Rangely Oil Field, Rio Blanco County, Colorado

Volume II

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Abstract of Report

In the early summer of 1925 the writer visited Rangely, where shallow oil production had already been discovered, and was impressed with the magnitude of the easily recognized anticlinal structure. The contrast between conditions existing at that time and the present active development is notable. Rangely, in point of area, is one of the largest oil fields in the Rocky Mountain region, and the recompletion of the Weber discovery well by The California Company, during the latter part of 1943, was a most important event for the oil industry of Colorado.

The writer has been closely associated with geologic and engineering work in the Rangely field, and would have preferred to have delayed the preparation of the present report until the engineering investigations of the Rangely Engineering Committee are in a more advanced stage of completion. It should be possible to prepare a much more comprehensive and reliable report when more cores of the producing formation have been studied and more bottom-hole samples have been analyzed. Although natural reservoir performance at Rangely will probably be inferior to many other Rocky Mountain fields, the unquestionable enormous oil content of the Weber reservoir presents a challenging recovery problem which is deserving of most thorough study and consideration.

The Rangely oil field is located in northwestern Colorado. By road it is about 105 miles distant from Craig, Colorado, the nearest railhead. The isolated location of the field delayed development for quite a few years after oil was first discovered in the Weber sandstone. The increased demand for oil brought about by recent war-time conditions provided the impetus for intensive development which has increased rather than diminished

since the cessation of hostilities.

The proven area of the Rangely field in the Weber sandstone should cover at least 20,000 acres and probably around 26,000 acres. At present, the field has a length of 7 miles and a maximum width of about 2 miles. With a well spacing of 1 well to 40 acres, it will take around 500 wells to develop the field completely which will cost from 65 to 70 million dollars to drill and equip.

The existence of the Rangely anticline was first noted by the U. S. Geological Survey in 1875. The discovery well was drilled to a depth of 2,130 feet in the summers of 1901 and 1902. The hole was lost at the total depth without an attempt at completion in shallow oil-bearing shale which was encountered at a depth of 750 feet. Subsequently, over 100 of the shallow shale wells were drilled in the field, and 5 wells have found gas in the deeper Dakota sandstone.

The Weber discovery well, The California Company's Raven No. 1, was commenced in 1931 and was drilled at great cost to a total depth of 7,173 feet with a rotary rig. The general hardness of the rocks encountered made the rate of penetration very slow and expensive. After proving the oil productive possibilities of the Weber, the well was shut in for about 12 years. After an incentive was provided for the recompletion of Raven No. 1 and its productive capacity was demonstrated, the drilling of other wells to the Weber was commenced shortly thereafter. Development work has been accelerated by the construction of a pipe line outlet for the field, and has been made economically feasible by the availability of improved drilling machinery which can cut the hard formations found in the Rangely field. However, it still costs in the range of $25.00 per foot to drill and complete an average well, which is substantially higher than costs in other fields of comparable depth.

The shale oil production has been refined principally for local consumption, although some of it was trucked to Salt Lake City. The Weber production is now moved from the field to various markets through the 10 inch line of Utah Oil Refining Company. Pipe line facilities are now available whereby Rangely crude can be moved to refineries in the vicinity of Chicago.

The accumulation of oil in the Rangely field has been controlled by a large, asymmetrical anticline, which is situated in the northern part of the Uinta Basin. The lowest closing contour of the surface structure encompasses an area of about 100 square miles, and the total closure amounts to a little over 2,300 feet. The subsurface structure on the top of the Weber sandstone conforms rather closely to the surface structure insofar as partially complete information permits comparison. There are extensive areas on the Rangely anticline in which wells have not been drilled to the Weber, and, on this account, in which information is lacking.

The rocks exposed at the surface in the Rangely field are of Upper Cretaceous age. Upper Cretaceous, Jurassic, Triassic, Permian, and Pennsylvanian rocks are penetrated in the wells drilled to the Weber sandstone which is of Pennsylvanian age. A thick section of Palaeozoic rocks are believed to underly the Weber at Rangely, but have not been tested by drilling.

In the Rangely field, some gas has been found in the Dakota sandstone, and oil has been found in the Mancos shale, in the Morrison formation, and in the Weber sandstone. The Weber is the most important producing horizon.

