with traces of bitumen

OGS 3 Kirby

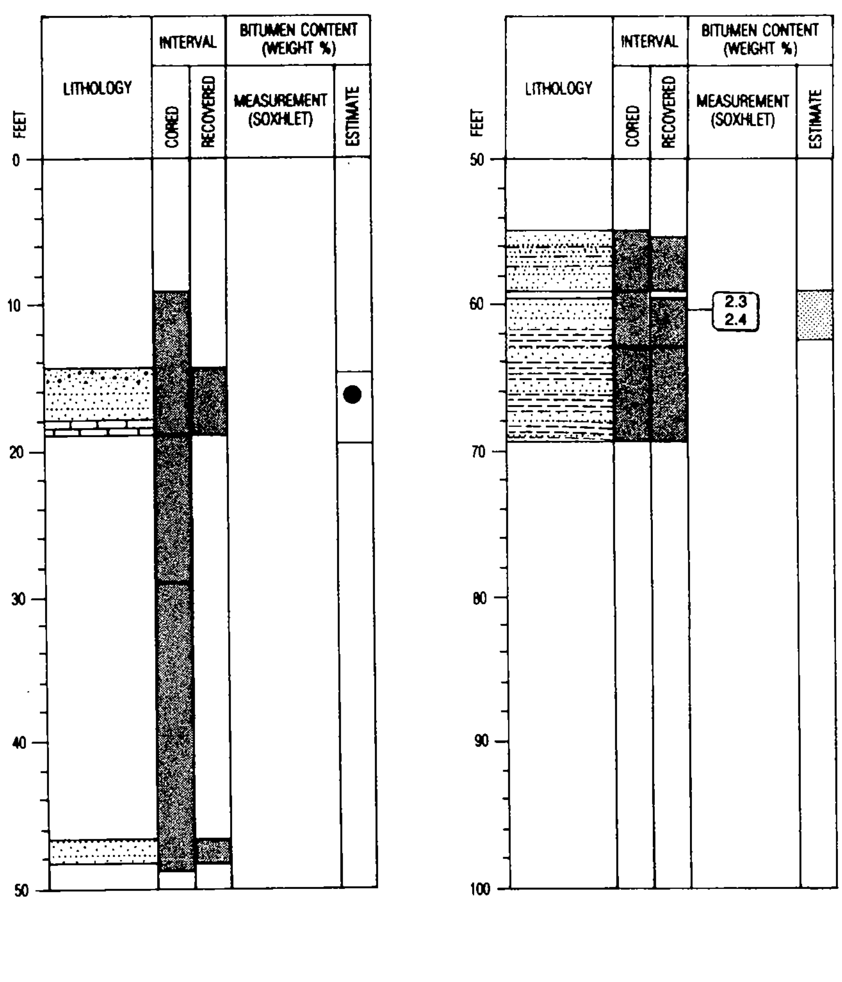


LITHOLOGY
INTERVAL
CORED
RECOVERED
BITUMEN CONTENT (WEIGHT %)
MEASUREMENT (SOXHLET)
ESTIMATE
FEET
0
10
20
30
40
50
3.4
0.6
0.6
0.4
1.4
0.6
0.5
60
70
80
90
100
6.8
6.7
3.0
2.8
1.4
4.9
7.6
110
120
130
140
150
160
170
180
190
8.3
8.1
10.1
9.8
9.7

OGS 2 Griffitts

(Borehole OGS 8, Fig. 4)
Murray County, Oklahoma
1,575 ft FNL, 1,730 ft FWL, sec. 22, T. 1 S., R. 3 E.
Total depth = 70.0 ft

(ft)	
0.0–9.0	Drilled
9.0–19.0	Cored, recovered 14.5–19.0 ft
14.5–14.8	Dark brown crystalline limestone
14.8–17.0	Fractured calcareous sandstone with scattered bitumen
17.0–18.8	Gray fine-grained sandstone with bitumen
18.8–19.0	Fractured crystalline limestone
19.0–29.0	Cored, no recovery
29.0–49.0	Cored, recovery 47.0–49.0 ft
47.0–49.0	Gray to tan calcareous sandstone with scattered bitumen
49.0–55.0	Drilled
55.0–59.0	Cored, recovered 55.4–59.0 ft
55.4–59.0	Gray to tan calcareous sandstone with scattered bitumen
59.0–63.0	Cored, recovered 59.5–65.0 ft
59.5–61.4	Sandstone as above, some shale stringers
61.4–63.0	Grayish-green shale with bitumen in shale partings
63.0–69.5	Cored, recovered 63.0–69.5 ft
63.0–69.5	Interbedded shale and fine-grained calcareous sandstone with scattered bitumen



OGS 1 U.S. Asphalt

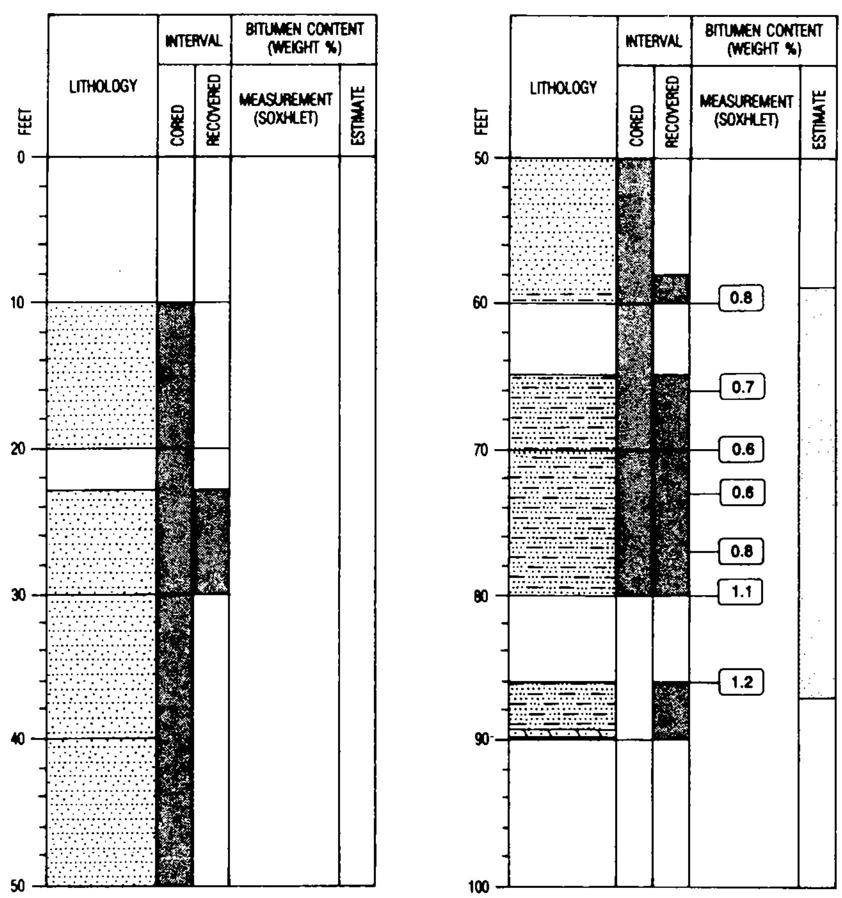
(Borehole OGS 9, Fig. 4)

Murray County, Oklahoma

2,200 ft FNL, 470 ft FWL, sec. 22, T. 1 S., R. 3 E.

