Bureau of Mines
Report of Investigations 4768

VARIABLE CHARACTERISTICS OF THE OIL IN THE TENSLEEP SANDSTONE RESERVOIR, ELK BASIN FIELD, WYOMING AND MONTANA

BY RALPH H. ESPACH AND JOSEPH FRY

United States Department of the Interior— April 1951

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UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary
BUREAU OF MINES
James Boyd, Director

This report represents work done under a cooperative agreement between the Bureau of Mines, United States Department of the Interior, and the University of Wyoming.

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by

Ralph H. Espach[1] and Joseph Fry[1]

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1/ Petroleum engineer.

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SUMMARY

In the spring of 1943, when it was evident that the Tensleep sandstone in the Elk Basin field, Wyoming and Montana, held a large reserve of petroleum, Bureau of Mines engineers obtained samples of oil from the bottom of nine wells and analyzed them for such physical characteristics as the volumes of gas in solution, saturation pressures or bubble points, shrinkage in volume caused by the release of gas from solution; expansion of the oil with decrease in pressure, and other related properties. The composition of the gas in solution in the oil was studied. The pressures and temperatures existing in the reservoir and the productivity characteristics of the oil wells were determined.

The data obtained indicate that the oil in the Tensleep reservoir of the Elk Basin field has unusually varying physical characteristics, such as a saturation pressure of 1,250 pounds per square inch absolute and 490 cubic feet of gas in solution in a barrel of oil at the crest of the structure, and a saturation pressure of 530 pounds per square inch absolute and 134 cubic feet of gas in solution in a barrel of oil low on the flanks. The hydrogen sulfide content of the gas in solution in the oil varies from 18 percent for oil on the crest to 5 percent for oil low on the flanks of the structure. Of even greater significance is the fact that these and other variable characteristics of the reservoir oil are related to the position of oil in the structure. Many geologists and petroleum engineers have considered all the oil in a petroleum reservoir to have uniform physical characteristics and that equilibrium conditions prevailed in all underground accumulations of oil and gas. That such is not always so is borne out by the results of the study made by the writers.

INTRODUCTION

The Rocky Mountain area is one in which confirmation as well as invalidation of accepted theories regarding oil and gas accumulation may be found. In the area are striking examples of the unusual as is evident from the following observations: The high helium content (7.6 percent) of the gas in the Ouray-Leadville limestone sequence in the Rattlesnake field, New Mexico and gases of similar helium contents in other fields; 50 to 55° A.P.I. gravity distillate in solution in carbon dioxide gas and recoverable through retrograde condensation, in the North McCallum field, Colorado; the occurrence of gas and oil in closely related structures contrary to the usual concepts of gravimetric segregation; the accumulation of gas, oil, or both in structures closely related to other structures that apparently are more favorable but do not contain oil or gas accumulations; the high hydrogen sulfide content (as high as 42 percent) of the gas associated with oil in some fields in the Big Horn Basin, Wyoming; and the wide range of fluid characteristics found in the Elk Basin reservoir.

Elk Basin, an interesting old oil field that has been producing oil from the Frontier formation since 1915, is situated in a highly eroded basin, resulting from the wearing away of the crest of an anticline and some of the underlying softer shales. The field came back into national prominence during 1943, when it became known that it was the largest single reserve of new oil found in the United States that year. The Tensleep sandstone was found to contain oil on November 26, 1942, when a well in the NE 1/4, NE 1/4, NE 1/4, sec. 31, T. 58 N., R. 99 W., Park County, Wyo., drilled to a depth of 4,538 feet (44 feet into the Tensleep sandstone), flowed oil at the rate of 2,500 barrels a day. By the end of 1945, 125 oil-producing wells and four dry holes had been drilled, and 9,419,271 barrels of oil had been produced. Three additional wells were drilled in each of the years 1946 and 1947, and the oil produced amounted to 5,605,833 barrels in 1946 and 5,869,123 barrels in 1947. Approximately 6,000 acres may be considered as productive of oil in the Tensleep reservoir, and estimates of the oil that will be produced average 200 million barrels.

The Tensleep reservoir is of further interest because it has greater closure than any oil field in the Rocky Mountain area; the closure of the Elk Basin anticline is variously estimated to be 5,000 to 10,000 feet, and the top 2,000 feet of the structure contained oil.

ACKNOWLEDGMENTS

The work covered in this report was conducted under a cooperative agreement between the Bureau of Mines, United States Department of the Interior, and the University of Wyoming.

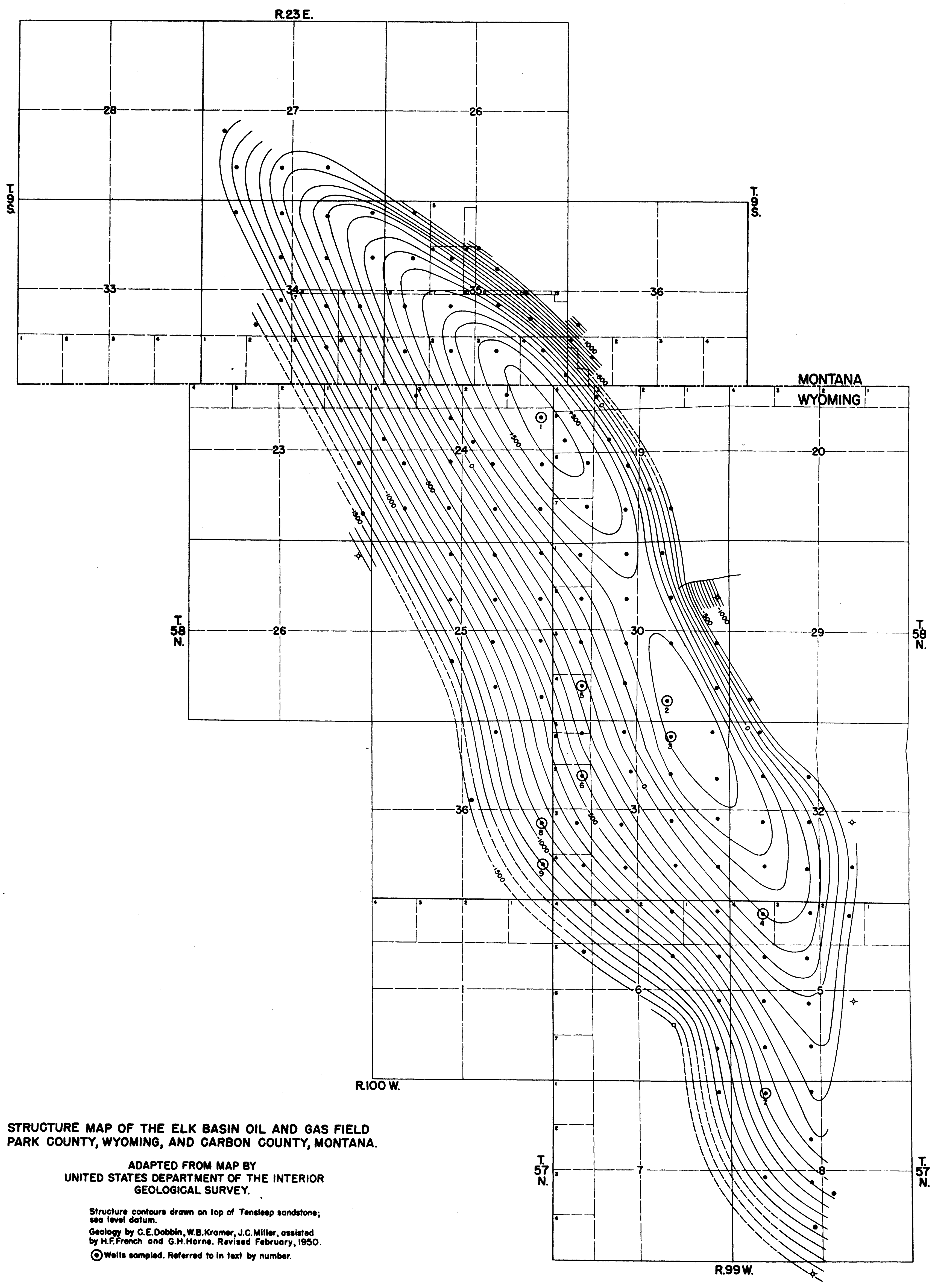
The writers and those engaged in the work appreciate the assistance of the operators in the Elk Basin field, who gave the engineers of the Bureau of Mines access to their properties, supplied the wells for testing and sampling purposes, and supplied most of the information pertaining to the Tensleep reservoir itself.

The report was prepared under the general supervision of R. A. Cattell, chief, Petroleum and Natural Gas Branch, Bureau of Mines, Washington, D. C., and H. P. Rue, supervising engineer, Petroleum and Oil-Shale Experiment Station, Bureau of Mines, Laramie, Wyo. The constructive criticisms of the manuscript by C. B. Carpenter (deceased), A. B. Cook, H. C. Miller, and E. M. Tignor, engineers of the Bureau of Mines, are gratefully acknowledged. The work of three engineers formerly at the Laramie experiment station - H. Karl Schmidt and Warren J. Mason on the first group of oil samples and Raymond A. Morgan on the second group of samples - in addition to that of the writers resulted in acquiring the data presented in this report. O. C. Heustis prepared the illustrations.

SUBSURFACE OIL SAMPLING

An electromagnetic-type sampler developed by the Bureau of Mines and described by Grandone and Cook,2/ was used in obtaining the subsurface oil samples.

2/ Grandone, Peter, and Cook, Alton B., Collecting and Examining Subsurface Samples of Petroleum: Bureau of Mines Tech. Paper 629, 1941, pp. 12-19 and 59-64.



STRUCTURE MAP OF THE ELK BASIN OIL AND GAS FIELD
PARK COUNTY, WYOMING, AND CARBON COUNTY, MONTANA.

ADAPTED FROM MAP BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY.

Structure contours drawn on top of Tensleep sandstone; sea level datum.
Geology by C.E. Dobbin, W.B. Kramer, J.C. Miller, assisted by H.F. French and G.H. Horne. Revised February, 1950.
⊙ Wells sampled. Referred to in text by number.

FIGURE I. ELK BASIN, TENSLEEP RESERVOIR, MAP.

As the wells were tubed nearly to bottom, the sampler was run as far as possible in the tubing but never below the top perforations. Thus, oil leaving the reservoir had to flow through or around the sampler on its way to the well head, and pressures at the sampling point were the maximum obtainable.

The following procedure in testing and sampling the wells was used: A well was shut in for at least 3 days, after which shut-in subsurface pressures and temperatures were measured. Generally, the well then was allowed to flow at a 10- to 20-barrel per hour rate for approximately 1 day, when a flowing temperature and pressure traverse was run. One day later, at the same production rate, a subsurface sample was obtained and transferred to a storage container. A second subsurface sample of oil then was procured, and if, in transferring, the pressure and volume data duplicated those of the first sample, both were considered satisfactory for analyses. After sampling was completed, the flow rate of the well was increased to two higher rates, and subsurface pressure traverses were obtained at each rate. A 12-hour subsurface-pressure build-up was obtained when the well was shut in following the highest rate of flow. A pressure gage recorded the tubing and casing pressures at the well head during the tests. The oil produced by the well during the tests was gaged in lease tanks at regular intervals, and the separator gas was measured with a recording orifice meter. The essential data pertaining to the wells are given in table 1.

Wells 7 and 9 were not producing when sampled. Well 7 had flowed most of the indicated production, but the flow gradually lessened, and the well finally quit flowing. It was sampled several days later. Well 9 was swabbed unsuccessfully to cause it to flow; it had been standing for about 30 days prior to sampling, and, as tubing had not been run to bottom, it was necessary to sample the oil at a relatively high point in the well.

It will be noted that wells 2 and 3 have essentially the same structural position, and for the purposes of this study it might seem that one well would suffice. Well 3, however, produced from the upper 44 feet of the Tensleep formation, and well 2 was completed so that only the zone between 66 and 192 feet below the top of the Tensleep formation produced oil through the tubing. Sampling both wells provided an excellent opportunity to study the possibility of the existence of more than one reservoir in the Tensleep formation, a postulate that had merit because of the rather extensive dolomitic zones extending throughout the sandstone body at depths greater than 70 to 80 feet in the formation. The almost identical results obtained in the analyses of the oil samples from both wells indicated that the oils were the same and that the Tensleep formation contained only one reservoir.

Figure 1 is a structural map of the Elk Basin Tensleep reservoir, on which the nine wells that were used in this study and the numbers corresponding to the well designations herein referred to are shown. Wells 1, 2, 3, 4, and 8 were tested and sampled during October and November 1943, and wells 5, 6, 7, and 9 during June and July 1944.