Oil-bearing strata are reported in the upper 600 feet of the Weber sandstone, but it is doubtful whether much more than 100 feet will make any substantial contribution to the production of oil under the pressure differentials now prevailing in the reservoir. Information presently available indicates that the best pay sections in the Weber occur in the northwestern part of the field and that it deteriorates in quality going toward the southeast. A weighted average of all core data available gives an average porosity of 10.8 per cent and an average permeability of 10 millidarcies. Calculations of effective permeability from data derived from productivity index determinations and from analyses of bottom-hole samples conform reasonably well to the determinations of permeability by core analysis.

The gas-oil contact has been found in the Weber reservoir at an elevation of -320 feet. The water-oil contact is found at an elevation of -1,150 feet. The vertical oil column, therefore, amounts to 830 feet. The connate water content of the sand, determined from cores cut with oil-base mud, has been found to average not more than 20 per cent.

All drilling of Weber wells is done with rotary rigs, and 7 inch casing is generally set at the top of the sandstone or through the gas-oil contact. It usually takes from 85 to 100 days to drill to the top of the Weber and from 40 to 70 days to penetrate the Weber, depending on the amount of coring which may be done. An average of 80 hard-rock bits are required for each hole. The use of oil-base mud is favored by most operators for well completion to prevent enfiltration of water from drilling fluid into the oil-bearing formation. The writer suggests a technique to drill the Weber with its own oil in a manner similar to successful methods employed in various Wyoming fields.

Up to the end of 1945 the Mancos shale production at Rangely had amounted to slightly over 1 1/2 million barrels of oil. The production from the Weber up to the first of June, 1946 has been almost 4 million barrels of oil. At that time production from the Weber was at a rate of about 19,500 barrels of oil per day. The produced gas-oil ratio has amounted to 557 cu. ft. per barrel, and if the excessive gas production from two wells is eliminated, the produced gas-oil ratio amounts to 293 cu. ft. per barrel.

Rangely crude has reasonably desirable refining qualities, and has a lower sulfur content than various Wyoming and Montana crudes produced from rocks of Pennsylvanian age. The gas produced from the Weber has a fairly high inert content which reduces its heating value.

Weber oil production in the Rangely field is allocated by a formula developed by the Engineering Committee which considers the factors of acreage, bottom-hole pressure, and gas-oil ratio.

Under current conditions the rate of return from an average well will provide a pay-out in about 2 years. However, if the present active development is continued and unless additional markets for crude are found and additional pipe line capacity provided the per well allowable will be reduced to such point that it may require from 4 1/2 to 5 years to pay out a well by the end of 1947.

Engineering studies in the Rangely field show that the gravity of the crude, the shrinkage factor, the solution gas content, the saturation pressure, and the subsurface viscosity of the oil are not constant throughout the large productive area but vary in accordance with structural position. The reason for these anomalous conditions possibly may be explained by the hypothesis that gas and oil migration into the reservoir was not contemporaneous, and that adjustments approaching a state of equilibrium were still taking place when withdrawals were first commenced.

The interpretation of productivity indices is considered, and it is suggested that when more core data become available they may prove to be a reliable indication of reservoir conditions. No positive evidence of production interference can be deduced from a series of tests made by the Rangely Engineering Committee, but it is believed possible that the voids of the reservoir may be a combination of fractures with interstitial porosity. Evidence of general intercommunication in the reservoir is apparent.

All information so far developed indicates that the Weber reservoir at Rangely is producing under dissolved gas drive, which is the most ineffective recovery process known. However, some benefits from water encroachment may already be realized in the northwestern part of the field. Facts relating to the amount of oil produced for each pound decline in bottom-hole pressure are presented, and it is emphasized that data from individual wells are probably a more reliable criteria than average figures for the field as a whole. There is fairly close conformity between estimations of future production determined by pressure-volume relations and by the volumetric method.

Most of the productivity tests made at variable flowing rates indicate that the most efficient utilization of reservoir energy is at lower production rates than those now generally in effect. It is considered most desirable that production rates be held at such levels that the bottom-hole pressure will not decline below the saturation pressure. The waste of gas from the reservoir is condemned, and unless it is arrested such loss cannot help but have a detrimental effect on the recovery of oil.

With proper conservation of reservoir energy, it is believed that an average recovery from the Weber reservoir of around 170 barrels per acre foot of pay section is possible. The possibilities for successful application of pressure maintenance are most impressive, and all phases of this problem are deserving of careful consideration. It is suggested that the Weber sandstone may be much better adapted to water injection than it is to gas injection.