Total depth = 90.0 ft

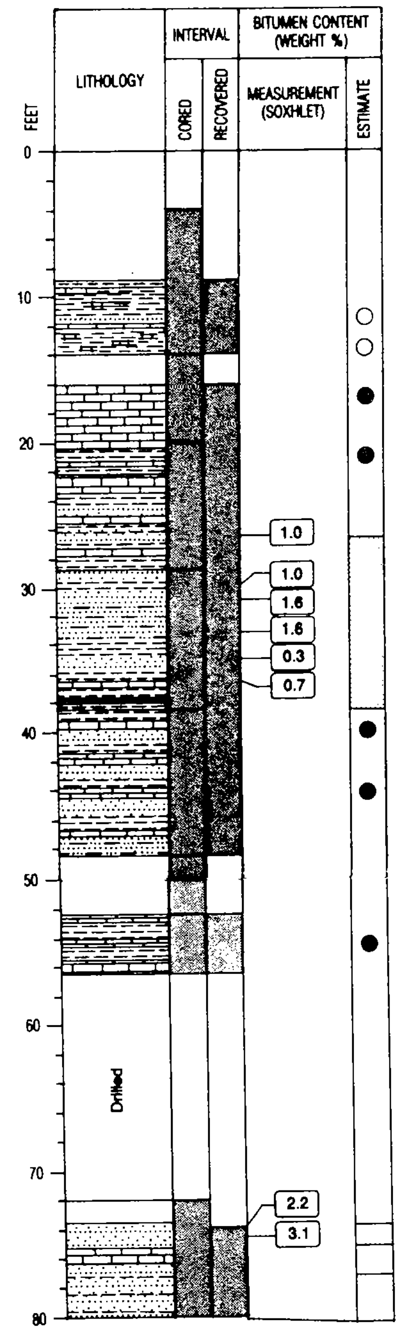
(ft)	
0.0–10.0	Drilled
10.0–20.0	Cored, no recovery
10.0–20.0	Description from cuttings: fine sandstone, well-rounded, well-sorted, poorly cemented with trace of bitumen
20.0–30.0	Cored, recovered 23.0–30.0 ft
23.0–30.0	Sandstone as above, moderately cemented
30.0–50.0	Cored, no recovery
30.0–50.0	Description from cuttings: clean quartz sandstone as above
50.0–60.0	Cored, recovered 58.0–60.0 ft
58.0–59.0	Fine sandstone, well-cemented, poor saturation
59.0–60.0	Fine sandstone with fractures and irregular stringers of green shale, moderately saturated
60.0–70.0	Cored, recovered 65.0–70.0 ft
65.0–70.0	Fine sandstone as above, good saturation 65.0–68.0 ft, poor to moderate saturation 68.0–70.0 ft
70.0–80.0	Cored, recovered 70.0–80.0 ft
70.0–80.0	Fine sandstone as above, moderate saturation
80.0–90.0	Cored, recovered 86.0–90.0 ft
86.0–88.5	Fine sandstone as above with shale stringers, moderate saturation 86.0–87.5 ft, poor saturation 87.5–88.5 ft
88.5–90.0	Fine sandstone with shale, grading downward into fine sandy dolomite



OGS 1 Griffitts

(Borehole OGS 10, Fig. 4)
Murray County, Oklahoma
1,750 ft FWL, 750 ft FNL, sec. 22, T. 1 S., R. 3 E.
Total depth = 80.0 ft

(ft)	
0.0–4.0	Drilled
4.0–14.0	Cored, recovered 9.0–14.0 ft
9.0–11.5	Pale green calcareous shale with white limestone clasts
11.5–12.0	Interbedded buff sandstone and white to brown limestone (trace of bitumen in sandstone)
12.0–13.0	Medium gray limestone clasts in gray-green clay matrix
13.0–14.0	Highly fractured interbedded green shale, buff limestone, and bitumen-bearing sandstone
14.0–20.0	Cored, recovered 16.0–20.0 ft
16.0–18.0	Highly fractured green limestone (bitumen in fractures)
18.0–20.0	Fossiliferous limestone
20.0–28.5	Cored, recovered 20.0–28.5 ft
20.0–22.0	Interbedded gray limestone and green calcareous shale, highly fractured (bitumen in fractures)
22.0–23.5	Gray fossiliferous limestone
23.5–24.0	Gray calcareous shale
24.0–26.0	Interbedded gray limestone, calcareous shale, and thin laminated sandstone (bitumen in sandstone)
26.0–27.0	Interbedded shale and sandstone
27.0–28.5	Calcareous shale and fractured limestone (bitumen in fractures)
28.5–38.5	Cored, recovered 28.5–38.5 ft
28.5–38.5	Interbedded grayish-green shale and fine sandstone (bitumen in sandstone)
38.5–48.5	Cored, recovered 38.5–48.5 ft
38.5–40.5	Interbedded calcareous shale and gray highly fractured limestone (bitumen in fractures)
40.5–48.5	Interbedded gray limestone, gray shale, and fine sandstone, highly fractured (bitumen in fractures)
48.5–56.5	Cored, recovered 52.5–56.5 ft
52.5–56.5	Interbedded calcareous shale and gray limestone, slightly fractured (bitumen in fractures)
56.5–72.0	Drilled, no samples
72.0–80.0	Cored, recovered 73.5–80.0 ft
73.5–75.0	Slightly calcareous sandstone, bitumen-bearing
75.0–76.5	Gray limestone with shale laminations, bitumen in limestone pores and fractures
76.5–80.0	Interbedded calcareous grayish-green shale and fine sandstone (bitumen in sandstone)



Appendix II-2

Lithologic Descriptions of Cores from the South Woodford Deposit

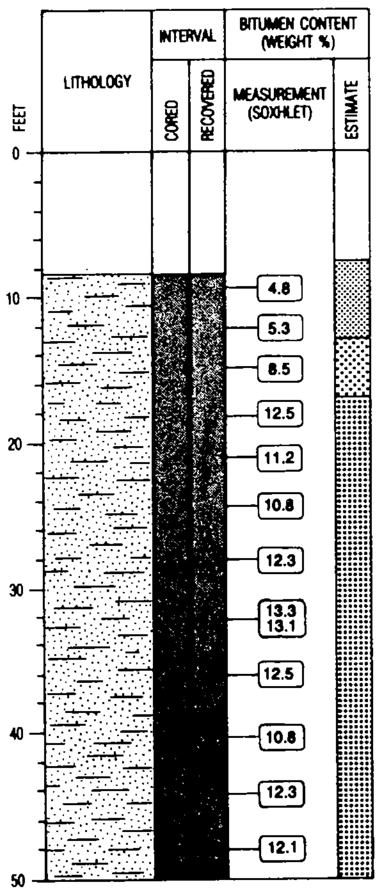
(Explanation on page 20.)

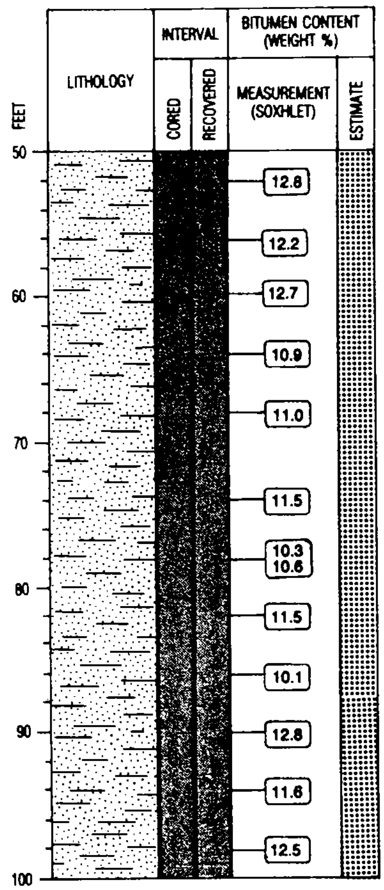
OGS 1 Fitzgerald

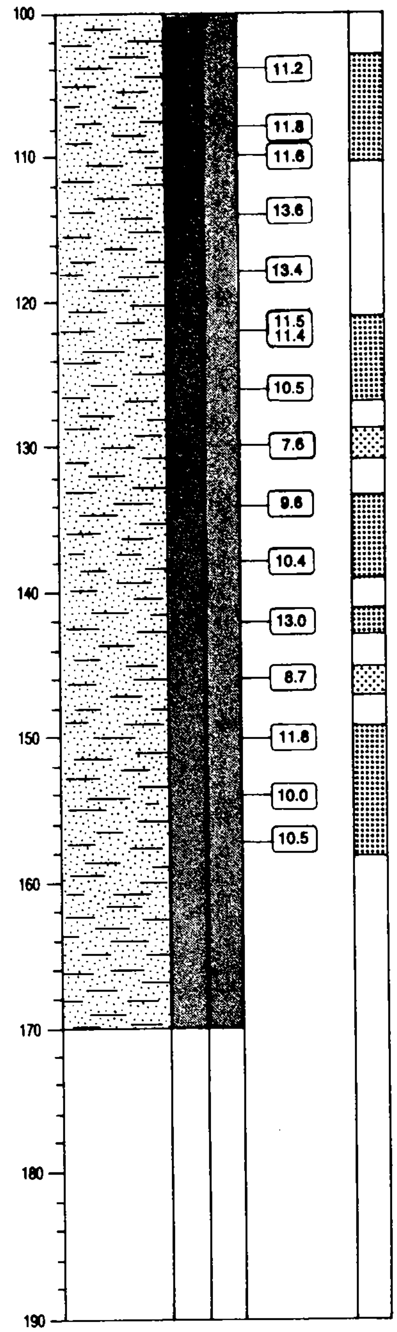
Carter County, Oklahoma
1,270 ft FSL, 2,550 ft FWL, sec. 2, T. 3 S., R. 1 W.
Total depth = 170.0 ft

(ft)