TABLE 1. - Data relative to wells sampled, Tensleep reservoir, Elk Basin field

Well No.	Date of well completion	Date of sampling	Oil produced to sampling date, bbl.	Gravity of produced oil, °A.P.I.	Top of Tensleep formation: Elevation, ft.	Top of Tensleep formation: Original pressure, p.s.i.a. 1/	Top of Tensleep formation: Temperature, °F. 2/	Sampling point: Elevation, ft.	Sampling point: Pressure, p.s.i.a.	Flow rate while sampling bbl./day
1	9-9-43	11-4-43	20,000	31.8	+655	1853	112	+488	1564	922
2	3-9-43	10-23-43	114,000	31.4	+471	1917	115	+283	1734	454
3	4-18-43	10-15-43	130,000	31.1	+422	1934	116	+413	1644	536
4	7-6-43	10-4-43	34,800	31.0	+ 89	2049	121	- 30	1905	420
5	4-28-44	6-11-44	6,200	30.6	-117	2120	125	-265	1570	486
6	5-2-44	6-21-44	9,200	30.0	-397	2218	129	-557	1720	240
7	4-4-44	6-15-44	13,800	29.1	-683	2319	134	-773	1882	Shut-in
8	8-7-43	10-9-43	52,700	28.4	-887	2392	137	-1044	2023	440
9	-	5-31-44	3/200	27.1	-1107	2472	141	-643	1770	Shut-in

1/ Calculated from estimated original reservoir pressure of 2,080 p.s.i.a. at sea-level datum and density of subsurface samples. See figure 12, Appendix.
2/ From temperature-gradient chart for the Elk Basin structure. See figure 12, Appendix.
3/ Production by swabbing in an attempt to cause the well to flow. Well was pumped subsequent to sampling.

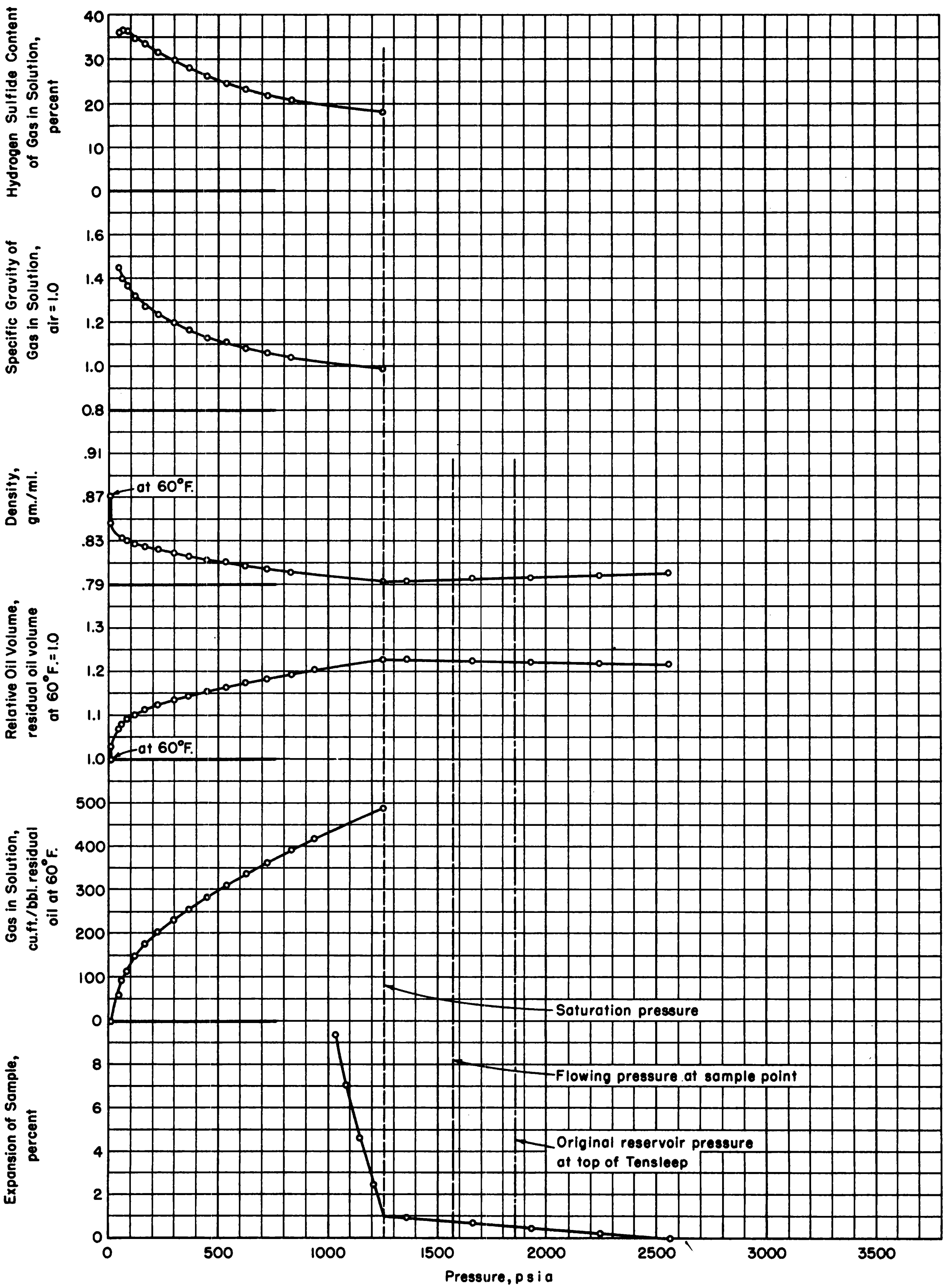


FIGURE 2. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 121°F., SUBSURFACE OIL SAMPLE FROM WELL 1, ELK BASIN FIELD.

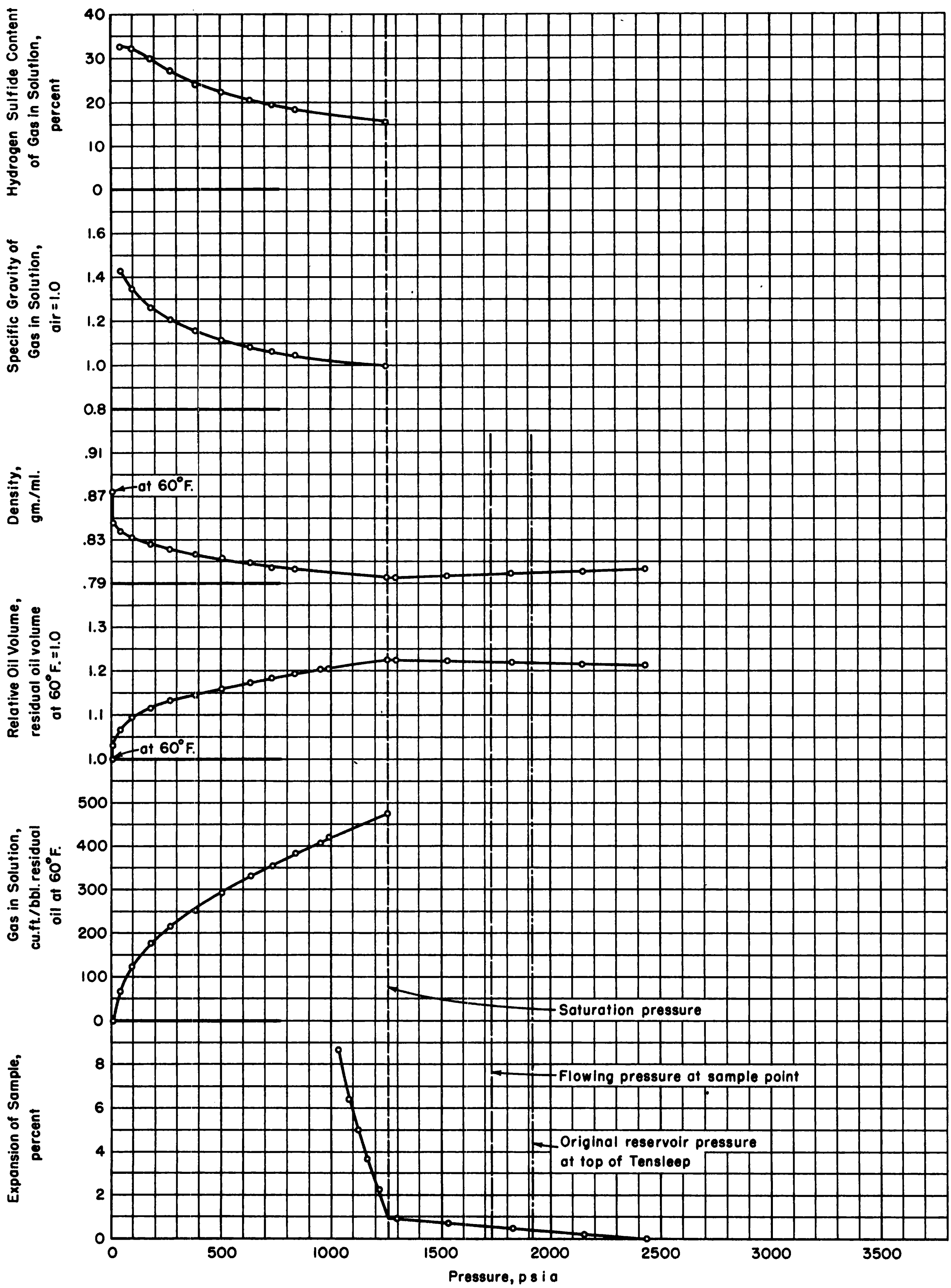


FIGURE 3. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 121°F., SUBSURFACE OIL SAMPLE FROM WELL 2, ELK BASIN FIELD.

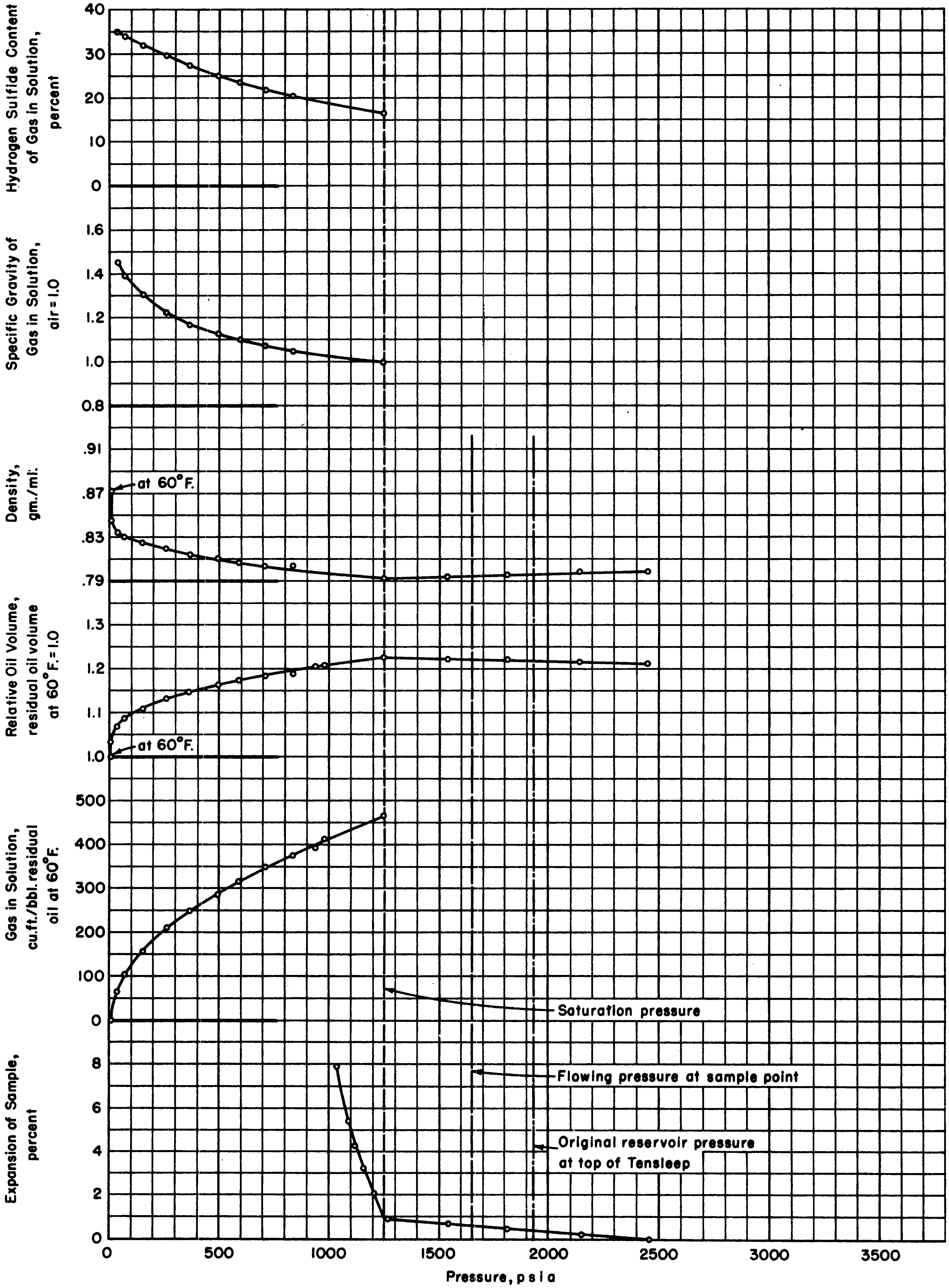


FIGURE 4. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 121°F., SUBSURFACE OIL SAMPLE FROM WELL 3, ELK BASIN FIELD.