The oil accumulation in the Weber reservoir of the Rangely field is one of the largest discovered in recent years in the United States. Under existing conditions only a small part of the enormous reserve will be recovered. Every possible measure should be taken to devise a technique which will result in the maximum efficient and profitable recovery of oil.

The recent discovery by Continental Oil Company of a new producing horizon in the northwestern part of the Rangely field may affect most favorably the reserve position of Idaho and Wasatch. These companies own a direct offset to the lease on which the new discovery well is located and, also, they hold other strategically located leases.

Foreword

In June 1925, immediately after University Commencement exercises, the writer went to Rawlins, Wyoming, and there joined Dr. Willis T. Lee, Geologist with the U. S. Geological Survey, who was organizing a pack train to be used for geologic exploration in western Colorado and eastern Utah. Traveling entirely by horseback, we left the high Platte divide country south of Rawlins and worked our way down to the valley of the Little Snake River at Baggs, Wyoming, just a few miles north of the Colorado line. From Baggs we proceeded on southwestward to the valley of the Yampa near the present crossroads of Sunbeam. The locality of Sunbeam previously had been a favorite camp site for marauding bands of Ute Indians and subsequently was used by sheepherders for the same purpose. From Sunbeam, sheep-wagon trails, which paralleled generally what is now U. S. Highway No. 40, were followed which took us westward to the vicinity of what is now the village of Skull Creek. Southward from Skull Creek, the torturous divide country between the Yampa and the Blanco was crossed, and in course of time we arrived at what was then known as the Raven anticline, now known as the Rangely anticline. During the course of this extended trip, and except for the country in the immediate vicinity of Baggs, Wyoming, only a few shepherds and their flocks were encountered. Very few people came to northwestern Colorado 20 to 25 years ago.

In coming to Rangely, the writer remembers distinctly the profound impression which the excellent exhibition of anticlinal folding made on his mind. Being fresh from class-room study of the mode of occurrence of oil fields, Rangely had every appearance of being a likely place to explore for an oil or gas field. After dropping down from the high Mesa Verde sandstone escarpment to the valley of the White River, the disappointment which was secretely experienced in the discovery that someone else had already discovered shallow oil production on the outstanding and easily recognized Rangely anticline can be recollected distinctly.

Almost 21 years later, in April 1946, the writer revisited Rangely, traveling this time by automobile from the improved U. S. Highway No. 40 to the field over a rought, but, nevertheless, a very passable, typical oil-country road, a great contrast to the sheepherder's trails which were followed in the course of the prior visit. Instead of a few primitive, steam-operated spudders, which represented drilling activity during the early summer of 1925, some 25 rotary rigs could be observed scattered about in the long, oval basin which marks the Rangely anticline. The array of tank batteries, the construction of permanent camps, the building of roads, and other characteristic evidence of active oil field development all served to emphasize the importance of the discovery of oil at Rangely in the Weber sandstone by the California Company. At Rangely one of the largest oil fields ever discovered in the Rocky Mountain region is being developed, and information becoming available indicates that the Weber sandstone oil accumulation may prove to be the largest volume of crude so far discovered in the mountain states. Consequently, the recompletion of the Weber discovery well, Raven No. 1, by the California Company during the latter part of 1943 was a notable event both for Colorado and for the United States. During 1945 and continuing into 1946, Rangely has been one of the most active oil fields of the country.

In 1944, as consultant for The Sharples Corporation, the writer studied reports on the early operations of the California Company in the Rangely field, and concurred in the selection of the first new location to be made after the recompletion of Raven No. 1. On this location was drilled Idaho-Sharples-Wasatch's A. C. McLaughlin No. 1-32. Subsequently, during 1945 and the early part of 1946, as representative of The Sharples Corporation, the writer attended meetings of the Rangely Operators at Denver, helped to organize the Rangely Engineering Committee, and served as temporary chairman of this Committee at the time when its engaged engineer, Mr. J. J. Zorichak, was unable to function by reason of illness.

While serving as Temporary Chairman of the Rangely Engineering Committee, the writer collaborated in the formulation of ambitious plans for a comprehensive study of the capacity and performance of the Weber sandstone reservoir. Unfortunately, much delay has been associated in carrying out the approved program for the coring of the Weber pay section and the analysis of the cores recovered, for the measurement of bottom hole pressures and the determination of productivity indices, and for the procurement and analysis of bottom-hole samples of reservoir fluid. It now appears likely that some form of artificial lift will have to be installed in certain wells before it is possible to evaluate properly the performance of the reservoir, and from the information so obtained to develop plans for the most effective recovery of oil.