0.0–8.5	Drilled
8.5–170.0	Cored, recovered 8.5–170.0 ft
8.5–157.5	Medium tan, fine- to very fine-grained sandstone, well-sorted, rounded to subangular with dark gray sandy clay mottling parallel to bedding, moderately to poorly cemented, very well-saturated 8.5–157.5 ft
157.5–170.0	Sandstone as above, no bitumen saturation



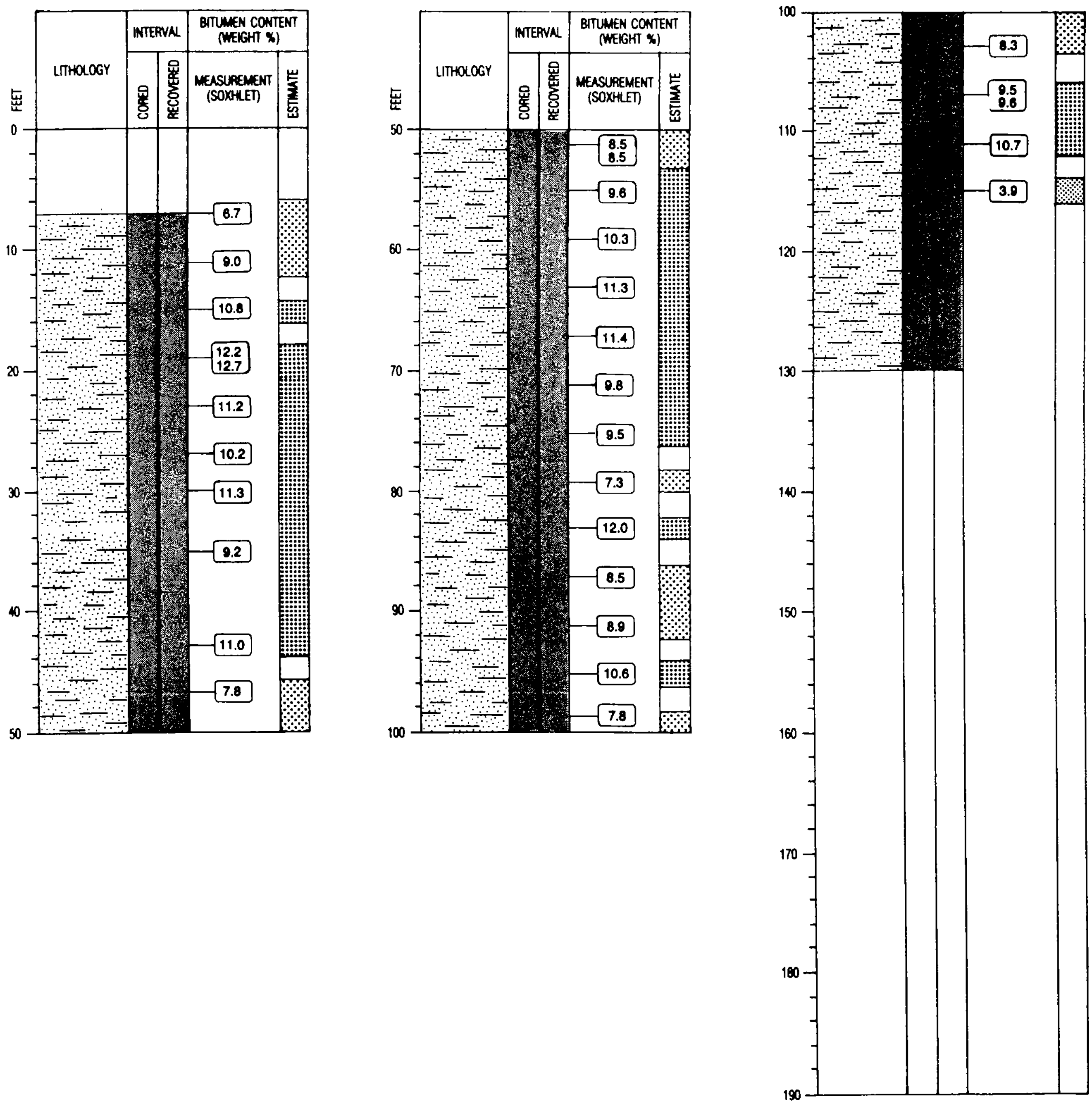




OGS 2 Fitzgerald

Carter County, Oklahoma
1,470 ft FSL, 2,000 ft FWL, sec. 2, T. 3 S., R. 1 W.
Total depth = 130.0 ft

(ft)	
0.0–7.0	Drilled
7.0–130.0	Cored, recovered 7.0–130.0 ft
7.0–115.0	Medium tan, fine- to very fine-grained, rounded to subangular, well-sorted, moderately cemented sandstone, with stringers of dark gray clay, sandy clay, and nonsaturated sandstone surrounded by clay
115.0–130.0	Sandstone as above with no bitumen saturation



OGS 3 Fitzgerald

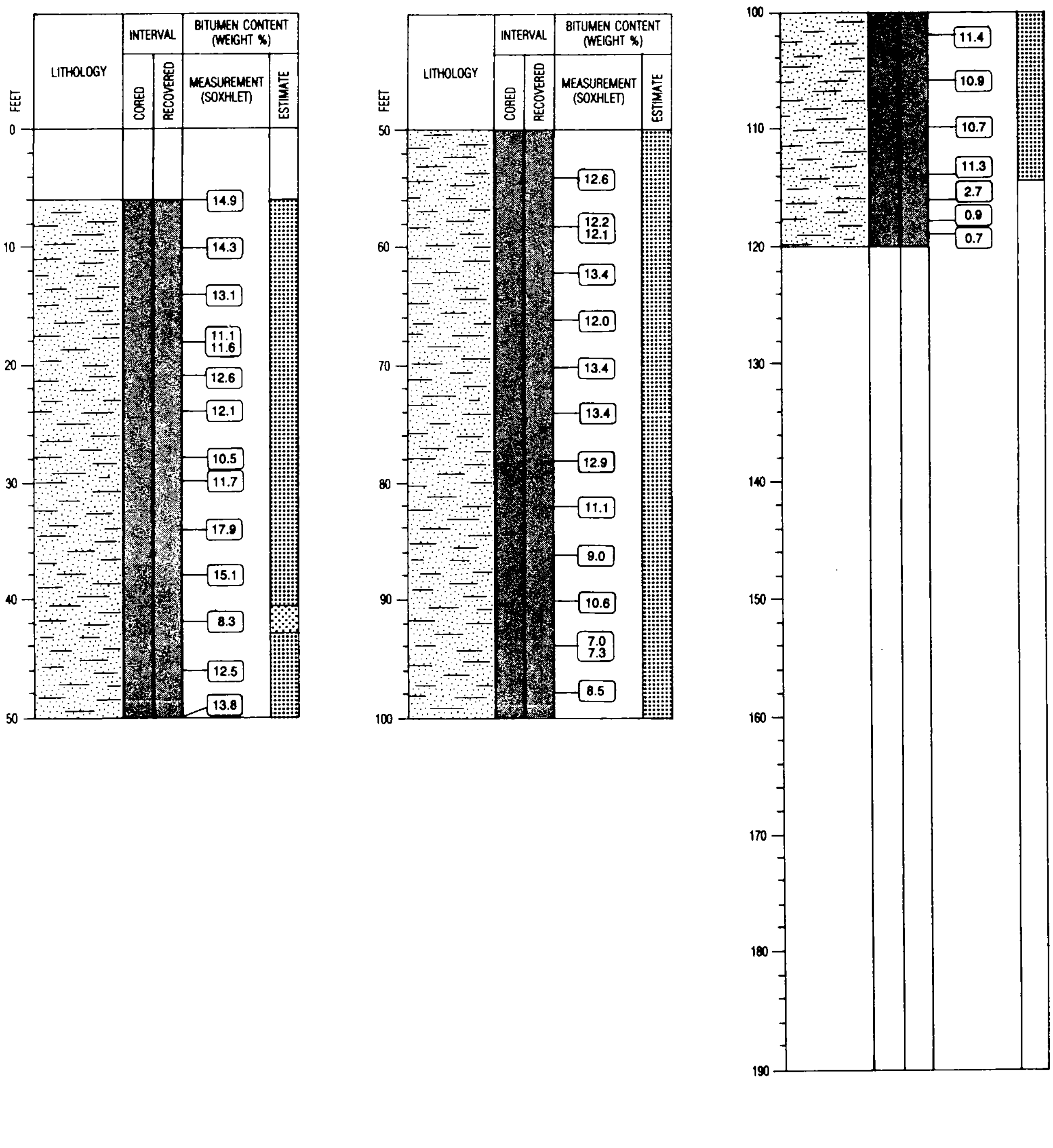
Carter County, Oklahoma
200 ft FNL, 1,100 ft FEL, sec. 11, T. 3 S., R. 1 W.
Total depth = 120.0 ft