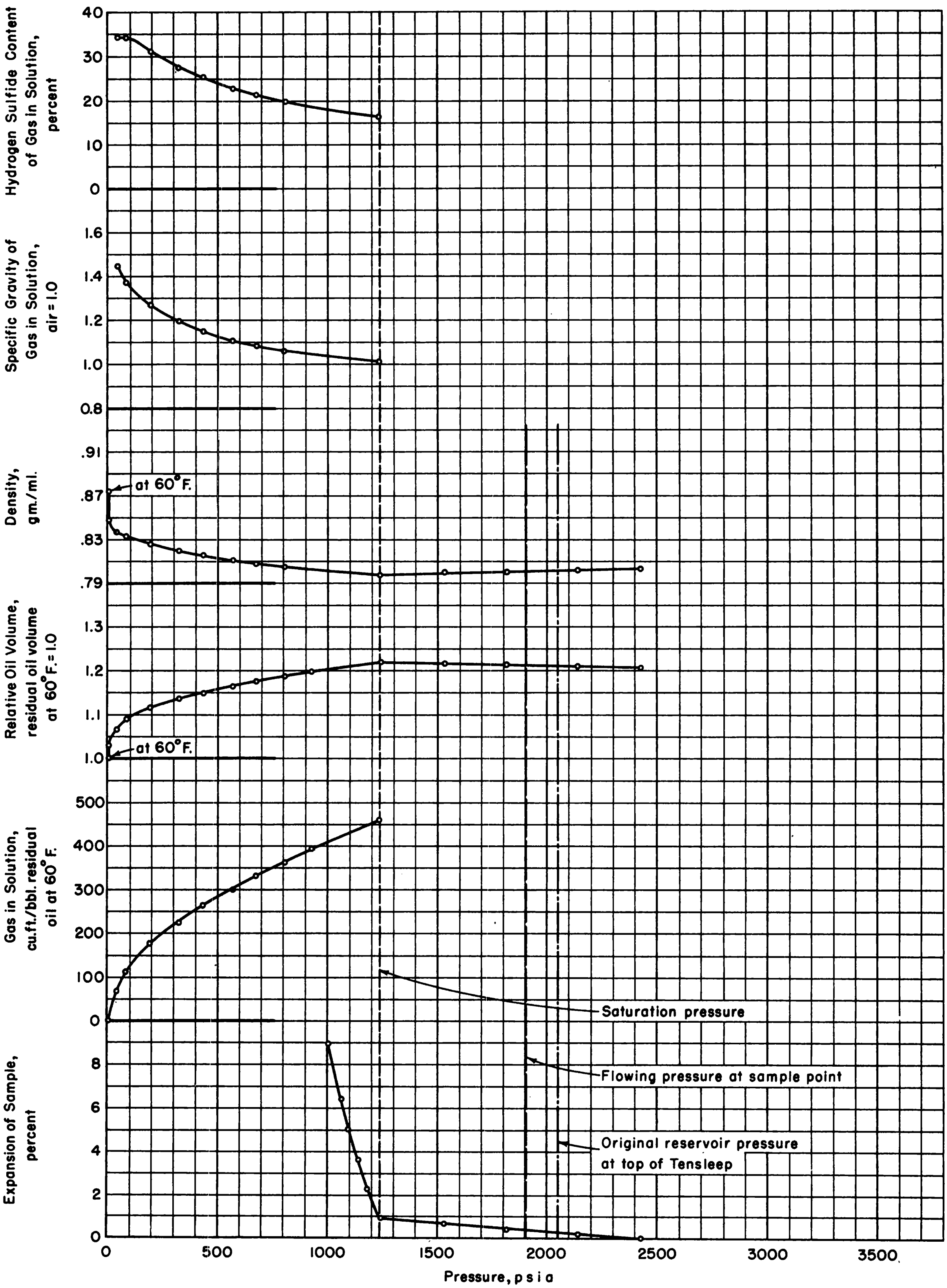


FIGURE 5. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 123°F., SUBSURFACE OIL SAMPLE FROM WELL 4, ELK BASIN FIELD.

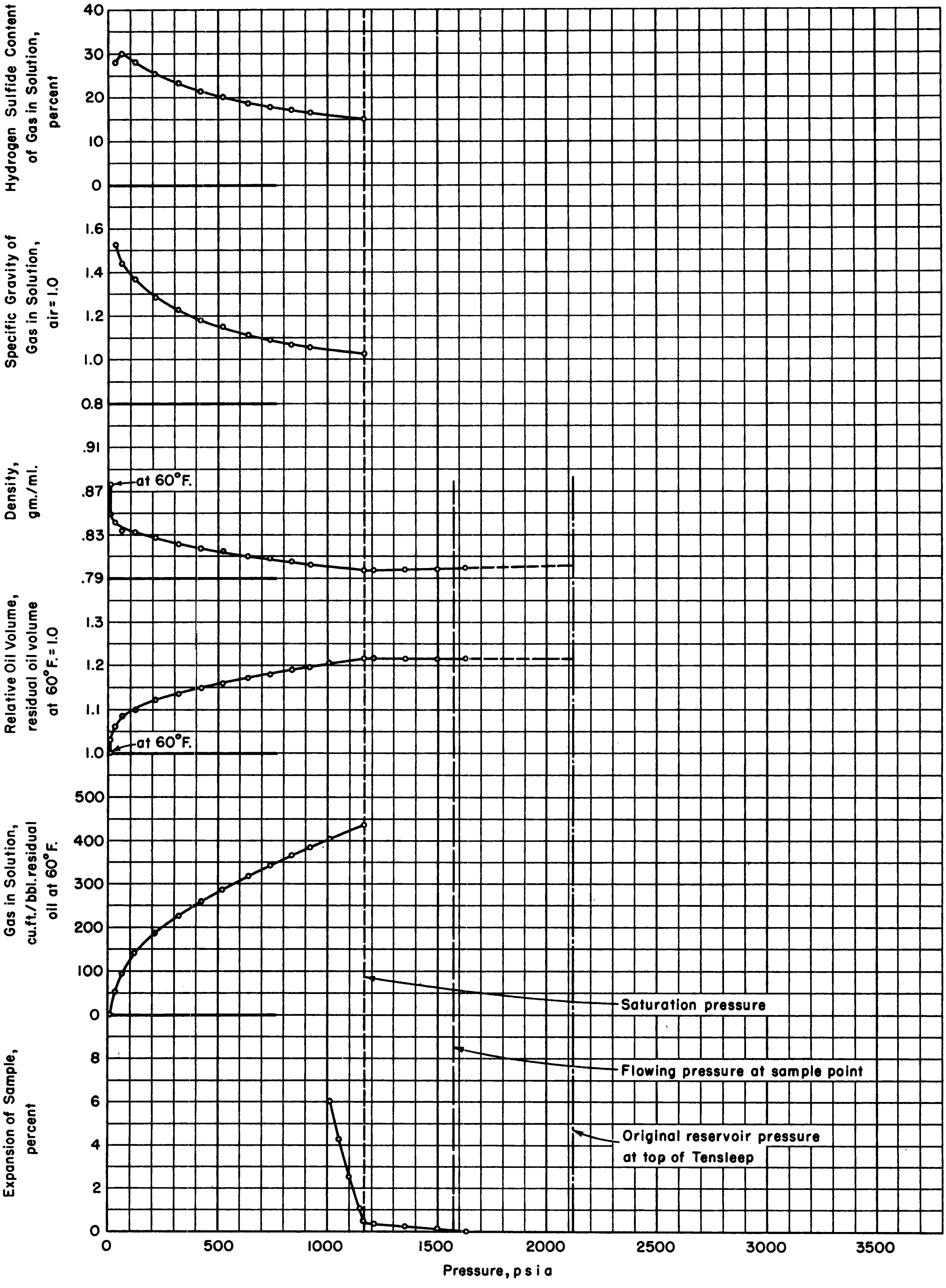


FIGURE 6. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 129°F., SUBSURFACE OIL SAMPLE FROM WELL 5, ELK BASIN FIELD.

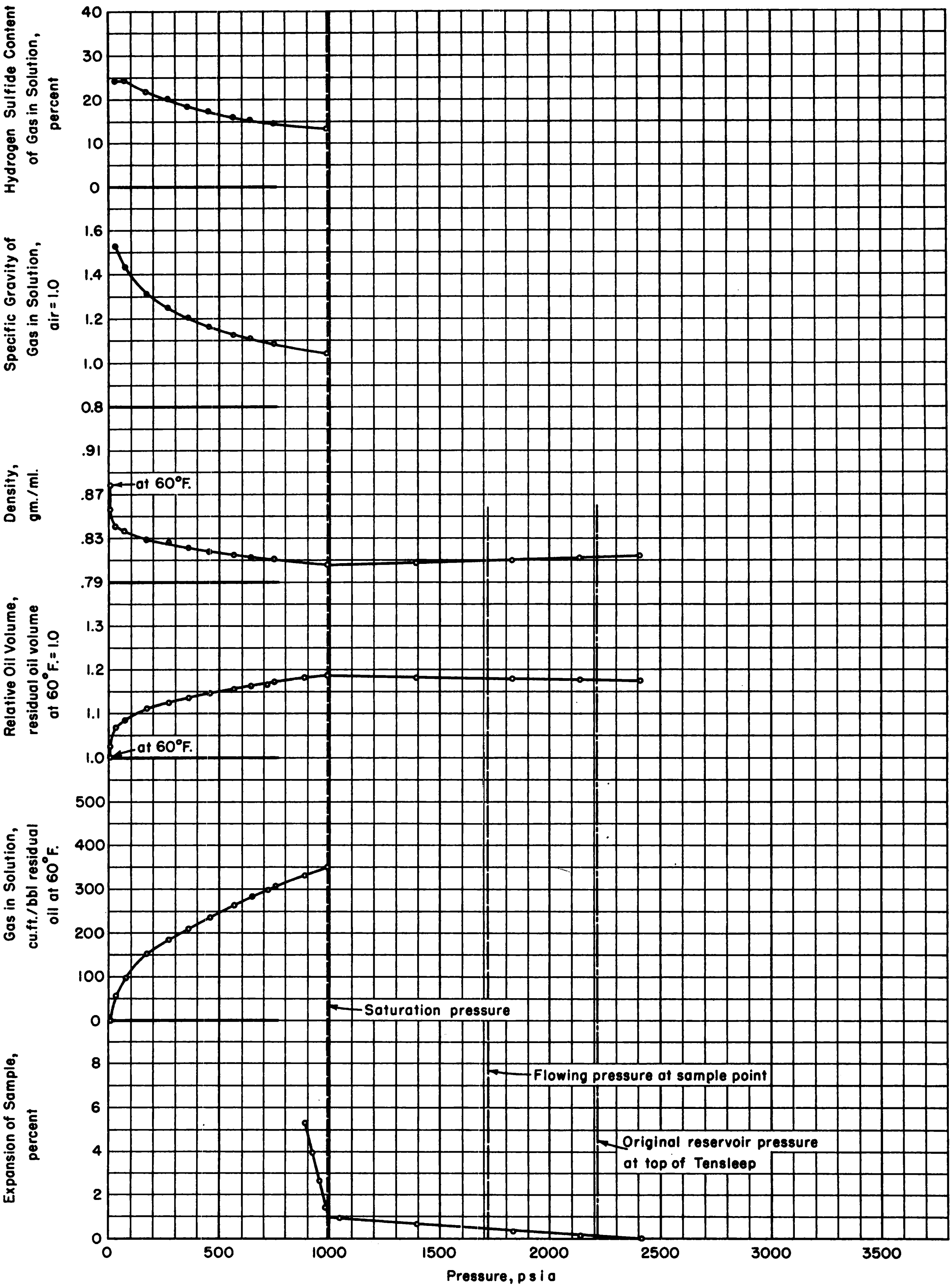


FIGURE 7. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 133°F., SUBSURFACE OIL SAMPLE FROM WELL 6, ELK BASIN FIELD.