During the past year the writer prepared several preliminary reports on Rangely for his employer without having an opportunity to visit the field or study the pay section. These reports were based chiefly on information obtained from the U. S. Bureau of Mines, and it is well known that this information, although undoubtedly correct as to detail, was meager and incomplete. In consequence, some errors of fact resulted which the writer regrets and wishes could be corrected. However, the fundamental conclusion presented on the inferior performance which could be expected from the Weber reservoir has never been disputed successfully, and, as a matter of fact, later and more complete information has tended to emphasize further this condition.

The complete program of coring and bottom-hole sampling now under way in the Rangely field should be completed in the course of three or four months, and will provide the type of information needed for a comprehensive engineering study of the field. This report must be regarded as a progress study which is subject to further amplification and revision as more data become available. However, it does contain much previously unreleased information, including complete data on every section of the Weber, except one, that had been cored in the Rangely field up to the time of the writer's visit.

The Rangely oil field has received a great deal of exaggerated publicity which appears to have been designed principally by unscrupulous interests to create inflated values for leases and royalties. Recognized oil trade journals have even carried articles which inferred, if they did not make an outright statement, that Rangely might possess a recoverable oil reserve that was equivalent to a substantial part of the proven oil reserve of the United States. Such preposterous and entirely unfounded statements have resulted in the "boom" which their instigators evidently desired, but the rush to get wells completed has produced an unfortunate situation where the establishment of facts which would assist in the formulation and development of plans for the most efficient recovery of oil has not kept pace with the drilling activity. In consequence, a great deal of drilling and other development in the field will have been completed without the benefit of information regarded as essential for the effective production of oil elsewhere.

Rangely's large proven area, the lack of dry holes within the recognized limits of production, and the considerable thickness of the Weber sandstone, when combined with the dearth of discoveries in other parts of the United States, has served to focus a great deal of attention to the field. Gradually, some of the excitement is being deflated, and it is becoming more generally recognized that Rangely is not the bonanza it was widely advertised to be. Rather, it is being realized that the recovery of oil by present practice will, in all probability, be mediocre in a field where development costs have been abnormally high and where future lifting costs may be excessive.

If the facts now available on the Rangely field are accepted, the present prospects must be quite disappointing to the promoters, but to the thoughtful operator the unquestioned very large oil content of the Weber reservoir should hold most intriguing possibilities. Certainly, it should be recognized that the conservation of all remaining reservoir energy is essential, and the adaptability of the reservoir to some form of pressure maintenance is surely worthy of careful consideration. In such studies, the work of the Engineering Committee and its Chairman is deserving of enthusiastic support.

From the beginning, the writer has personally, but not officially, advocated the unitization of the field as a solution to many of the competitive problems which have developed already during the short productive life. There is now ample evidence to show that much money could have been saved and much more efficient recovery of oil obtained if there had been some better cooperation in concerted planning for the development and operation of the field in accordance with accepted petroleum engineering practice even if legal obstacles might make actual unitization impractical. From the standpoint of conservation, and actually for the ultimate benefit of the operators and royalty owners, it can be regretted that the State of Colorado does not possess the authority to compel the production of oil not in excess of the maximum efficient rate. The dissipation of natural reservoir energy, brought about by the production of oil from a well in excess of the maximum efficient rate, or the wasteful production of gas, will provide incentives and convincing arguments for the bureaucrats in the Federal government who are loosing sleep trying to devise new ways and means for securing control of the oil industry.

Chapter I
Introduction

This report deals with the petroleum geology and production of oil from the Rangely field, Rio Blanco County, Colorado, and considers particularly the properties and oil reserves of the Idaho Refining Company and the Wasatch Oil Refining Company located therein.

Geography of the Rangely Field

The Rangely oil field is located in the northern part of the Uinta Basin, northwestern Colorado, only a short distance from the Utah line. U. S. Highway No. 40 is about 14 miles from the northern part of the field and a typically rough, but nevertheless passable, oil field road extends southward from it to the field and continues on to Grand Junction, Colorado, about 100 miles to the south. The nearest rail shipping point for Rangely is Craig, Colorado, a distance of 92 miles east on Highway No. 40 from its intersection with the field road. Most of the material and equipment used in the Rangely field are trucked in from Craig. The town of Vernal, Utah is only 31 miles west from the junction between the Rangely road and Highway No. 40, and, on account of its greater proximity to the field, has been adopted as the temporary home for many technical and supervisory employees pending the completion of the construction of permanent camps. Since Vernal has no railroad connection it has not been considered to be a suitable location for supply houses.