(ft)

0.0--6.0 Drilled

6.0–120.0 Cored, recovered 6.0–120.0 ft

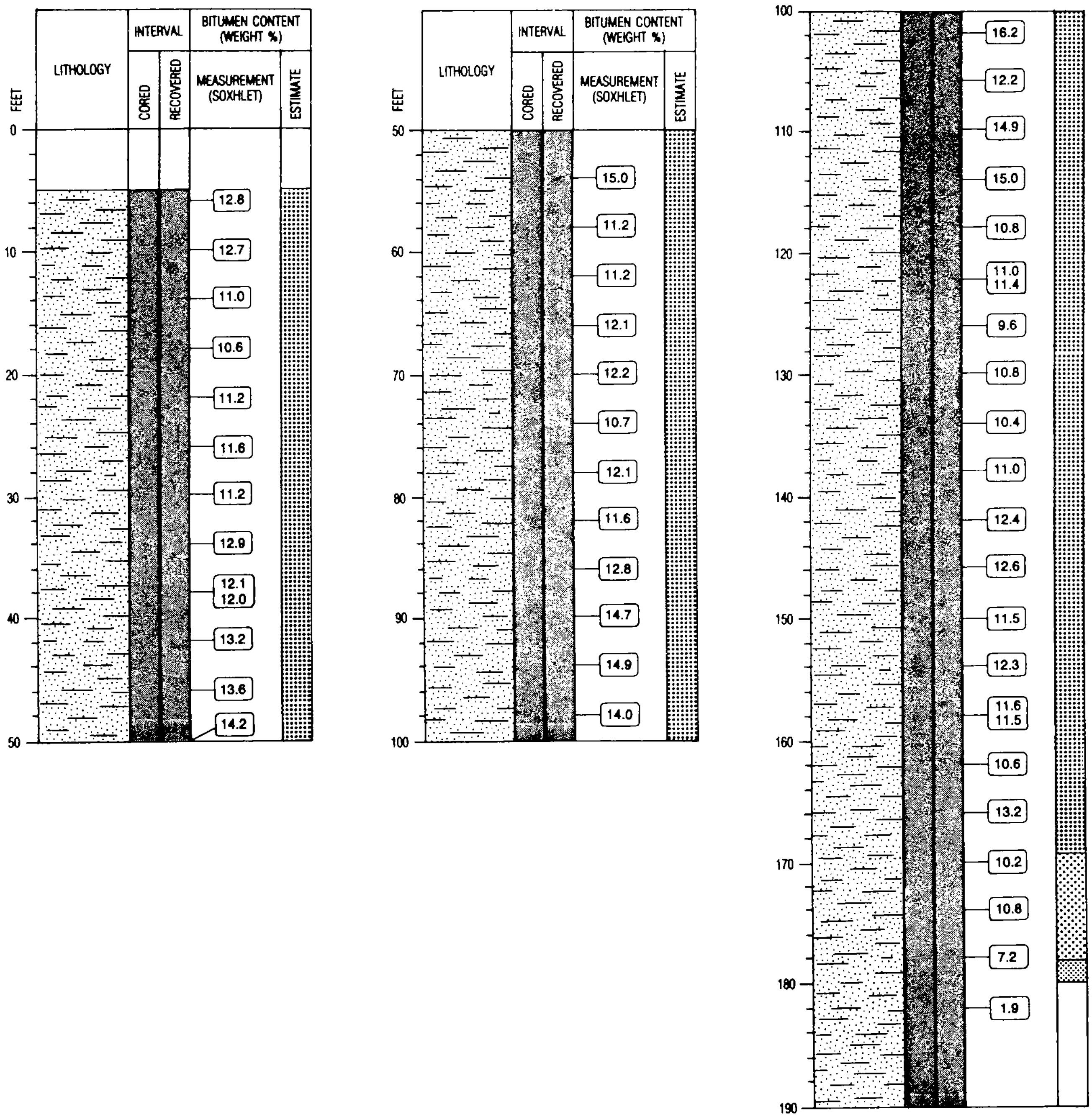
- 6.0–120.0 Fine- to very fine-grained sandstone, well-sorted, rounded to subangular with stringers of dark gray clay, sandy clay and brown sandstone; core extremely well-saturated throughout
- 114.0–120.0 Sandstone as above with occasional secondary calcite cement; rock is very hard, brittle and fractured, white in color, bitumen saturation good to 115.0 ft, poor from 118.0–120.0 ft



OGS 4 Fitzgerald

Carter County, Oklahoma
1,000 ft FNL, 100 ft FEL, sec. 11, T. 3 S., R. 1 W.
Total depth = 190.0 ft

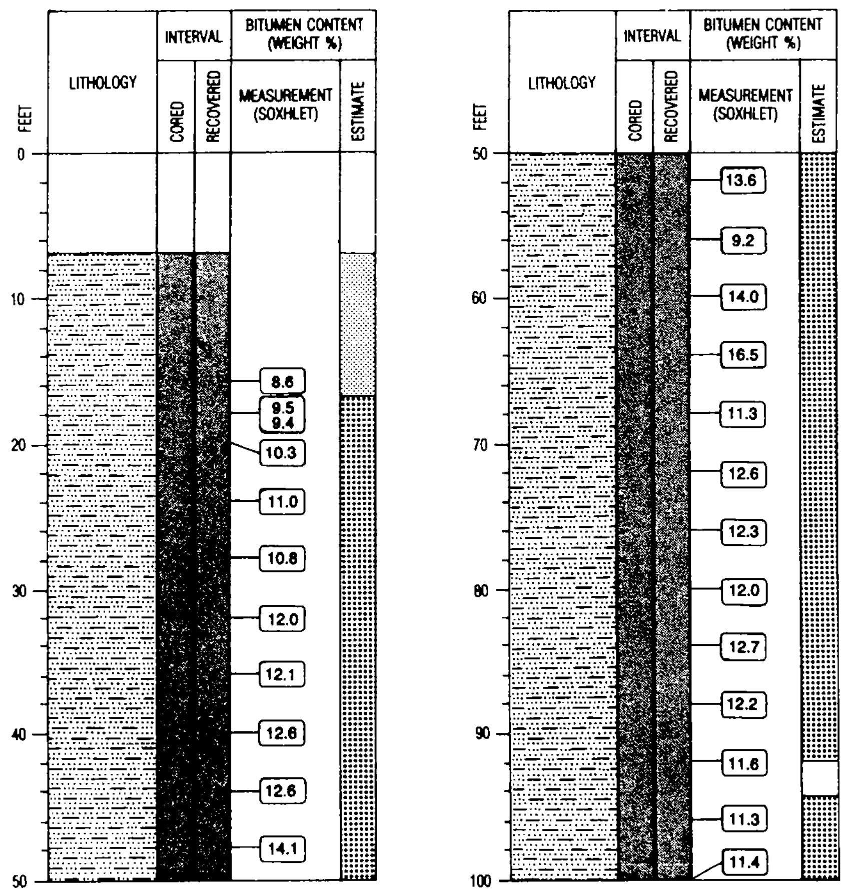
(ft)	
0.0–5.0	Drilled
5.0–190.0	Cored, recovered 5.0–190.0 ft
5.0–179.0	Fine to very fine quartz sandstone, well-sorted, rounded to subangular, moderately cemented, stringers of white clayey sand throughout, extremely well-saturated 5.0–170.0 ft, good saturation 170.0–178.0 ft, moderate saturation 178.0–179.0 ft
179.0–190.0	Sandstone as above, medium tan to light brown, trace of live oil