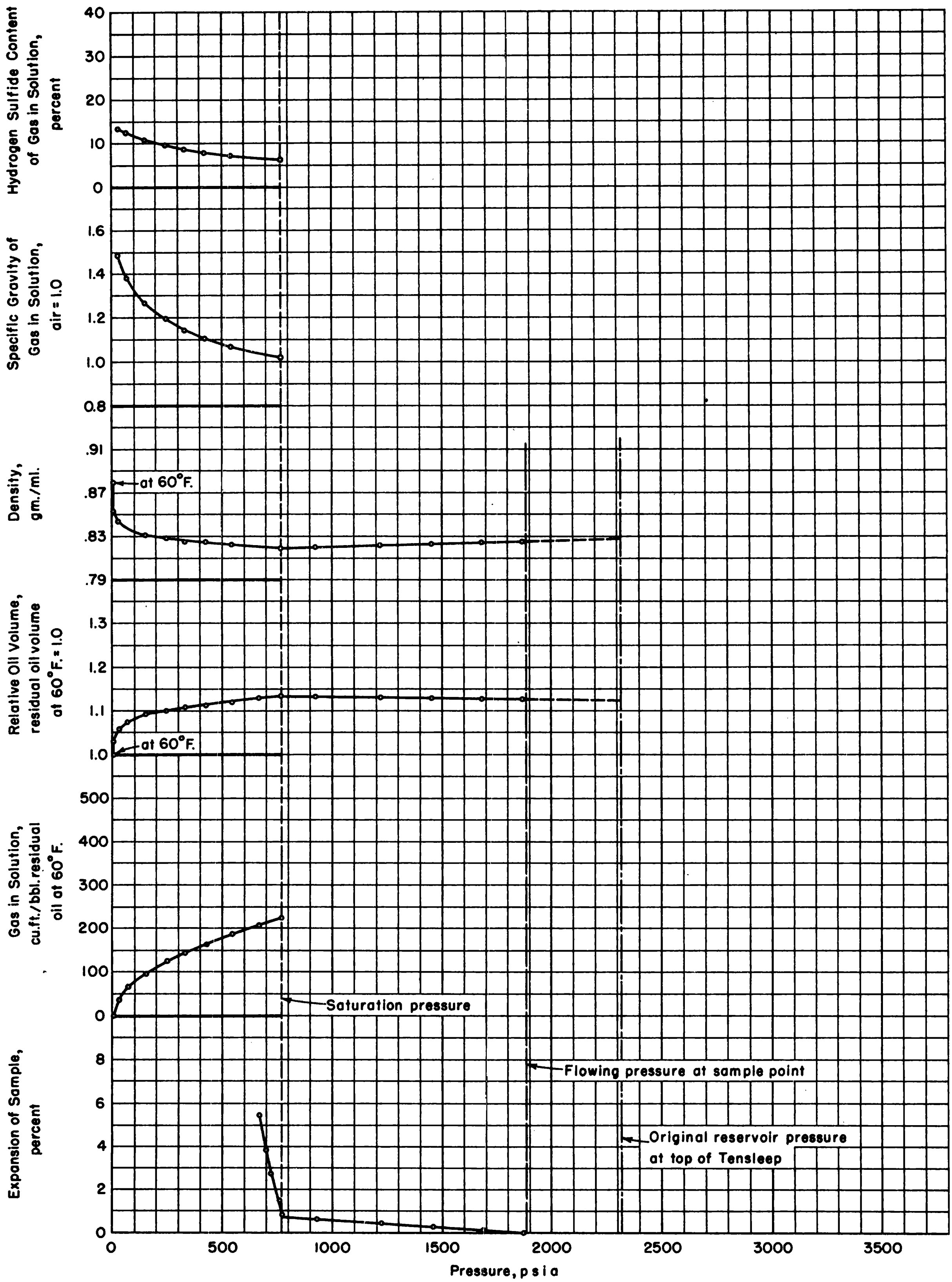


FIGURE 8. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 134°F., SUBSURFACE OIL SAMPLE FROM WELL 7, ELK BASIN FIELD.

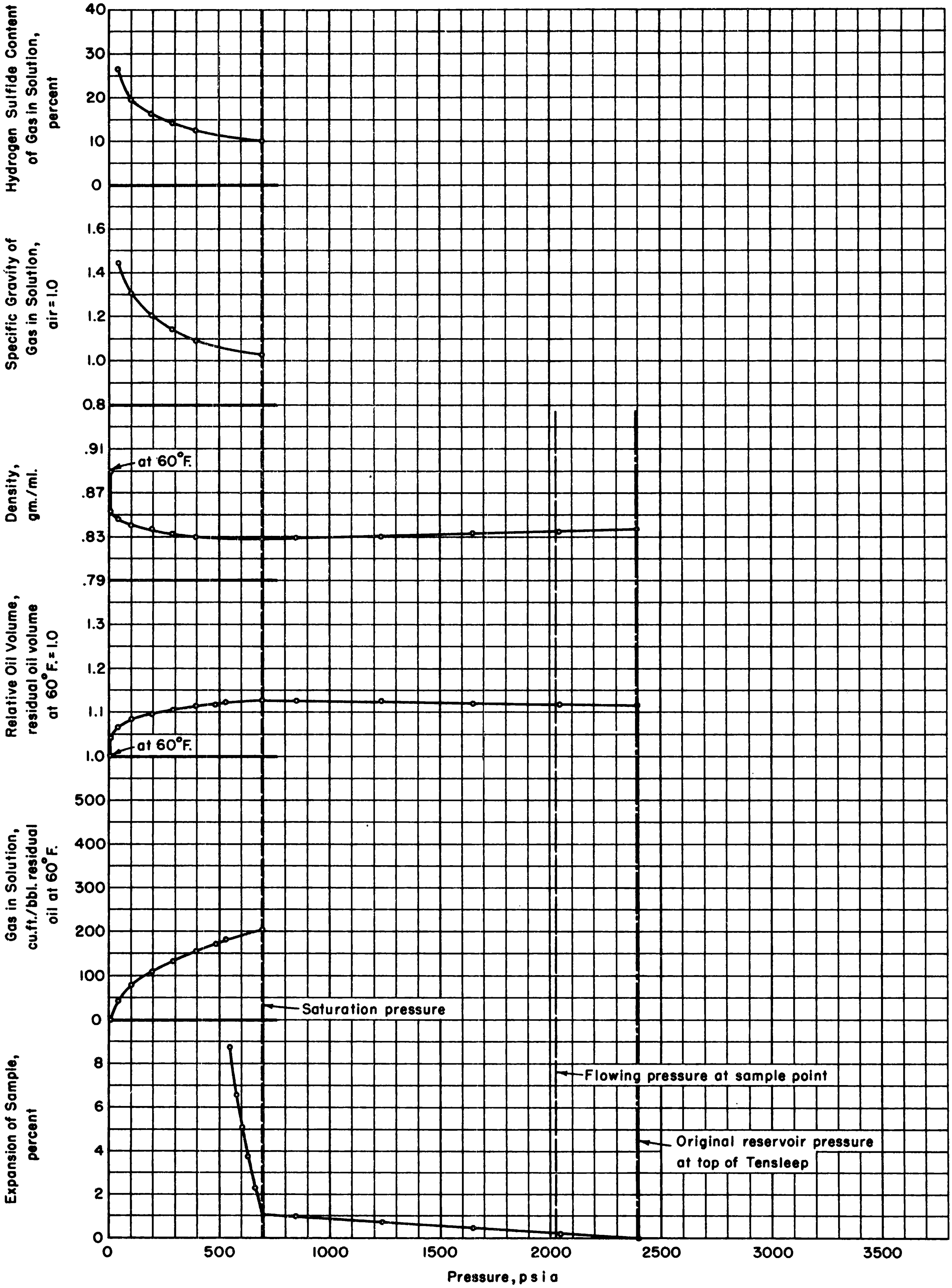


FIGURE 9. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 140°F., SUBSURFACE OIL SAMPLE FROM WELL 8, ELK BASIN FIELD.

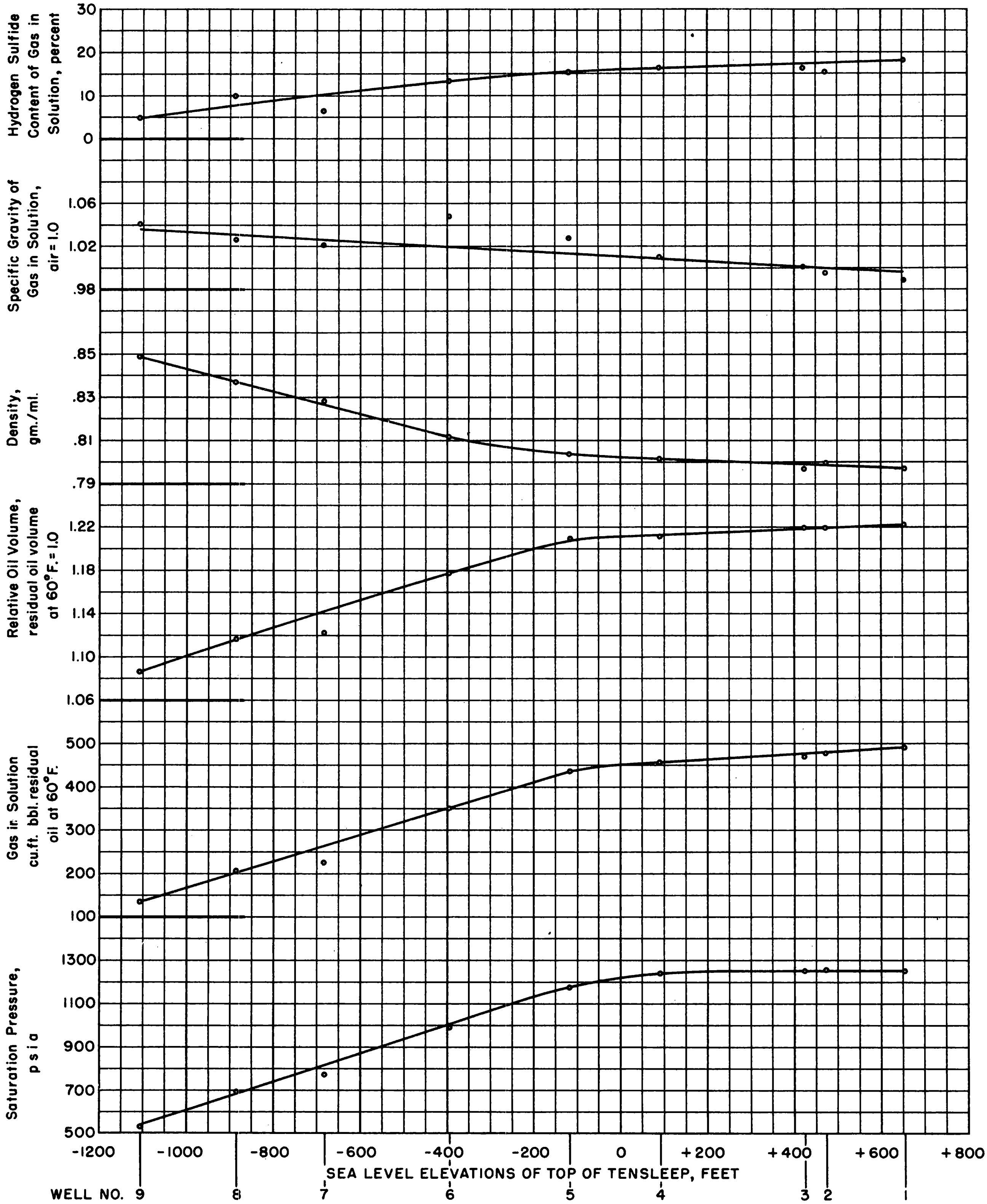


FIGURE 11. RELATIONSHIP OF THE CHARACTERISTICS OF THE OIL AT ORIGINAL CONDITIONS TO THE LOCATION OF THE OIL IN THE TENSLEEP RESERVOIR, ELK BASIN FIELD.