The highest part of the Rangely structure is located in a well defined basin, formerly referred to as Raven Park, which is surrounded by rugged and broken hills making up the Mesa Verde sandstone escarpment. The valley of the White or Blanco river crosses the southern end of the basin, ~~[illegible]~~.

The basin is of oval shape and, except along the course of the river, is a barren wasteland of clay hills which support sparse, arid-type vegetation, and which erodes easily when washed by infrequent rains.

The isolated location of the Rangely field has been one of the factors which influenced the restricted attention which was given to it up until the time when Raven No. 1 was re-completed by the California Company. Most of the precipitation which the region receives comes in the winter time in the form of snow which may accumulate to considerable depth and render the field temporarily inaccessible.

Housing facilities were virtually nonexistant for both company and drilling contractor employees when the active development of the Weber reservoir got under way. Most of the contractors have housed their employees in temporary trailer camps, whereas the oil companies have been building neat, permanent camps as rapidly as scarce construction materials became available. Recent inspection reveals that living conditions in part are still inadequate with some people camping in squalid hovels along the river channel, entirely lacking in sanitary facilities and certainly providing an open invitation to the incidence of epidemic disease.

The climate at Rangely is characteristic of the high western plateau country, with extreme variations in temperature. In the winter time the temperature will drop occasionally to as low as -30° F, and in the summer time will rise to over +100° F. The cold weather, with occasional blizzards, makes rotary drilling of wells difficult, because of freezing conditions, but it is recognized that it would not be practical to use cable tools.

The construction and improvement of roads in the field are being carried on by most of the operating companies, with scant assistance from the county and the state, but under the best of conditions the movement of supplies into the field will remain expensive and production costs may be expected, generally, to be above the average for fields of similar depth.

Extent of Development

When the Rangely field was visited in the spring of 1946 there were some 70 producing wells completed in the Weber sandstone, and some 25 wells were either rigging up, drilling, or in various stages of completion. Numerous locations have been staked in what is regarded as the proven area of the field, which now has a length of about 7 miles and a maximum width of about 2 miles.

The proven area of the field cannot be defined as yet with precision, but the water-oil contact, as now projected, encompasses some 26,000 acres. It is virtually certain that over 20,000 acres will produce oil in varying amount from the Weber sandstone. As such, Rangely will probably rank next to Cut Bank and Kevin-Sunburst in point of size among Rocky Mountain fields.

Under the present well-spacing pattern of 1 well to 40 acres, it is probable that around 500 wells will be drilled at Rangely through the Weber pay zone, and the total development cost involved will approach some 65 to 70 million dollars. The magnitude of the development program still confronting the operators should prompt early and careful consideration of the methods which will result in the maximum economical recovery of oil.

History

The Rangely anticline was first noted by geologists for the Hayden Survey of the U. S. Geological Survey, the original pioneering geologic exploration of the Rocky Mountain States, in

1875, and was named by them the Raven Park anticline. The possibilities of the region for oil production were first determined by the discovery of an oil seep in the southwest corner of Section 5, Township 1 North, Range 102 West. When the U. S. Geological Survey made its first detailed study of the Rangely area in the summer of 1907, the exact location of the seepage could not be ascertained. Apparently, it was authentic for when its existence was reported, around the end of the 19th century, a number of companies were organized locally for exploration purposes and numerous oil-placer claims were filed.

The early filings for oil-placer claims in the Rangely field were controlled by the accepted corners of the original land surveys of the region. At about the same time when interest in the possible occurrence of oil became manifest, the original land surveys were discovered to be greatly in error, and a resurvey of the entire region was made by the General Land Office which altered considerably many of the land lines previously accepted. However, it was decided that the resurvey would not affect necessarily the location of all oil-placer claims filed on prior to the time it was made, and, under this condition, they would be subject to patent. This decision has been responsible for the irregular subdivisions encountered so frequently in the southern part of the field, which do not conform to the lines or corners of the new survey.

During the original period of development, oil-placer claims were filed on about 45,000 acres or some 70 square miles in the Rangely area. Most of these claims later lapsed on account of lack of drilling performance, but in the area where shallow production had been developed certain claims were preserved and still control lease boundaries.