OGS 5 Fitzgerald

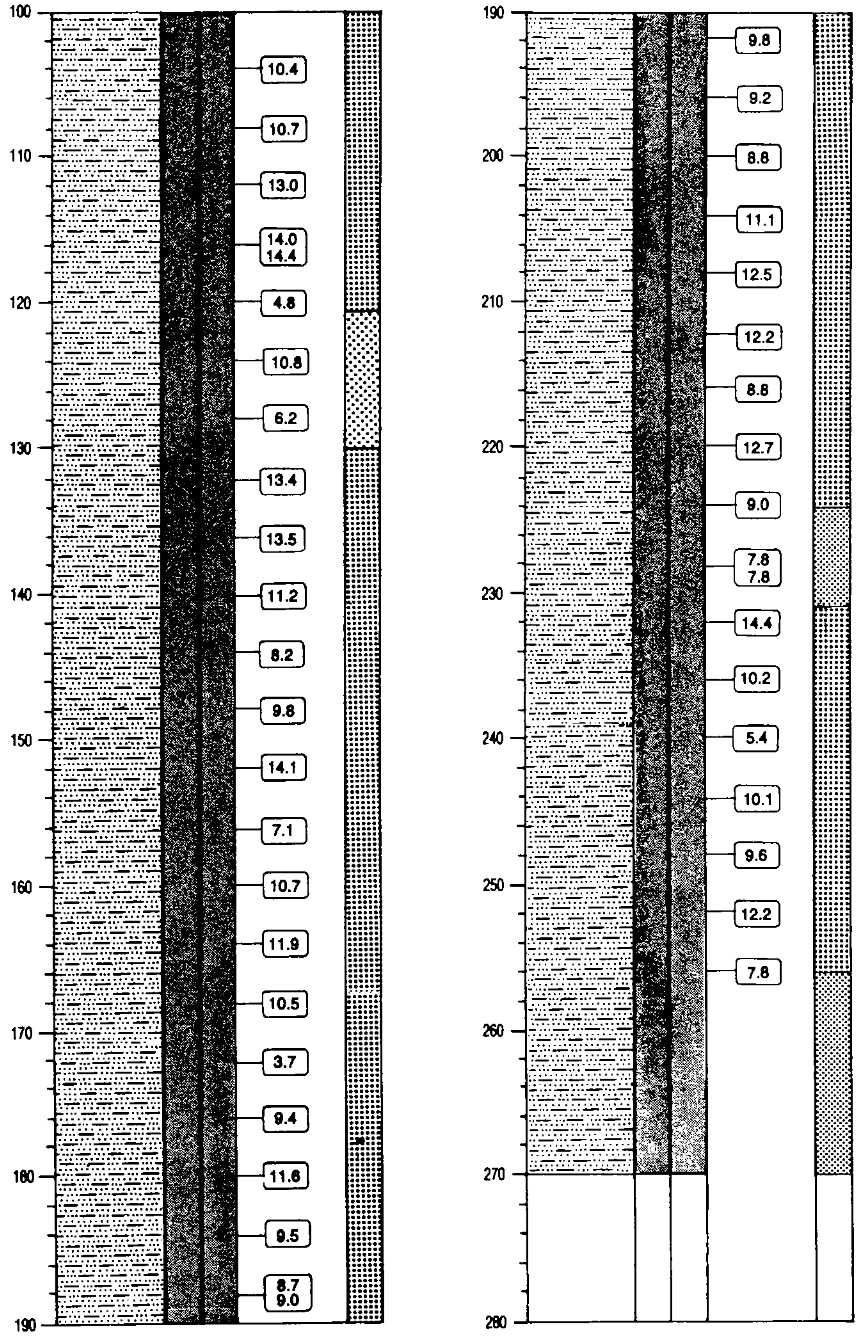
Carter County, Oklahoma
1,800 ft FNL, 1,050 ft FWL, sec. 12, T. 3 S., R. 1 W.
Total depth = 270.0 ft

(ft)	
0.0–7.0	Drilled
7.0–270.0	Cored, recovered 7.0–270.0 ft
7.0–270.0	Tan, very fine-grained sandstone, subrounded to subangular with stringers of dark gray clay and sandy clay; mostly good to excellent saturation, 18.0–224.0 ft



(continued on next page)

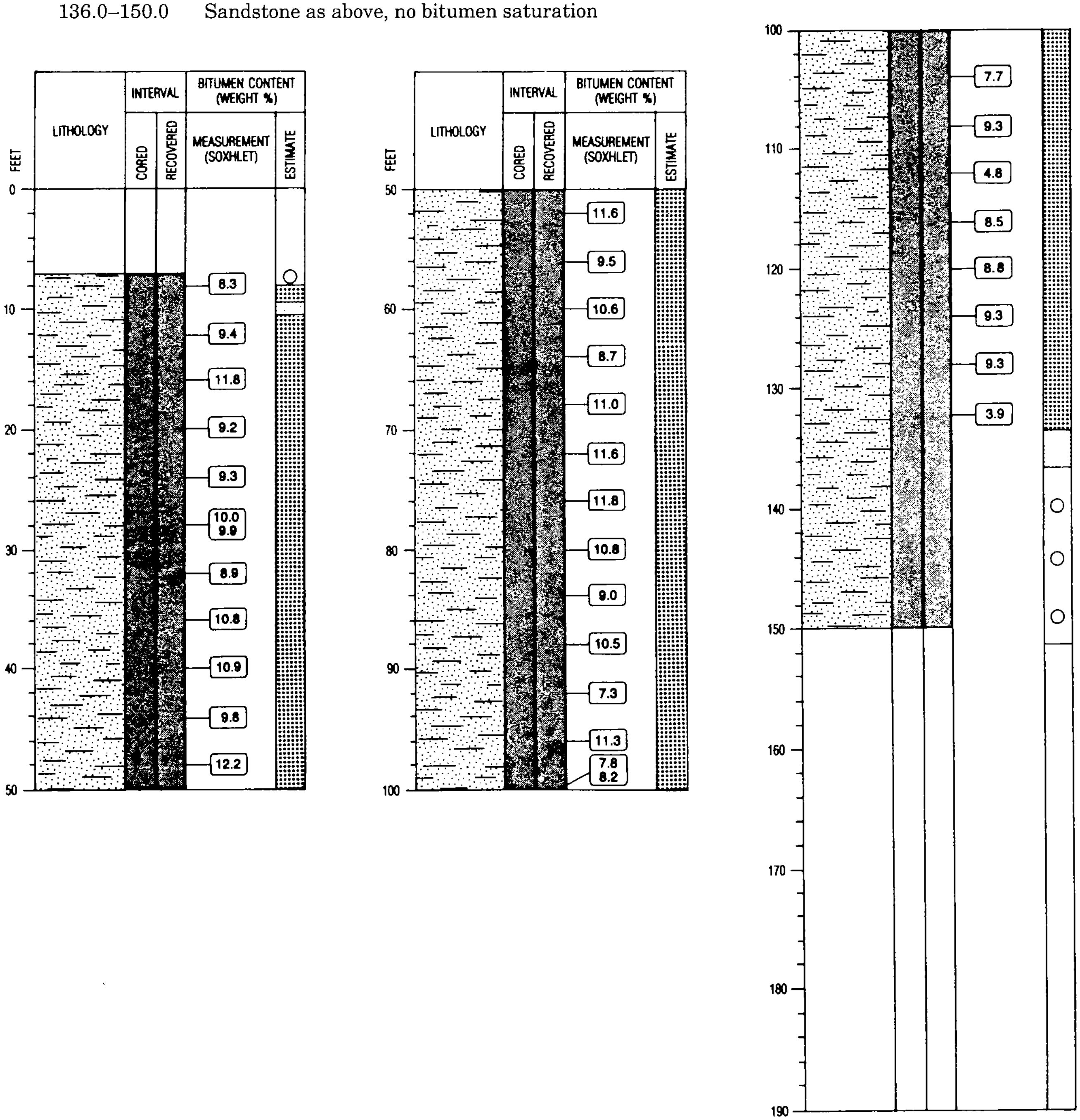
OGS 5 Fitzgerald *(continued)*



OGS 6 Fitzgerald

Carter County, Oklahoma
2,600 ft FNL, 2,000 ft FWL, sec. 12, T. 3 S., R. 1 W.
Total depth = 150.0 ft

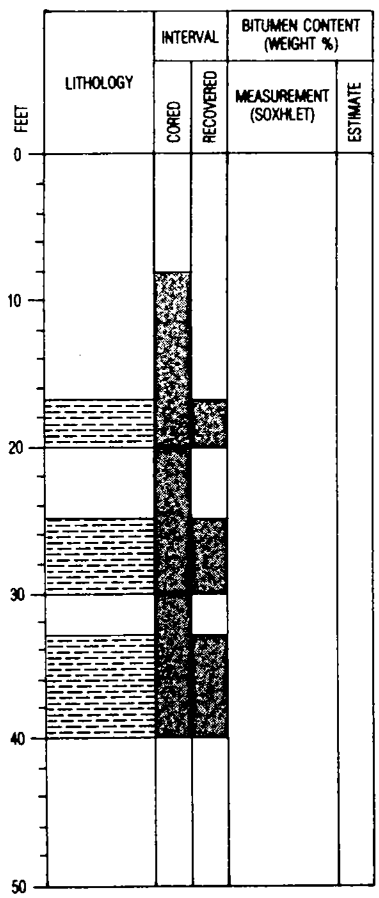
(ft)	
0.0–7.0	Drilled
7.0–150.0	Cored, recovered 7.0–150.0 ft
7.0–136.0	Medium tan, very fine-grained sandstone, subrounded to subangular with stringers of dark gray clay and light gray clayey sandstone along bedding planes; good to excellent saturation 10.0–130.0 ft
7.9–8.0, 84.25–84.8, 130.0–134.0	Shows of heavy oil
136.0–150.0	Sandstone as above, no bitumen saturation