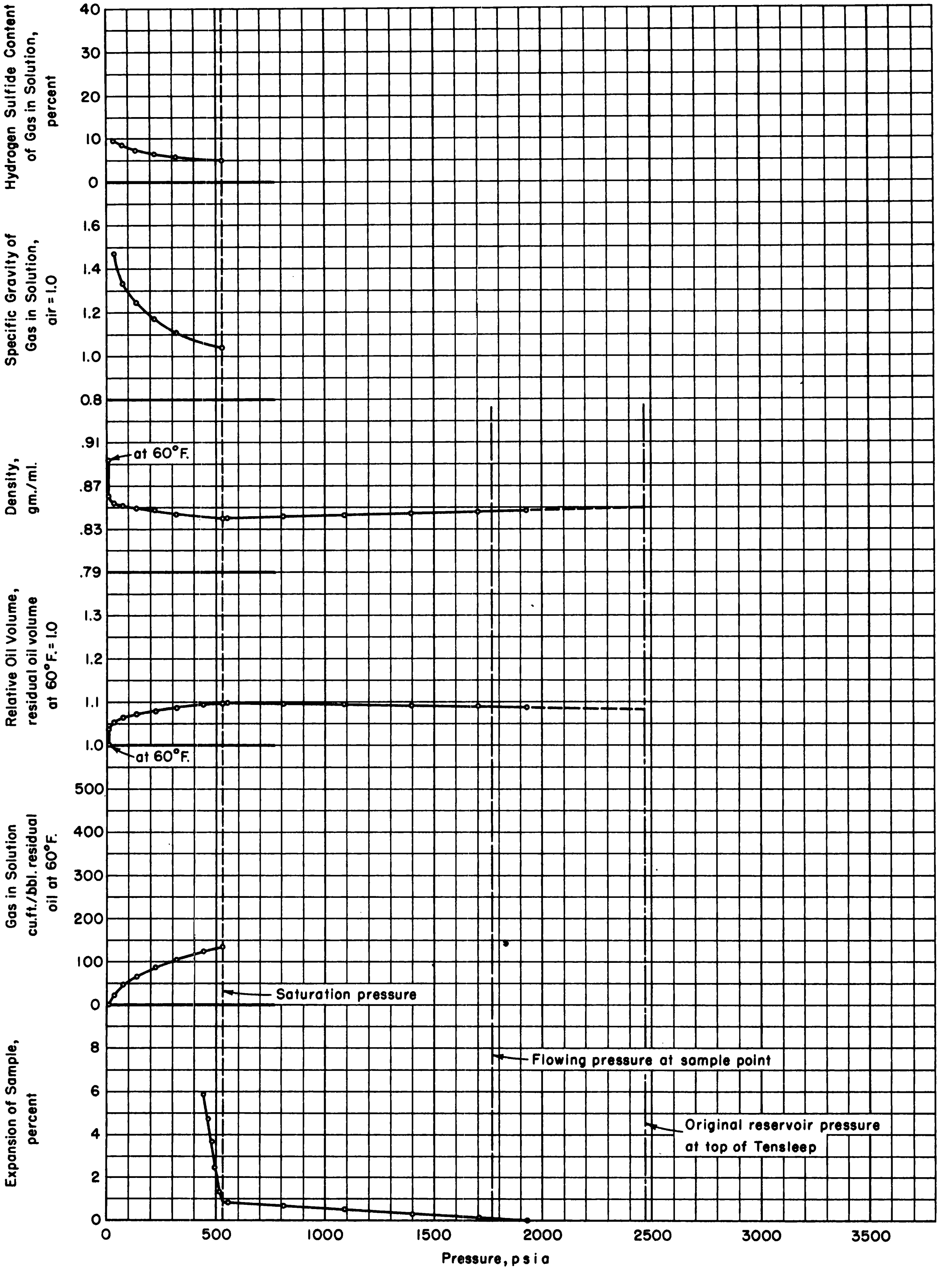


FIGURE 10. RESULTS OF DIFFERENTIAL GAS-LIBERATION ANALYSIS AT 141°F., SUBSURFACE OIL SAMPLE FROM WELL 9, ELK BASIN FIELD.

RESERVOIR OIL CHARACTERISTICS

The subsurface oil samples were analyzed by the differential gas-liberation method outlined by Grandone and Cook.2/ The laboratory analyses of the oil samples were performed at the Petroleum Experiment Station (now Petroleum and Oil-Shale Experiment Station), Bureau of Mines, Laramie, Wyo., during several months following sampling of the wells. The general results are given in table 2. Individual gas-liberation data for the nine samples are given in tables 8 to 16, inclusive (in the Appendix), and are shown in figures 2 to 10, inclusive.

In these figures the graphs of "expansion of sample" are self-explanatory. The values for the gas in the "gas-in-solution" graphs are figured at conditions of 60° F. and 14.4 pounds per square inch absolute pressure. The "relative oil volume" graphs show the volume relationship between the oil in the reservoir under reservoir conditions and the residual oil at 60° F. The "density of sample" graphs indicate the change in density as changes in pressure and release of solution gas take place. The "specific gravity of gas in solution" graphs show the specific gravity of the gas that is in solution in the oil at the different pressures and in volumes as shown by the "gas in solution" graphs. The values for the specific gravity of the gas in solution were obtained by using a 220 ml. gas density balloon, weighing samples of gas liberated between the pressure points as shown on the graph, and calculating the composite to any pressure by using the volumes and weights of the several increments of liberated gas.

The "hydrogen sulfide content of gas in solution" graphs show the percentage of hydrogen sulfide in the gas that is in solution in the oil at the different pressures and in volume as shown by the "gas in solution" graphs. The percentages of H_2S were obtained by running both Tutwiler and Orsat analyses of the increments of liberated gas during analyses of samples from wells 5, 6, 7, and 9, and Orsat analyses for acid gases of the increments of liberated gas during analyses of samples from wells 1, 2, 3, 4, and 8. Where Orsat values alone were determined, from 5 to 6-1/2 percent was subtracted from them as a correction for the carbon dioxide content of the gas. The "hydrogen sulfide content of gas in solution" graphs represent values obtained from the determined percentages of hydrogen sulfide in the several increments of gas liberated between any two adjacent pressures, as indicated by the points on the curves, the volumes of the several increments, and the calculated composites of these to various pressures. Of interest in connection with the "gas in solution" graphs are the data on the H_2S contents of the several increments of gas liberated during the differential gas liberation of a subsurface sample of oil. Such data from the sample of oil from well 1 are given in table 3.

TABLE 2. - General results of analyses of subsurface oil samples, Tensleep reservoir, Elk Basin field

Well No.	Gravity, °A.P.I.		Gas liberation temperature, °F.	Saturation pressure, p.s.i.a.	Gas in solution, cu.ft./bbl. residual oil1/	Relative oil volume2/	Expansibility factor3/	Specific gravity of gas in solution	Hydrogen sulfide content of gas in solution, percent
	At original reservoir pressure	Residual oil, after liberation of gas							
1	45.4	30.7	121	1250	490	1.223	$82x10^{-7}$	0.989	18.2
2	44.9	30.2	121	1255	478	1.220	$82x10^{-7}$	.996	15.8
3	45.4	30.6	121	1250	469	1.221	$79x10^{-7}$	1.001	16.6
4	44.3	30.6	123	1235	459	1.212	$77x10^{-7}$	1.011	16.5
5	44.6	30.2	129	1177	437	1.210	4/$84x10^{-7}$	1.028	15.2
6	42.3	29.5	133	990	350	1.178	$70x10^{-7}$	1.048	13.4
7	39.2	29.1	134	772	225	1.122	$68x10^{-7}$	1.021	6.4
8	37.3	27.7	140	695	205	1.116	$64x10^{-7}$	1.026	10.1
9	34.9	27.0	141	530	134	1.086	$63x10^{-7}$	1.041	4.9

1/ Based upon differential gas-liberation method. Base 14.4 p.s.i.a. and 60° F.
2/ Ratio of reservoir oil volume (at original reservoir conditions at top of Tensleep formation) to residual oil volume at 60° F.
3/ Volumes per volume per p.s.i. pressure change, reservoir oil at pressures above saturation pressure.
4/ This figure probably is in error. Corresponding data from other samples indicate that it should have been approximately $75x10^{-7}$.

TABLE 3. - Hydrogen sulfide content of liberated gas, differential gas liberation, oil sample from well 1

Pressure range in which gas increment liberated, p.s.i.a.	Hydrogen sulfide content of gas increment, percent
1250 to 835	7.6
835 to 725	5.1
725 to 625	5.9
625 to 535	6.8
535 to 450	6.1
450 to 365	10.2
365 to 300	13.0
300 to 225	16.0
225 to 165	19.4
165 to 120	26.7
120 to 85	28.6
85 to 60	35.0
60 to 45	38.0
45 to 11	36.1

The great change in H_2S content of the gas as it is released from solution when the pressure is lowered is significant. It reflects the solubility of H_2S in crude oil. These data and the "gas in solution" graph indicate that at Elk Basin the H_2S content of the gas from the oil in the upper part of the reservoir would increase as reservoir pressures decreased in accordance with the graph, provided the gas:oil ratio during production would not exceed that in solution in the oil. However, increasing gas:oil ratios that normally occur in solution gas drive reservoirs as the pressure declines will result in decreasing the H_2S content of the produced gas, because any volume of gas in excess of that in solution in the oil will contain a smaller percentage of H_2S than the solution gas. Later in the life of the reservoir and declining gas:oil ratios the reverse can be expected.

Owing to the method by which the data were obtained, those data relating to the specific gravity of the increments of gas liberated from the subsurface oil samples and the hydrogen sulfide content of the gas samples are the least accurate of all results reported. In fact, the data show changes in one or two instances that are inconsistent with the data from other samples.

The writers are indebted to two of the operators for information on the viscosity of the reservoir oil from well 2. Oil from well 2 is representative of the oil in the upper 500 or more feet of closure. The viscosity, in centipoises, of the oil at a temperature of 123° F. and at several gage pressures and the estimated viscosities of the oil near the edge of the reservoir are given in table 4.

TABLE 4. - Viscosity of reservoir oil

Pressure, p.s.i.	Oil from well 2, centipoise	Oil from edge wells, centipoise (estimated)
2500	1.59	4.6
2000	1.50	-
1500	1.42	4.3
1130	1.35	-
1000	1.40	-
800	1.50	4.1
600	1.65	4.0
400	1.82	4.1
200	2.05	4.7
0	4.50	8.0

Discussion

A review of the data shown in figures 2 to 10, inclusive, reveals a very interesting conclusion that should be considered in all studies of petroleum reservoirs, namely, that the oil in a reservoir may have rather widely varying physical characteristics. That these characteristics may be related to the location of the oil in the structure will be discussed in a subsequent section of this report.

In general, many engineers and geologists have reasoned that, considering the length of time involved in the formation of an oil field, equilibrium must have been attained between the fluids in the reservoir, and if any of the oil was saturated with gas under existing pressures and temperatures, then all of it was saturated, or very nearly so, or, conversely, if some of the oil was undersaturated, then all of it would be undersaturated to about the same degree. Some recorded observations in other fields seem to indicate that equilibrium conditions may not exist in all fields, but incontrovertible proof of that has been lacking. Estabrook and Rader[3/] noted the presence of a "zone of dead oil" in the Second Wall Creek sand in the Salt Creek field and reported that "the distribution of dissolved gas in the oil seems to have been fairly uniform over the field except toward the edges."

The study of the subsurface oil samples from Elk Basin definitely proves that the fluids in a reservoir are not necessarily in equilibrium. It is concluded that either extremely long periods of time are necessary to effect equilibrium, or that accumulation can be quite young or is still taking place in some petroleum reservoirs.

RELATIONSHIP OF OIL CHARACTERISTICS TO RESERVOIR STRUCTURE

The relationship of the characteristics of the oil to the location of the oil in the Elk Basin, Tensleep reservoir, is shown in figure 11. In figure, 11 values of the saturation pressure, gas in solution, relative oil volume, density of the reservoir oil, specific gravity of the gas in solution, and hydrogen sulfide content of the gas in solution for the nine subsurface oil samples are plotted as ordinates against the common abscissa of sea-level elevations of the top of the Tensleep formation over the structure. The nine

3/ Estabrook, E. L., and Rader, C. M., History of Production of Salt Creek Oil Field, Wyoming: Am. Inst. Min. and Met. Eng., Petroleum Development and Technology in 1925, 1926, p. 216.

wells shown in figure 1 are identified by number along the abscissa of figure 11 at positions corresponding to the elevation of the top of the Tensleep in each well. Although the wells are plotted according to formation "tops," the oil from each of these wells came from some greater depth, depending on the penetration (160 to 200 feet) of the formation in each well.

The composite sample data for the oil from each of the wells sampled, as derived from the individual analyses shown in figures 2 to 10, inclusive, are shown in figure 11 to have a very definite relationship to the structure of the reservoir from which the oil came, and to the writers' knowledge this is the first time that such a relationship has been shown to exist.