The discovery well of the Rangely field was known as the Pool well and was drilled in the summers of 1901 and 1902. This well was located in the SE 1/4 NW 1/4, Section 33, T2N R102W, and derived its name from a merger of interests of three different companies, this being one of the first unitization agreements known. The Pool well was projected originally to the Dakota sandstone but never reached its objective, and was abandoned at a depth of 2,130 feet because of a crooked hole. At a depth of 750 feet it was reported that oil-bearing formation was encountered that was capable of producing a couple barrels of oil per day.

Following the abandonment of the Pool well, the showing of oil found in it encouraged other similar operations and in the next 6 years 5 additional wells were drilled within an area of some 2,500 acres. These wells were carried to various depths, and found, generally, the shallow shale oil, first discovered by the Pool well, at depths of from 500 to 1,000 feet. Most of these early wells were projected to be drilled to the Dakota sand, but the records available indicate that this horizon was never reached.

Sporadic development continued up until 1919 when Emerald Oil Company completed its No. 1 well, located in the SE 1/4 NW 1/4, Section 31, T2N R102W, from the Mancos shale at a depth of 521 feet with an initial production of 130 barrels of oil per day. This completion stimulated other shallow drilling which has been fairly continuous up to the present time. Over 100 shallow wells, producing from the shale formation, are known to have been drilled in the Rangely field, with initial productions ranging from a few barrels to over 100 barrels of oil per day. Generally, the shale wells have not had a long productive life, but about 25 of them currently are being produced. The shale oil has desirable refining qualities and has been processed locally, and also shipped by truck to Jensen and Salt Lake City, Utah where it has a ready market.

Up until the time when active development of the Weber reservoir was commenced, 8 wells at Rangely had been carried down to the Dakota or to deeper horizons. Five of these wells encountered appreciable gas flows in the Dakota, and one of them had a spectacular blow-out with an estimated temporary flow of some 74 million cubic feet per day. This large and uncontrolled production was soon drowned out, and the well was abandoned. Since no oil was found in the Dakota, and since there was no nearby market for gas there was no incentive to drill other Dakota gas wells.

Prior to the completion of the California Company's discovery well in the Weber sandstone, the deepest test well at Rangely had been drilled by the Associated Oil Company. This well was located in the SE 1/4, Section 24, T2N R102W, and was drilled in 1926. It was carried down to a total depth of 4,772 feet where it was abandoned in rocks of Jurassic age. Small oil and gas shows were reported to have been encountered in the Morrison formation, below the Dakota which was dry, but oil and gas in commercial quantities were not found.

In 1931 the California Company commenced the drilling of its Raven No. 1, located in the NW 1/4 SE 1/4, Section 30, T2N R102W. The well was drilled with a rotary rig at very great cost, principally because rock bits of proper design and construction were not then available for the effective penetration of the hard rocks encountered in the Pennsylvanian formations. Raven No. 1 was drilled to a total depth of 7,173 feet and still remains the deepest well that has been drilled in the Rangely field.

After encountering some gas in the Dakota and in a Jurassic sandstone, Raven No. 1 penetrated oil-bearing formation at a depth of 5,704 feet in the Weber sandstone. Intermittent zones of oil saturation were found in hard, fine-grained sandstone for slightly over 600 feet of the Weber section down to a depth of 6,320 feet. The hole was then carried on deeper through some 800 feet more of the Weber series, which is reported to have been barren of oil, and ended up in the top of a succeeding series of undifferentiated Pennsylvania rocks. Since none of the rocks below a depth of 6,320 feet were reported to be oil-bearing, the hole was plugged back to the upper part of the Weber and was shot repeatedly. Much time was consumed in cleaning out and in testing, and the well produced at a maximum rate of slightly over 200 barrels of oil per day. The oil was found to have a high sulfur content, and since there was no market available at the time where the crude could be sold profitably, Raven No. 1 was shut in and remained idle for about 12 years.

The advent of war conditions, with greatly accelerated demand for fuel oil, which can be manufactured from the heavy, black, sulfur-bearing crudes produced in the Rocky Mountain States from various fields, created an unusual demand for crude of this type and provided an incentive to the California Company to put Raven No. 1 back on production. This was done, and when the well was retested it flowed at a rate of 229 barrels of oil per day, which is approximately the same as its production was before being shut in.