OGS 1 Skelton

Carter County, Oklahoma
2,500 ft FNL, 450 ft FEL, sec. 3, T. 3 S., R. 1 W.
Total depth = 40.0 ft

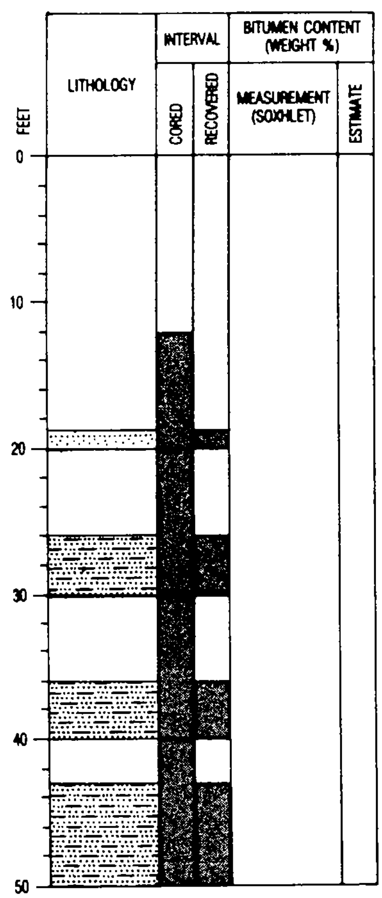
(ft)	
0.0–8.0	Drilled
8.0–10.0	Cored, no recovery
10.0–20.0	Cored, recovered 17.0–20.0 ft
17.0–20.0	Brown to dark gray shale with partings, near-vertical dip
20.0–30.0	Cored, recovered 25.25–30.0 ft
25.25–30.0	Shale as above
30.0–40.0	Cored, recovered 32.75–40.0 ft
32.75–40.0	Shale as above



OGS 2 Skelton

Carter County, Oklahoma
2,575 ft FNL, 510 ft FEL, sec. 3, T. 3 S., R. 1 W.
Total depth = 50.0 ft

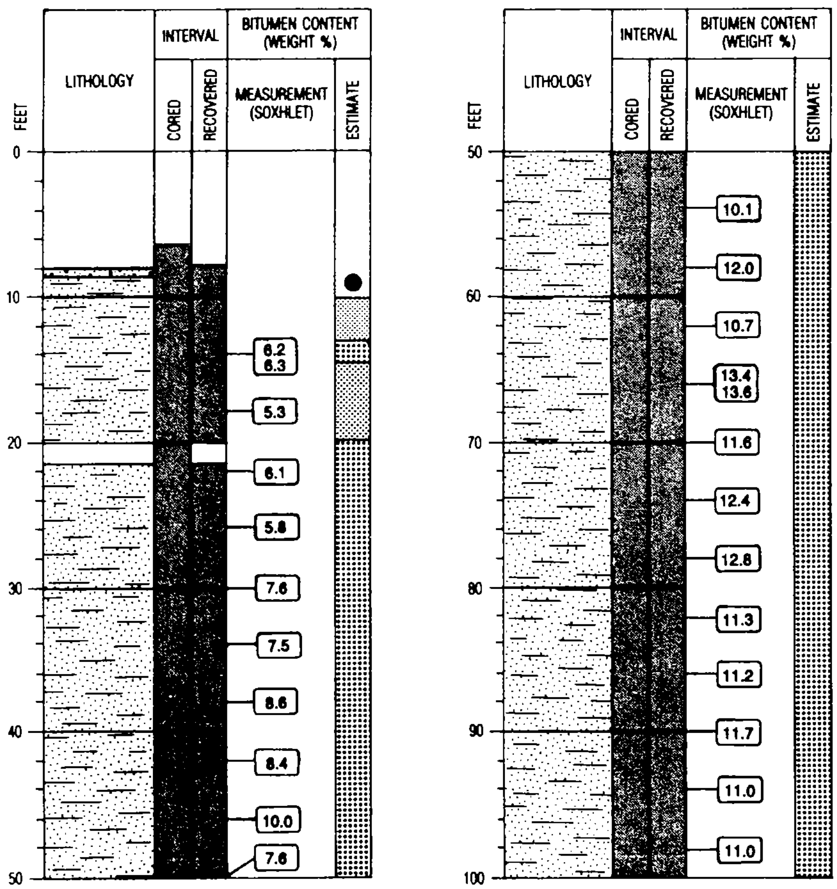
(ft)	
0.0–12.0	Drilled
12.0–20.0	Cored, recovered 19.0–20.0 ft
19.0–20.0	Very fine white to light tan sandstone, well-sorted, very friable
20.0–30.0	Cored, recovered 26.0–30.0 ft
26.0–30.0	Fractured sandstone as above, some gray clay in bedding planes
30.0–40.0	Cored, recovered 36.0–40.0 ft
36.0–40.0	Sandstone as above
40.0–50.0	Cored, recovered 43.0–50.0 ft
43.0–50.0	Very fine brown sandstone with numerous stringers of gray clay, very friable with a possible show of live oil

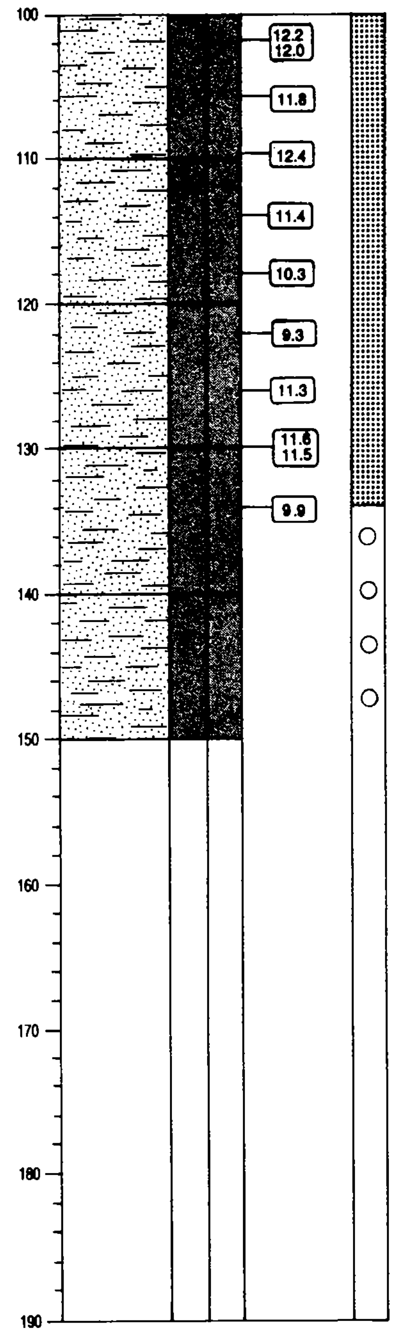


OGS 3 Skelton

Carter County, Oklahoma
800 ft FNL, 2,050 ft FWL, sec. 3, T. 3 S., R. 1 W.
Total depth = 150.0 ft

(ft)	
0.0–7.0	Drilled
8.0–150.0	Cored, recovered 8.0–150.0 ft
8.0–8.8	Gray and brown limestone cobbles, possibly from conglomerate
8.8–150.0	Very fine tan sandstone with stringers of dark gray clay on bedding surfaces, very friable, good saturation 13.0–135.7 ft





Appendix II-3

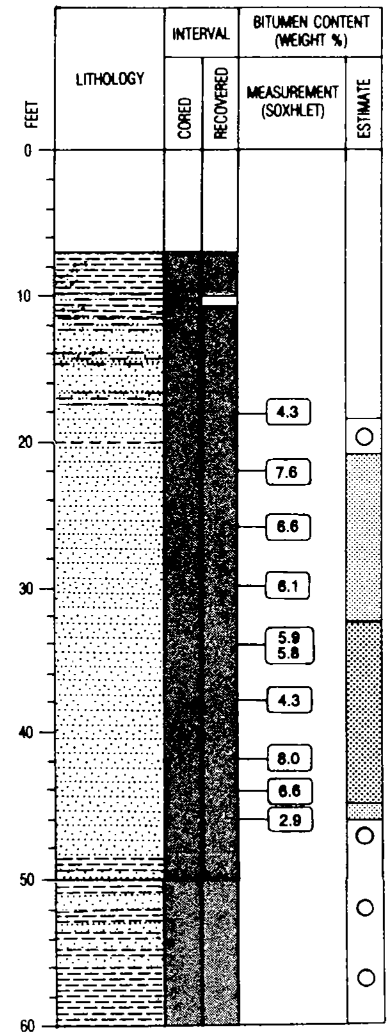
Lithologic Description of the OGS 1 Overbrook

(Explanation on page 20.)