A study of figure 11 would indicate that possibly the subsurface sample of oil from well 7 was not truly representative of the reservoir oil at well 7, and that the sample had been conditioned somewhat. This was referred to in the section on subsurface oil sampling. The data for the specific gravity of the gas in solution show the least consistent relationship of all the data. Attention has been called earlier in this report to the manner in which these data were acquired.

The physical characteristics of the oil throughout the crestal 500 to 600 feet of the reservoir are very much alike - all oil samples from the crestal part of the reservoir showed a saturation pressure of 1,235 to 1,250 pounds per square inch absolute and contained 460 to 490 cubic feet of gas in solution based on a barrel of residual oil. As a consequence of this gas in solution, 1.22 barrels of oil in the reservoir are required to produce one barrel of residual or stock tank oil. At a depth of about 100 feet above sea level, a decided change begins to occur in the character of the reservoir oil - the saturation pressure becomes lower, and the volume of gas in solution decreases. The other characteristics begin to change also. These changes continue with depth until the oil from a well in which the top of the producing formation is at an elevation of 1,107 feet below sea level, contains only 134 cubic feet of gas in solution per barrel of oil (on a residual-oil basis), and its saturation pressure is only 530 pounds per square inch absolute. Edge water is present in the reservoir at an elevation of about 1,500 feet below sea level. The writers have no information on the characteristics of the oil coming from wells in which the top of the Tensleep sandstone is below a depth of 1,107 feet below sea level. Characteristics may be inferred from an extension of the several curves to elevations of 1,200 or 1,500 feet below sea level.

The hydrogen sulfide content of the gas in solution in the oil as compared to the volume of gas in solution in the different oil samples is a rather interesting relationship. The gas in solution in the oil on top of the structure contains 18 percent hydrogen sulfide, that in solution in the oil on the edge of the structure contains 5 percent, and the variation is almost directly proportional to the volume of gas in the different samples. This suggests a plausible hypothesis for the movement and characteristics of the fluids in the reservoir and further substantiates the supposition that equilibrium has not yet been attained in the whole mass of reservoir oil.

Hypothesis for Variable Reservoir-Oil Characteristics

The sedimentary rocks in the north end of the Big Horn Basin were folded between the Beartooth Mountains on the west and the Big Horn Mountains on the east. In the early stages of folding, an accumulation of gas containing possibly 13 percent H_2S may have been surrounded by a ring of oil with water beneath. With the uplift of the mountain masses, an increasing hydrostatic head would have been applied to the fluids. Under these conditions the oil ring would have moved into the top of the Elk Basin anticline following the compression of the gas above and solution of the gas in the oil. This action would have continued until all the free gas disappeared into solution at a pressure possibly of 1,500 pounds per square inch, and would have persisted until some unknown pressure was reached.

At the time of discovery, the pressure was 1,853 pounds per square inch absolute at the crest of the oil accumulation. As the oil ring moved higher into the trap, it was confined in an increasingly smaller areal extent and accordingly increased in thickness until, at the time the field was discovered, oil filled more than 2,000 feet of closure. As the oil encroached into the space occupied by free gas, the upper part or foremost edge of this oil constantly mixed with and dissolved gas. The dissolved gas then passed from the highly concentrated zone by diffusion to lower levels of the oil body, resulting in progressively lower concentrations of solution gas with depth. The oil at the advancing front dissolved H_2S more rapidly than methane, because the products of the partial pressure and solubility coefficient for H_2S exceeded the corresponding value for methane; the latter being by far the largest single component in the gas phase. However, in the oil-gas solution the methane moved down-dip in the reservoir more rapidly than the H_2S, inasmuch as this is a diffusion process, and among other things the rate of this process varies inversely as the square roots of the densities. The advancing upper part of the oil, when pushed up into the top of the trap by the encroaching water, assumed appreciable depth, which accounts for the fact that the characterisitcs of the oil in the top 500 to 600 feet of the structure are approximately uniform.

Had geologic time since this movement of the oil been of sufficient duration, the volume and composition of the gas in solution in the oil at the top of the structure would have been much the same as that in the oil elsewhere in the structure, and the state of equilibrium of the reservoir-oil would have been similar to that found throughout other oil-bearing provinces in the United States, where, according to the common concept, the whole mass of oil in a reservoir has rather uniform characteristics. In the Tensleep reservoir at Elk Basin, the oil progressively farther down structure below the top 500 to 600 feet was increasingly undersaturated with gas, and the gas that was in solution contained progressively less H_2S. The H_2S content of less than 18 percent could be explained by the process of diffusion to the lower levels of the oil body, and by assuming that equilibrium processes were in action after accumulation but had not proceeded very far prior to the discovery of the field. The low value of 5 percent H_2S content might be explained by assuming that the small volume of gas associated with the oil prior to the orogenic movement contained 5 percent or less of H_2S.

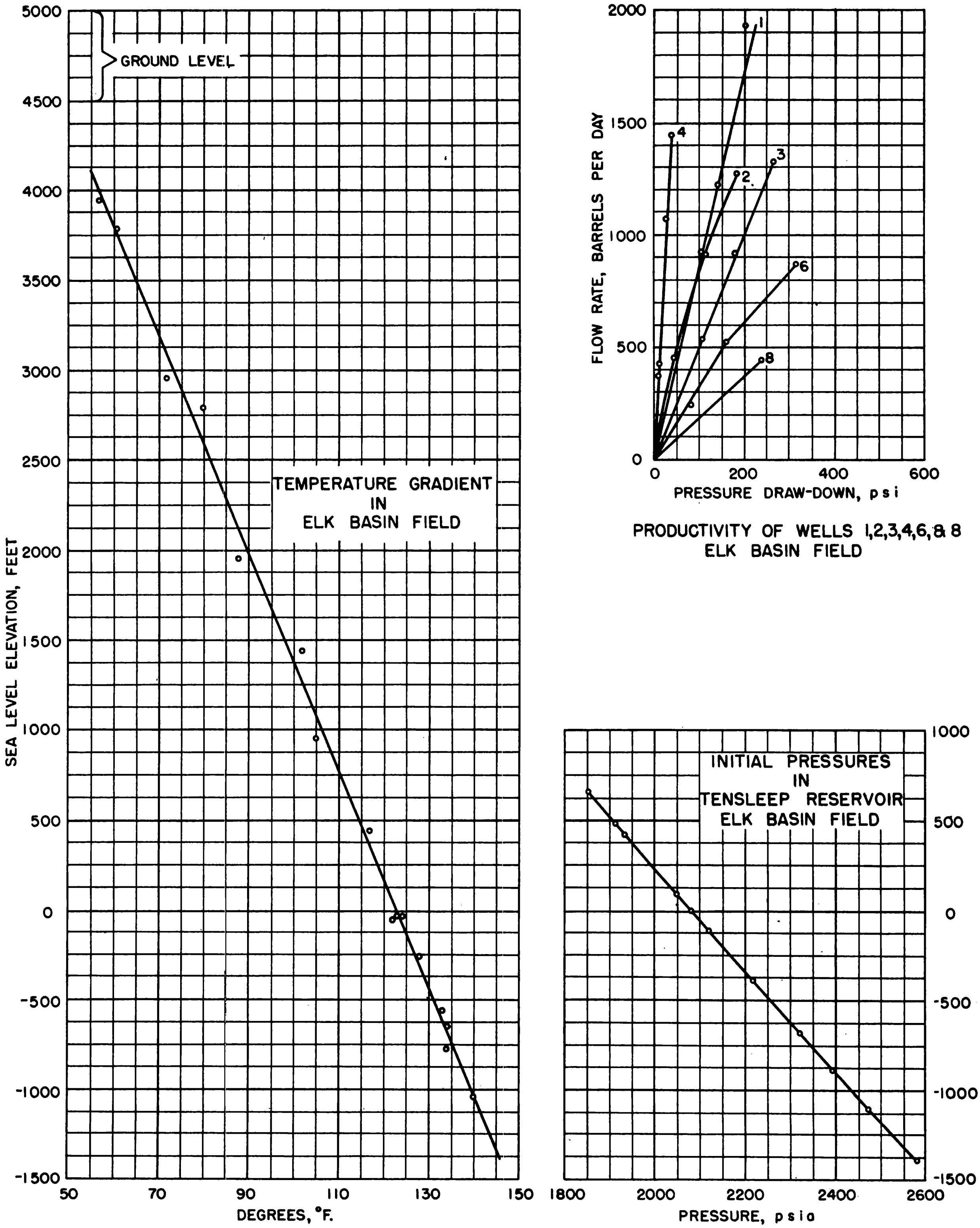


FIGURE 12. PRESSURES AND TEMPERATURES, ELK BASIN FIELD

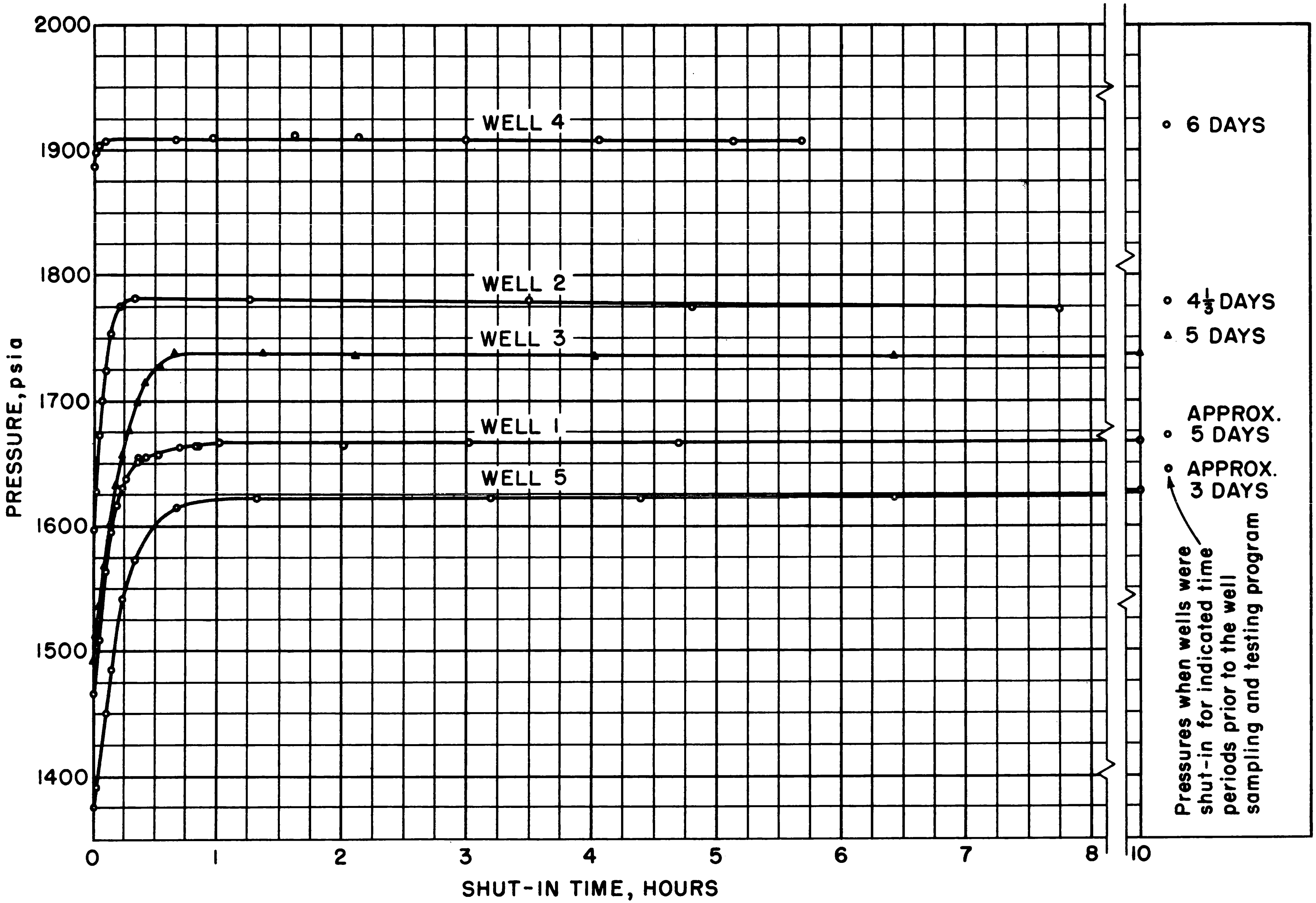


FIGURE 13. BOTTOM-HOLE PRESSURE BUILD-UP, WELLS 1,2,3,4, and 5, ELK BASIN FIELD

APPENDIX

When the first work of well testing and sampling by the writers was being done in the Elk Basin field in the fall of 1943, less than 20 wells had been completed in the Tensleep reservoir, and only a limited amount of subsurface engineering data were available. Consequently, while conditioning the wells for sampling, opportunities were available to obtain information relative to the formation and to the characteristics of the wells that would be of value in the evaluation and interpretation of the subsurface oil-sample data. Information and data on temperature gradients, original pressures, characteristics of the producing formation, quality, and characteristics of the produced oil are of appreciable import in a study of a reservoir. Consequently, such information as was obtained in appended to this report.