OGS 1 Overbrook

Carter County, Oklahoma
1,400 ft FNL, 1,900 ft FWL, sec. 26, T. 5 S., R. 1 E.
Total depth = 60.0 ft

(ft)	
0.0–7.0	Drilled
7.0–10.0	Cored, recovered 7.8–10.0 ft
7.8–9.8	Gray shale with scattered chert pebbles
9.8–10.0	Reddish-brown, calcareous, fossiliferous siltstone or mudstone
10.0–20.0	Cored, recovered 10.5–20.0 ft
10.5–12.1	Interbedded gray pebbly shale and reddish-brown siltstone
12.1–20.0	Brown, very fine-grained, silty, laminated sandstone with show of live oil, trace of bitumen 18.0–20.0 ft
20.0–30.0	Cored, recovered 20.0–30.0 ft
20.0–20.1	Gray shale
20.1–30.0	Very fine-grained laminated sandstone, poor to moderate saturation
30.0–40.0	Cored, recovered 30.0–40.0 ft
30.0–40.0	Sandstone as above
40.0–50.0	Cored, recovered 40.0–50.0 ft
40.0–48.6	Sandstone as above, moderate to good saturation 40.0–45.0 ft
48.6–49.4	Light gray sandy shale
49.4–50.0	Light brown very fine sandstone with possible oil stain
50.0–60.0	Cored, recovered 50.0–60.0 ft
50.0–55.0	Thin interbedded gray to tan shale and reddish-brown very fine sandstone with possible oil stain in sandstone
55.0–60.0	Light gray to light greenish-gray shale with small plant fragments



Appendix III-1

Bitumen Content of Selected OGS Cores from the Sulphur Deposit

Core	Depth (ft)	Bitumen (wt.%)
OGS 1	—	No bitumen present
OGS 2	25.4	3.3
	25.7	3.3
	62.2	2.2
	62.4	2.3
	80.4	6.0
	80.7	5.6
	118.2	3.5
	118.4	3.5
	Average	3.7
OGS 3	106.0	8.2
	110.0	4.1
	111.5	5.3
	115.0	2.4
	119.0	3.4
	121.0	5.7
	121.1	5.7
	124.0	0.7
	127.0	0.9
	130.0	0.8
	133.0	2.2
	136.0	3.6
	139.0	1.3
	142.0	1.5
	144.5	1.0
	Average	3.1
OGS 4	55.0	4.3
	58.0	3.2
	67.0	3.0
	70.0	3.6
	76.0	4.0
	79.0	3.7
	88.0	3.9
	90.0	1.8
	93.0	3.4
	96.0	5.4
	100.0	3.4
	106.0	2.6
	109.0	4.2
	115.0	8.4
	122.0	9.1
	122.1	8.7
	125.0	8.4
	127.0	7.8
	130.0	3.3
	134.0	0.6
	138.0	0.7
	142.0	1.0
	Average	4.3

(continued in right column)

Core	Depth (ft)	Bitumen (wt.%)
OGS 5	19.0	3.4
	22.0	0.6
	25.0	0.6
	28.0	0.4
	39.0	1.4
	43.0	0.6
	46.0	0.5
	53.6	6.8
	53.7	6.7
	57.0	3.0
	60.0	2.8
	63.0	1.4
	80.0	5.2
	83.0	1.4
	86.0	2.6
	89.0	5.6
	92.0	4.9
	98.0	0.4
	100.0	7.6
	105.0	9.8
	108.0	8.3
	108.1	8.1
	115.0	10.1
	120.0	8.2
	125.0	9.8
	125.1	9.7
	130.0	10.9
	135.0	6.1
	Average	4.9
OGS 6	—	No bitumen present
OGS 7	—	No bitumen present
OGS 8	60.3	2.3
	60.5	2.4
	Average	2.4
OGS 9	60.0	0.8
	66.0	0.7
	70.0	0.5
	73.5	0.6
	77.0	0.8
	80.0	1.1
	86.5	1.2
	Average	0.8
OGS 10	27.5	1.0
	30.0	1.0
	31.0	1.6
	33.5	1.6
	35.6	0.3
	36.0	0.7
	72.4	2.2
	73.0	3.1
	Average	1.4

Appendix III-2

Bitumen Content of Selected OGS Cores from the South Woodford Deposit

Core	Depth (ft)	Bitumen (wt.%)
OGS 1 Skelton		
	—	nbp*
OGS 2 Skelton		
	—	nbp*
OGS 3 Skelton		
	14.0	6.2
	14.5	6.3
	18.0	5.3
	22.0	6.1
	26.0	5.8
	30.0	7.6
	34.0	7.5
	38.0	8.6
	42.0	8.4
	46.0	10.0
	50.0	7.6
	54.0	10.1
	58.0	12.1
	62.0	10.7
	66.0	13.4
	66.5	13.6
	70.0	11.6
	74.0	12.4
	78.0	12.8
	82.0	11.3
	86.0	11.2
	90.0	11.7
	94.0	11.0
	98.0	11.0
	102.0	12.2
	102.5	12.0
	106.0	11.8
	110.0	12.4
	114.0	11.4
	118.0	10.3
	122.0	9.3
	126.0	11.3
	130.0	11.6
	130.5	11.5
	134.0	9.9
	Average	10.2
OGS 1 Fitzgerald		
	9.0	4.8
	12.0	5.3
	15.0	8.5
	18.0	12.5
	21.0	12.5
	24.0	10.8
	28.0	12.3
	32.0	13.3
OGS 1 Fitzgerald *(continued)*		
	32.5	13.1
	36.0	12.5
	40.0	10.8
	44.0	12.3
	48.0	12.1
	52.0	12.8
	56.0	12.2
	60.0	12.7
	64.0	10.9
	68.0	11.0
	74.0	11.5
	78.0	10.3
	78.5	10.6
	82.0	11.5
	86.0	10.1
	90.0	12.8
	94.0	11.6
	98.0	12.5
	104.0	11.2
	108.0	11.8
	110.0	11.6
	114.0	13.6
	118.0	13.4
	122.0	11.5
	122.5	11.4
	126.0	10.5
	130.0	7.6
	134.0	9.6
	138.0	10.4
	142.0	13.0
	146.0	8.7
	150.0	11.8
	154.0	10.0
	157.5	10.5
	Average	13.3
OGS 2 Fitzgerald		
	7.0	6.7
	11.0	9.0
	15.0	10.8
	19.0	12.2
	19.5	12.7
	23.0	11.2
	27.0	10.2
	31.0	11.3
	35.0	9.2
	39.0	10.5
	43.0	11.0
	47.0	7.8
	51.0	8.5
	51.5	8.5
	55.0	9.6
OGS 2 Fitzgerald *(continued)*		
	59.0	10.3
	63.0	11.3
	67.0	11.4
	71.0	9.8
	75.0	9.5
	79.0	7.3
	83.0	12.0
	87.0	8.5
	91.0	8.9
	95.0	10.6
	99.0	7.8
	103.0	8.3
	107.0	9.5
	107.5	9.6
	111.0	10.7
	115.0	3.9
	Average	9.6
OGS 3 Fitzgerald		
	6.0	14.9
	10.0	14.3
	14.0	13.1
	18.0	11.1
	18.5	11.6
	21.0	12.6
	24.0	12.1
	28.0	10.5
	30.0	11.7
	34.0	17.9
	38.0	15.1
	42.0	8.3
	46.0	12.5
	50.0	13.8
	54.0	12.6
	58.0	12.1
	58.5	12.1
	62.0	13.4
	66.0	12.0
	70.0	13.4
	74.0	13.4
	78.0	12.9
	82.0	11.1
	86.0	9.0
	90.0	10.6
	Average	12.5
OGS 4 Fitzgerald		
	6.0	12.8
	10.0	12.7
	14.0	11.0

(continued on next page)

Appendix III-2: Bitumen Content of Selected OGS Cores from the South Woodford Deposit *(continued)*

Core	Depth (ft)	Bitumen (wt.%)
OGS 4 Fitzgerald *(continued)*		
	18.0	10.6
	22.0	11.2
	26.0	11.6
	30.0	11.2
	34.0	12.9
	38.0	12.1
	38.5	12.5
	42.0	13.2
	46.0	13.6
	50.0	14.2
	54.0	15.0
	58.0	11.2
	62.0	11.2
	66.0	12.1
	70.0	12.2
	74.0	10.7
	78.0	12.1
	82.0	11.6
	86.0	12.8
	90.0	14.7
	94.0	14.9
	98.0	14.0
	102.0	16.2
	106.0	12.2
	110.0	14.9
	114.0	15.0
	118.0	10.8
	122.0	11.0
	122.5	11.4
	126.0	9.6
	130.0	10.8
	134.0	10.4
	138.0	11.0
	142.0	12.4
	146.0	12.6
	150.0	11.5
	154.0	12.3
	158.0	11.6
	158.5	11.5
	162.0	10.6
	166.0	13.2
	170.0	10.2
	174.0	10.8
	178.0	7.2
	182.0	1.9
	Average	14.0
OGS 5 Fitzgerald		
	16.0	8.6
	18.0	9.5
	18.5	9.4
	20.0	10.3
	24.0	11.0
	28.0	10.8
OGS 5 Fitzgerald *(continued)*		
	32.0	12.0
	36.0	12.1
	40.0	12.6
	44.0	12.6
	48.1	14.1
	52.0	13.6
	56.0	9.2
	60.0	14.0
	64.0	16.5
	68.0	11.3
	72.0	12.6
	76.0	12.3
	80.0	12.0
	84.0	12.7
	88.0	12.2
	92.0	11.6
	96.0	11.3
	100.0	11.4
	104.0	10.4
	108.0	10.7
	112.0	13.0
	116.0	14.0
	116.5	14.4
	120.0	4.8
	124.0	10.8
	128.0	6.2
	132.0	13.4
	136.0	13.5
	140.0	11.2
	144.0	8.2
	148.0	9.8
	152.0	14.1
	156.0	7.1
	160.0	10.7
	164.0	11.9
	168.0	10.5
	172.0	3.7
	176.0	9.4
	180.0	11.6
	184.0	9.5
	188.0	8.7
	188.5	9.0
	192.0	9.8
	196.0	9.2
	200.0	8.8
	204.0	11.1
	208.0	12.5
	212.0	12.2
	216.0	8.8
	220.0	12.7
	224.0	9.0
	228.0	7.8
	228.5	7.8
	232.0	14.4
OGS 5 Fitzgerald *(continued)*		
	236.0	10.2
	240.0	5.4
	244.0	10.1
	248.0	9.6
	252.0	12.2
	256.0	7.8
	Average	10.8
OGS 6 Fitzgerald		
	8.0	8.3
	12.0	9.4
	16.0	11.8
	20.0	9.2
	24.0	9.3
	28.0	10.0
	28.5	9.9
	32.0	8.9
	36.0	10.8
	40.0	10.9
	44.0	9.8
	48.0	12.2
	52.0	11.6
	56.0	9.5
	60.0	10.6
	64.0	8.7
	68.0	11.0
	72.0	11.6
	76.0	11.8
	80.0	10.8
	84.0	9.0
	88.0	10.5
	92.0	7.3
	96.0	11.3
	100.0	7.8
	100.5	8.2
	104.0	7.7
	108.0	9.3
	112.0	4.8
	116.0	8.5
	120.0	8.8
	124.0	9.3
	128.0	9.3
	132.0	3.9
	Average	9.5

*No bitumen present.

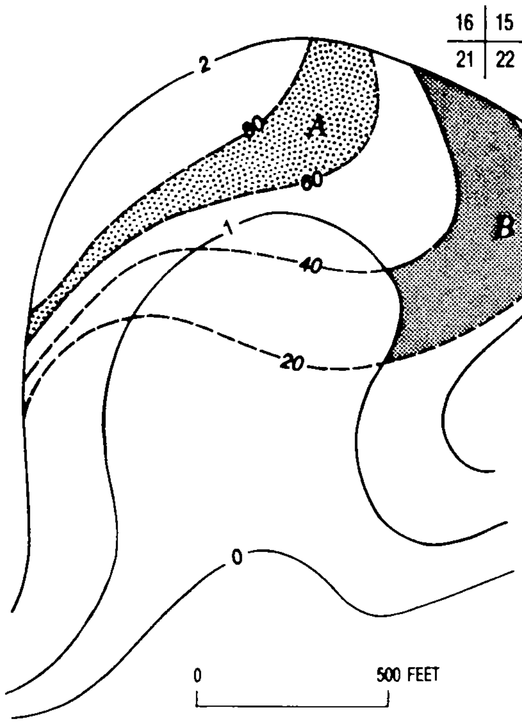
Appendix III-3

Bitumen Content of Selected Cores from the OGS 1 Overbrook

Depth (ft)	Percent bitumen (wt.)
18.0	4.3
22.0	7.6
26.0	6.6
30.0	6.1
34.0	5.9
34.5	5.8
38.0	4.3
42.0	8.0
44.0	6.6
46.0	2.9
Average	5.8

Appendix IV-1

Sample Calculation for In-Place Bitumen Determination, Sulphur Deposit



Area A Calculation:

A = 0.61 in.^{2} = 3.50 acres
Bitumen content = 1.5 weight percent
Sandstone thickness = 70 feet
Bitumen S.G. = 1.043 g/cc
Silica sand S.G. = 2.65 g/cc
197.2 bbl bitumen in 1 acre-foot at 1.0 weight percent
(3.50 acres)(70 feet) = 245 acre-feet
(245 acre-feet)(1.5 × 197.2) = *72,471 bbl bitumen*

Area B Calculation:

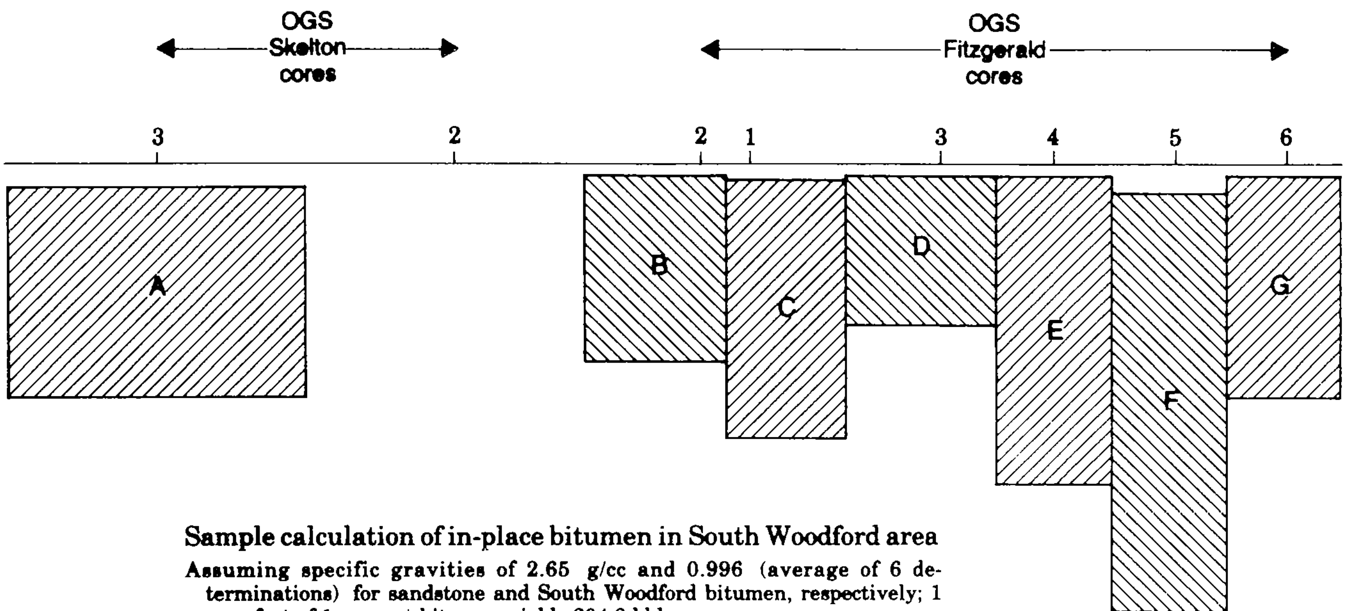
B = 3.90 acres
Bitumen content = 1.5 weight percent
Sandstone thickness = 30 feet
(117 acre-feet) (1.5 × 197.2) = *34,609 bbl bitumen*

——— Bitumen content (wt. %)

– – – Sandstone thickness (feet)

Appendix IV-2

Sample Calculation for In-Place Bitumen Determination, South Woodford Deposit



Sample calculation of in-place bitumen in South Woodford area

Assuming specific gravities of 2.65 g/cc and 0.996 (average of 6 determinations) for sandstone and South Woodford bitumen, respectively; 1 acre-foot of 1-percent bitumen yields 204.8 bbl.

Sample calculation of in-place bitumen. Width of bitumen-impregnated sandstone is 85 feet. Block C is 1,375 feet long (bounded by mid-point between Fitzgerald cores 1 and 2, and 1 and 3) and has a total bitumen-impregnated thickness of 149 feet. Average bitumen content (4 determinations) is 13.3% (wt.).

(1375)(85) = 2.68 acres

(2.68)(149)(13.3)(204.9) = 1,087,685 bbl