Reservoir Data and Producing Characteristics of Wells

Figure 12 is a graph of the temperature gradient in the Elk Basin structure; the data are essentially those obtained in wells 5 and 7, from which little oil had been produced before the tests were made. One well had been shut in for 4 days and the other 45 days at the time the temperatures were obtained. The density of data points below sea level results from the use of bottom-hole temperature data obtained from the other wells that were sampled. The temperatures existing in any of the wells between ground level and 1,000 feet in depth were not used. Figure 12 indicates that the temperature in the Elk Basin field increases with depth at the rate of 1.64° F. per hundred feet.

The chart in the lower right corner of figure 12 has the same sea-level elevation ordinate as the temperature gradient curve and shows the original pressures that existed in the Tensleep reservoir at time of discovery. This chart was developed by establishing the original pressure at sea-level elevation and using the data from the curve of density at original pressure shown in figure 11. The original pressure at sea level was determined by plotting the pressures existing at successive cumulative productions and extending the curve to zero production.

The graph in the upper right corner of figure 12 shows the productivity of several of the wells. The graph shows the amount of drawdown in pressure obtained below the tops of the Tensleep formation in several wells as a result of flowing them at different rates. Well 4 was completed in a fractured zone in the Tensleep formation, which accounts for its high productivity as compared with other wells. The curves represent conditons in the early life of each of the wells, or, with one exception, within 6 months of initial production.

Figure 13 shows some curves of the pressure changes at sampling-point elevations that took place following the shutting-in of several of the wells that had been producing at high rates. The pressure points for the time period up to 10 hours after the wells were shut in, were obtained by a subsurface pressure gage that had been lowered into the wells just prior to shutting them in. The pressure points at 3 to 6 days were determined with a subsurface pressure gage after the wells had been shut in prior to the time of flowing the wells for sampling and productivity testing. The wells were producing oil, before being shut in, at the following rates, in barrels, per day:

Well 1, 1,930; well 2, 1,265; well 3, 1,320; well 4, 1,440; and well 5, 1,150. The curve for well 4 shows the effect of completion in a fractured zone in the Tensleep formation. All curves show that a pressure determination made 1 hour after shutting in a well would yield a pressure almost as great as that which would be obtained after a shut-down of several days.

Analyses of Produced Oil

Bureau of Mines routine analyses of the crude oils from six of the wells in the Elk Basin field are given in tables 5, 6, and 7 on the following pages. The samples of crude oil came from wells 1, 4, 6, 7, 8, and 9, and the analyses show the slight variations in the characteristics of the produced oil from wells at the top of the structure and increasingly farther down toward the edge.

TABLE 5. BUREAU OF MINES ROUTINE ANALYSES OF CRUDE OILS FROM WELLS 1 AND 4

Sample 43L-34

Elk Basin Field
Tensleep
3938-4137 feet

Well 1

Wyoming
Park County
NE¼SE¼NE¼ sec. 24,
T. 58 N., R. 100 W.

GENERAL CHARACTERISTICS

Specific gravity, 0.867 — A.P.I. gravity, 31.8
Sulfur, percent, 1.82 — Color, Dark brown
Saybolt Universal viscosity at 77°F., 58 sec., at 100°F., 47 sec.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 592 mm. First drop 28°C. (83°F.)

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	3.1	3.1	0.637	90.6			
2	75	167	3.0	6.1	.674	78.4	6.1		
3	100	212	4.0	10.1	.712	67.2	14		
4	125	257	4.9	15.0	.742	59.2	20		
5	150	302	5.1	20.1	.766	53.2	24		
6	175	347	4.5	24.6	.787	48.3	27		
7	200	392	4.7	29.3	.803	44.7	29		
8	225	437	4.8	34.1	.818	41.5	30		
9	250	482	5.0	39.1	.837	37.6	34		
10	275	527	5.6	44.7	.858	33.4	40		
Distillation continued at 40 mm.									
11	200	392	0.9	45.6	0.875	30.2	44	42	5
12	225	437	5.6	51.2	.885	28.4	45	50	20
13	250	482	6.2	57.4	.907	24.5	52	72	35
14	275	527	5.4	62.8	.919	22.5	54	115	55
15	300	572	6.6	69.4	.933	20.2	58	230	75
Residuum			29.2	98.6	.988	11.7			

Carbon residue of residuum 10.2 percent; carbon residue of crude 3.4 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	10.1	0.678	77.2	
Total gasoline and naphtha	29.3	.741	59.5	
Kerosine distillate	4.8	.818	41.5	
Gas oil	14.3	.858	33.4	
Nonviscous lubricating distillate	9.7	.885-.915	28.4-23.1	50-100
Medium lubricating distillate	6.4	.915-.929	23.1-20.8	100-200
Viscous lubricating distillate	4.9	.929-.941	20.8-18.9	Above 200
Residuum	29.2	.988	11.7	
Distillation loss	1.4			

Sample 43L-38

Elk Basin Field
Tensleep
4711-4871 feet

Well 4

Wyoming
Park County
NE lot 4 NW¼ sec. 5
T 57 N., R. 99 W.

GENERAL CHARACTERISTICS

Specific gravity, 0.871 — A.P.I. gravity, 31.0
Sulfur, percent, 1.83 — Color, Dark brown
Saybolt Universal viscosity at 77°F., 55.4 sec., at 100°F., 49.6 sec.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 580 mm. First drop 24°C. (76°F.).

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	3.2	3.2	0.654	84.9			
2	75	167	3.0	6.2	.674	78.4	6.1		
3	100	212	4.3	10.5	.715	66.4	16		
4	125	257	4.7	15.2	.744	58.7	21		
5	150	302	5.0	20.2	.770	52.3	26		
6	175	347	4.7	24.9	.790	47.6	28		
7	200	392	4.3	29.2	.805	44.3	30		
8	225	437	4.9	34.1	.821	40.9	32		
9	250	482	5.1	39.2	.841	36.8	36		
10	275	527	8.0	47.2	.862	32.7	41		
Distillation continued at 40 mm.									
11	200	392	0.3	47.5					
12	225	437	5.7	53.2	0.888	27.9	46	50	20
13	250	482	6.7	59.9	.906	24.7	52	71	40
14	275	527	5.7	65.6	.921	22.1	55	120	60
15	300	572	6.0	71.6	.930	20.7	57	270	75
Residuum			27.6	99.2	.992	11.1			

Carbon residue of residuum 11.7 percent; carbon residue of crude 3.7 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	10.5	0.685	75.1	
Total gasoline and naphtha	29.2	.741	59.5	
Kerosine distillate	4.9	.821	40.9	
Gas oil	16.3	.850	35.0	
Nonviscous lubricating distillate	9.8	.888-.915	27.9-23.1	50-100
Medium lubricating distillate	5.7	.915-.926	23.1-21.3	100-200
Viscous lubricating distillate	5.7	.926-.935	21.3-19.8	Above 200
Residuum	27.6	.992	11.1	
Distillation loss	0.8			

TABLE 6. BUREAU OF MINES ROUTINE ANALYES OF CRUDE OILS FROM WELLS 6 AND 7

Sample 44-L-7

Elk Basin Field
Tensleep
5195-5384 feet

Well 6

Wyoming
Park County
NE lot 2 NW¼ sec. 31
T 58 N., R. 99 W.

GENERAL CHARACTERISTICS

Specific gravity, 0.876
Sulfur, percent, 1.87
Saybolt Universal Viscosity at 77°F., 68 sec., at 100°F., 58.3 sec.

A.P.I. gravity, 30.0
Pour point, below 5°F.
Color, Brown

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 591 mm. First drop 28°C. (82°F.)

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	2.8	2.8	0.635	91.3	--		
2	75	167	3.0	5.8	.675	78.1	6.6		
3	100	212	3.7	9.5	.713	67.0	15		
4	125	257	4.7	14.2	.744	58.7	21		
5	150	302	4.6	18.8	.767	53.0	24		
6	175	347	4.8	23.6	.790	47.6	28		
7	200	392	4.3	27.9	.806	44.1	30		
8	225	437	4.7	32.6	.823	40.4	33		
9	250	482	4.0	36.6	.841	36.8	36		
10	275	527	6.0	42.6	.859	33.2	40		
Distillation continued at 40 mm.									
11	200	392	1.4	44.0	0.876	30.0	44	43	Less than 5°F.
12	225	437	5.8	49.8	.883	28.7	44	46	15
13	250	482	5.8	55.6	.906	24.7	52	63	35
14	275	527	5.6	61.2	.919	22.5	54	105	55
15	300	572	7.9	69.1	.932	20.3	58	220	75
Residuum			29.9	99.0	.997	10.4			

Carbon residue of residuum 13.3 percent; carbon residue of crude 4.0 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	9.5	0.678	77.2	
Total gasoline and naphtha	27.9	.743	58.9	
Kerosine distillate	4.7	.823	40.4	
Gas oil	15.6	.862	32.6	
Nonviscous lubricating distillate	9.7	.888-.918	27.8-22.6	50-100
Medium lubricating distillate	3.6	.918-.930	22.6-20.6	100-200
Viscous lubricating distillate	7.6	.930-.958	20.6-16.2	Above 200
Residuum	29.9	.997	10.4	
Distillation loss	1.0			

Sample 44-L-9

Elk Basin Field
Tensleep
5640-5805 feet

Well 7

Wyoming
Park County
NE¼NW¼NW¼ sec. 8
T. 57 N., R. 99 W.

GENERAL CHARACTERISTICS

Specific gravity, 0.881
Sulfur, percent, 1.97
Saybolt Universal viscosity at 77°F., 70 sec., at 100°F., 65 sec.

A.P.I. gravity, 29.1
Pour point, below 5°F.
Color, Brown

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 596 mm. First drop 31°C. (88°F.)

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	2.9	2.9	0.643	88.6			
2	75	167	2.5	5.4	.680	76.6	8.9		
3	100	212	3.6	9.0	.717	65.8	17		
4	125	257	4.0	13.0	.744	58.7	21		
5	150	302	4.7	17.7	.769	52.5	25		
6	175	347	4.1	21.8	.788	48.1	28		
7	200	392	3.8	25.6	.802	44.9	28		
8	225	437	5.3	30.9	.824	40.2	33		
9	250	482	5.7	36.6	.843	36.4	37		
10	275	527	6.3	42.9	.864	32.3	42		
Distillation continued at 40 mm.									
11	200	392	.8	43.7	0.873	30.6	43	43	10
12	225	437	5.7	49.4	.887	28.0	46	49	20
13	250	482	6.2	55.6	.909	24.6	53	67	40
14	275	527	6.1	61.7	.921	21.1	55	115	55
15	300	572	8.0	69.7	.933	20.2	58	260	75
Residuum			30.3	100.0	.998	10.3			

Carbon residue of residuum 13.7 percent; carbon residue of crude 4.1 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	9.0	0.683	75.7	
Total gasoline and naphtha	25.6	.743	58.9	
Kerosine distillate	5.3	.824	40.2	
Gas oil	16.0	.861	32.8	
Nonviscous lubricating distillate	9.8	.889-.917	27.7-22.8	50-100
Medium lubricating distillate	6.0	.917-.928	22.8-21.0	100-200
Viscous lubricating distillate	7.0	.928-.940	21.0-19.0	Above 200
Residuum	30.3	.998	.10.3	
Distillation loss	0.0			

TABLE 7. BUREAU OF MINES ROUTINE ANALYSES OF CRUDE OILS FROM WELLS 8 AND 9

Sample 43-L-37

Elk Basin Field Tensleep 5409-5581 feet	Well 8	Wyoming Park County NE¼NE¼SE¼ sec. 36 T. 58 N., R. 100 W.

GENERAL CHARACTERISTICS

Specific gravity, 0.885 — A.P.I. gravity, 28.4
Sulfur, percent, 1.94 — Color, Dark brown
Saybolt Universal viscosity at 77°F., 78 sec., at 100°F., 63 sec.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 587 mm. First drop 26°C. (78°F.)

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	2.3	2.3	0.652	85.5			
2	75	167	2.5	4.8	.671	79.4	4.7		
3	100	212	3.4	8.2	.711	67.5	14		
4	125	257	3.8	12.0	.742	59.2	20		
5	150	302	4.1	16.1	.767	53.0	24		
6	175	347	4.1	20.2	.786	48.5	27		
7	200	392	3.8	24.0	.803	44.7	29		
8	225	437	4.7	28.7	.822	40.6	32		
9	250	482	5.0	33.7	.841	36.8	36		
10	275	527	6.1	39.8	.861	32.8	41		
Distillation continued at 40 mm.									
11	200	392	2.0	41.8	0.877	29.9	45	45	5
12	225	437	6.3	48.1	.888	27.9	46	55	30
13	250	482	6.8	54.9	.907	24.5	52	74	45
14	275	527	5.8	60.7	.919	22.5	54	135	60
15	300	572	9.6	70.3	.931	20.5	57	270	75
Residuum			28.9	99.2	1.004	9.44			

Carbon residue of residuum 15.5 percent; carbon residue of crude 5.1 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	8.2	0.682	76.0	
Total gasoline and naphtha	24.0	.776	50.9	
Kerosine distillate	4.7	.822	40.6	
Gas oil	14.1	.858	33.4	
Nonviscous lubricating distillate	11.3	.882-.912	28.9-23.7	50-100
Medium lubricating distillate	7.4	.912-.925	23.7-21.5	100-200
Viscous lubricating distillate	8.8	.925-.939	21.5-19.2	Above 200
Residuum	28.9	1.004	9.44	
Distillation loss	0.8			

Sample 44L-10

Elk Basin Field Tensleep 5620-5697 feet	Well 9	Wyoming Park County NE¼SE¼SE¼ sec. 36 T. 58 N., R. 100 W.

GENERAL CHARACTERISTICS

A.P.I. gravity, 27.1
Specific gravity, 0.892 — Pour point, below 5°F.
Sulfur, percent, 1.92 — Color, Black
Saybolt Universal viscosity at 77°F., 100 sec., at 100°F., 75 sec.

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 588 mm. First drop 25°C. (77°F.)

Fraction No.	Cut °C.	at °F.	Per-cent	Sum per-cent	Sp. Gr. 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc. 100°F.	Cloud test °F.
1	50	122	2.3	2.3	0.644	88.2			
2	75	167	2.1	4.4	.674	78.4	6.1		
3	100	212	3.0	7.4	.711	67.5	14		
4	125	257	3.5	10.9	.739	60.0	18		
5	150	302	3.7	14.6	.763	54.0	22		
6	175	347	3.7	18.3	.781	50.0	24		
7	200	392	3.8	22.1	.801	45.2	28		
8	225	437	4.5	26.6	.821	40.9	32		
9	250	482	4.8	31.4	.840	37.0	36		
10	275	527	6.0	37.4	.860	33.0	40		
Distillation continued at 40 mm.									
11	200	392	1.4	38.8	0.873	30.6	43	43	Below 5°F.
12	225	437	6.1	44.9	.882	28.9	43	49	15
13	250	482	7.7	52.6	.903	25.2	50	69	35
14	275	527	6.0	58.6	.917	22.8	53	130	55
15	300	572	8.6	67.2	.933	20.2	58	290	75
Residuum			33.0	100.2	1.005	9.2			

Carbon residue of residuum 15.6 percent; carbon residue of crude 5.1 percent.

APPROXIMATE SUMMARY

	Percent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	7.4	0.680	76.6	
Total gasoline and naphtha	22.1	.741	59.5	
Kerosine distillate	4.5	.821	40.9	
Gas oil	15.6	.859	33.2	
Nonviscous lubricating distillate	10.1	.883-.910	28.8-24.0	50-100
Medium lubricating distillate	6.5	.910-.924	24.0-21.6	100-200
Viscous lubricating distillate	8.4	.924-.942	21.6-18.7	Above 200
Residuum	33.0	1.005	9.2	
Distillation loss	0.0			

TABLE 8. - Results of differential gas-liberation analysis at 121° F., subsurface oil sample from well 1, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
2565	0		1.217	0.801		
2245	0.22		1.220	.800		
1930	.49		1.223	.797		
1660	.69		1.226	.796		
1360	.98		1.229	.794		
1250 2/	1.08	490	1.230	.793	0.989	18.2
1210	2.47					
1145	4.67					
1080	7.09					
1035	9.42					
975	11.74					
940		419	1.206			
835		392	1.195	.802	1.043	20.9
725		365	1.185	.805	1.062	22.0
625		339	1.176	.808	1.084	23.3
535		311	1.166	.811	1.108	24.7
450		285	1.157	.813	1.135	26.4
365		259	1.147	.817	1.166	28.1
300		232	1.137	.819	1.201	29.9
225		205	1.126	.823	1.239	31.7
165		178	1.115	.826	1.278	33.5
120		150	1.105	.828	1.320	34.8
85		116	1.092	.831	1.364	36.3
60		92	1.079	.833	1.405	36.7
45		61	1.070	-	1.451	36.1
11		0	1.030	.847		
11 3/			1.000	.872		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 9. - Results of differential gas-liberation analysis at 121° F., subsurface oil sample from well 2, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
2435	0		1.215	0.804		
2150	0.22		1.218	.802		
1825	.49		1.221	.800		
1530	.74		1.224	.798		
1295	.94		1.226	.796		
1255 2/	.97	478	1.227	.796	0.996	15.8
1220	2.28					
1165	3.69					
1125	5.03					
1080	6.43					
1035	8.74					
990	10.99	421	1.208			
955		409	1.204			
840		384	1.195	.804	1.044	18.7
735		357	1.185	.807	1.062	19.7
635		332	1.176	.809	1.082	20.7
505		293	1.161	.814	1.118	22.5
385		255	1.147	.818	1.160	24.2
270		217	1.133	.822	1.208	27.4
180		179	1.117	.827	1.263	30.1
95		124	1.094	.833	1.347	32.2
45		68	1.068	.839	1.430	32.9
11		0	1.032	.847		
11 3/			1.000	.875		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 10. - Results of differential gas-liberation analysis at 121° F. subsurface oil sample from well 3, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution percent
2455	0		1.216	0.800		
2145	0.21		1.219	.799		
1815	.48		1.222	.797		
1540	.70		1.225	.795		
1265	.94		-	-		
1250 2/ ...	.96	469	1.228	.793	1.001	16.6
1205	2.07					
1160	3.24					
1120	4.34					
1090	5.43					
1035	7.91					
980	10.75	416	1.210			
940		393	1.206			
835		379	1.189	.805	1.052	20.6
710		348	1.185	.804	1.074	22.1
590		318	1.174	.807	1.100	23.7
495		287	1.162	.811	1.130	25.1
365		250	1.148	.815	1.172	27.6
260		211	1.133	.819	1.223	29.7
155		158	1.111	.825	1.302	32.1
70		105	1.088	.831	1.388	34.1
40		66	1.070	.835	1.453	34.9
11		0	1.033	.845		
11 3/ ...			1.000	.873		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 11. - Results of differential gas-liberation analysis at 123° F., subsurface oil sample from well 4, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
2430	0		1.208	0.804		
2142	0.19		1.211	.802		
1817	.44		1.214	.801		
1535	.67		1.217	.799		
1245	.91		1.220	-		
1235 2/ ...	.92	459	1.220	.797	1.011	16.5
1185	2.28					
1145	3.62					
1100	5.05					
1070	6.43					
1010	8.96					
930	11.31	392	1.199			
805		361	1.186	.805	1.061	20.0
675		331	1.175	.808	1.084	21.6
570		300	1.163	.812	1.111	23.1
440		263	1.149	.816	1.149	25.3
325		227	1.135	.820	1.195	27.8
195		177	1.115	.826	1.269	31.1
85		111	1.088	.833	1.373	34.3
45		64	1.067	.837	1.450	34.5
11		0	1.030	.848		
11 3/ ...			1.000	.873		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 12. - Results of differential gas-liberation analysis at 129° F., subsurface oil sample from well 5, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
1631	0		1.214	0.800		
1502	0.10		1.215	.799		
1348	.23		1.217	.798		
1211	.34		1.218	.797		
1177 2/ ...	.38	437	1.218	.797	1.028	15.2
1170	.52					
1154	1.03					
1097	2.51					
1050	4.32					
1010	6.06	404	1.206			
925		384	1.197	.803	1.061	16.7
840		365	1.190	.806	1.074	17.2
740		341	1.180	.809	1.094	18.1
640		317	1.173	.810	1.115	18.9
525		287	1.161	.814	1.147	20.2
424		256	1.149	.818	1.183	21.6
321		225	1.135	.823	1.228	23.4
219		188	1.120	.827	1.285	25.6
121		140	1.099	.833	1.365	28.2
63		92	1.083	.834	1.441	30.1
35		51	1.058	.842	1.526	28.2
11		0	1.030	.849		
11 3/ ...			1.000	.875		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 13. - Results of differential gas-liberation analysis at 133° F., subsurface oil sample from well 6, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
2415	0		1.176	0.814		
2142	0.18		1.178	.812		
1837	.39		1.181	.810		
1396	.70		1.184	.808		
1056	.97		-	-		
990 2/	1.00	350	1.188	.806	1.048	13.4
980	1.47					
955	2.68					
925	3.94					
890	5.37	330	1.181			
755		308	1.171	.811	1.084	14.7
720		296	1.165	-	-	-
645		282	1.162	.813	1.110	15.5
565		262	1.156	.815	1.131	16.2
458		235	1.146	.818	1.165	17.4
367		210	1.135	.822	1.204	18.6
272		183	1.122	.827	1.254	20.2
178		151	1.112	.829	1.318	22.0
76		95	1.085	.837	1.437	24.4
38		55	1.069	.840	1.526	24.1
11		0	1.025	.857		
11 3/			1.000	.879		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 14. - Results of differential gas-liberation analysis at 134° F., subsurface oil sample from well 7, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F.1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
1874	0		1.127	0.825		
1684	0.14		1.128	.824		
1458	.27		1.130	.823		
1223	.43		1.132	.822		
930	.65		1.134	.820		
772 2/	.75	225	1.135	.819	1.021	6.4
770	.85					
760	1.48					
720	2.77					
700	3.88					
670	5.49	209	1.130			
545		187	1.121	.824	1.070	7.3
430		165	1.114	.825	1.105	8.0
337		145	1.110	.825	1.145	8.7
248		125	1.100	.829	1.196	9.6
155		99	1.092	.831	1.272	10.8
74		67	1.075	.838	1.384	12.6
36 ...		39	1.059	.844	1.489	13.3
11		0	1.032	.853		
11 3/ ...			1.000	.881		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 15. - Results of differential gas liberation analysis at 140° F., subsurface oil sample from well 8, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F. 1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
2400	0		1.116	0.837		
2045	0.20		1.118	.835		
1650	.45		1.121	.833		
1235	.71		1.124	.831		
850	.99		1.127	.829		
695 2/ ...	1.09	205	1.128	.828	1.026	10.1
663	2.35					
632	3.76					
607	5.13					
581	6.59					
551	8.78					
530	10.95	183	1.123			
485		172	1.118			
398		156	1.114	.830	1.092	12.6
291		133	1.105	.833	1.141	14.3
194		109	1.096	.837	1.205	16.3
103		80	1.084	.840	1.305	19.6
43		43	1.066	.846	1.443	26.7
11		0	1.042	.853		
11 3/ ...			1.000	.889		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.

TABLE 16. - Results of differential gas-liberation analysis at 141° F., subsurface oil sample from well 9, Elk Basin field

Pressure, p.s.i.a.	Expansion of sample, percent	Gas in solution, cu. ft./bbl. residual oil at 60° F. 1/	Relative oil volume, residual oil volume at 60° F. = 1.0	Density, gm./ml.	Specific gravity of gas in solution, air = 1.0	Hydrogen sulfide content of gas in solution, percent
1931	0		1.089	0.847		
1703	0.13		1.090	.846		
1401	.31		1.092	.845		
1092	.50		1.094	.843		
810	.68		1.096	.842		
555	.85		1.098	.840		
530 2/	.88	134	1.098	.840	1.041	4.9
520	1.36					
496	2.44					
482	3.67					
467	4.73					
445	5.83	123	1.094			
315		103	1.087	.844	1.109	5.9
223		85	1.078	.848	1.166	6.7
137		65	1.072	.849	1.243	7.6
75		47	1.064	.852	1.336	8.5
35		23	1.053	.855	1.467	9.6
11		0	1.037	.861		
11 3/ ...			1.000	.893		

1/ Gas volumes at 14.4 p.s.i.a. and 60° F.
2/ Saturation pressure.
3/ At 60° F.