Raven No. 1 was produced intermittently during the winter of 1943-44 without creating a great deal of interest. However, several wells were commenced in 1944 and after they were completed as commercial oil producers, drilling activity began to expand, and has been continuous up to the present time. Many of the early wells, upon completion, had to be shut in for lack of outlet. Although some oil was trucked from the field, steady and uninterrupted production was not possible until the field gathering system and pump station were completed and connected to the Utah Oil Refining Company's pipe line.

The increased demand for oil, brought about by war-time conditions, combined with a decline in the rate of discovery of new fields, proved to be a very stimulating factor in the early development of the Weber reservoir at Rangely. Of equal importance has been the availability of improved drilling equipment and methods, which were unknown when Raven No. 1 was drilled, that have enabled the drilling and completion of wells much more rapidly and at greatly reduced cost over what was possible from 10 to 15 years preceding. However, notwithstanding greatly improved accessibility, superior drilling machinery and technique, and a pipe line outlet for crude, the cost of development in the Rangely field has been high. In order to comply with lease obligations, quite a few wells had to be started under most adverse climatic conditions, and since there was such a great demand for drilling rigs, contractors could exact work on a cost-plus basis. Some of these unfavorable conditions gradually are being remedied to some extent as roads are being improved and since some company-owned rigs have been moved into the field. Nevertheless, drilling and completion costs still remain so high that the economy of the present well spacing of 1 well to 40 acres has been questioned.

Currently, more rigs are being moved to the Rangely field, and unless drilling should be curtailed drastically on account of material shortages, no diminution in activity can be forseen for the remainder of 1946.

<u>Outlet for Crude</u>

Before the development of the Weber reservoir got under way, the small shale-oil production from Rangely was processed locally at the Raven topping plant and at the nearby plant of the Equity Oil Refining Company at Jensen, Utah. In addition, some oil from time to time was trucked to Salt Lake City, a distance of 215 miles.

The facilities which were available for handling the shale-oil production were, of course, inadequate for the rapidly increasing potential production from the Weber sand wells. The completion of Utah Oil Refining Company's 10 inch pipe line from Rangely to Wamsutter, Wyoming, where it connects with the pipe line to Salt Lake City, during the latter part of 1945, has provided a badly needed outlet for the entire field. Currently, Rangely oil is being moved completely by pipe line to the plants of Wasatch Oil Refining Company at Woods Cross, Utah, and Utah Oil Refining Company, at Salt Lake City Utah. Idaho Refining Company, at Pocatello, Idaho receives Rangely crude that is carried by pipe line to Wamsutter and thence by tank car to Pocatello.

Facilities are now available to move Rangely crude to the central part of the United States through the pipe line system of the Standard Oil Company of Indiana, but it would probably be at a competitive disadvantage with Oklahoma and Kansas crude because of the longer haul and on account of inferior quality. However, unless well production allowables are curtailed, the increasing number of wells completed in the field may soon require an additional market outlet. It is fortunate that such additional outlet might be provided without prolonged delay.

Chapter II
Petroleum Geology of the Rangely Oil Field

Regional Geology

The Rangely oil field, as shown in Figure No. 1, is located on the northern margin of the Uinta Basin, a large structural depression situated about equally in northwestern Colorado and eastern Utah. The Rangely anticline, which has been the controlling factor in the accumulation of oil in the Rangely field, is an intermediate structure between the more intensely folded Midland anticline to the north, which forms the southern part of the Uinta mountain system and is known locally as Blue Mountain, and the large but more gently folded Douglas Creek anticline to the south. The folding of the Midland anticline has been sufficiently intense to bring Carboniferous rocks to the surface. At Rangely, the Cretaceous Mancos shale is at the surface on the higher part of the structure with Mesa Verde sandstone outcropping along the flanks, whereas at Douglas Creek the Mesa Verde is the oldest rock exposed. The Rangely anticline is separated from the Midland anticline by the large and well defined Red Wash syncline, which so depresses the strata that Tertiary rocks are exposed at the surface along its axis. To the south, the Rangely anticline is separated from the Douglas Creek anticline by a narrow, abrupt syncline in which, likewise, the rocks are so depressed that Tertiary formations are at the surface. The relation of these paralleling folds is shown in Figure No. 2.

The rocks which produce oil and gas in the Rangely field are brought to the surface on the Midland anticline. Rangely, therefore, represents a somewhat unusual oil accumulation in that commercial production is found in the first line of folding away from the outcrop of the producing rocks.

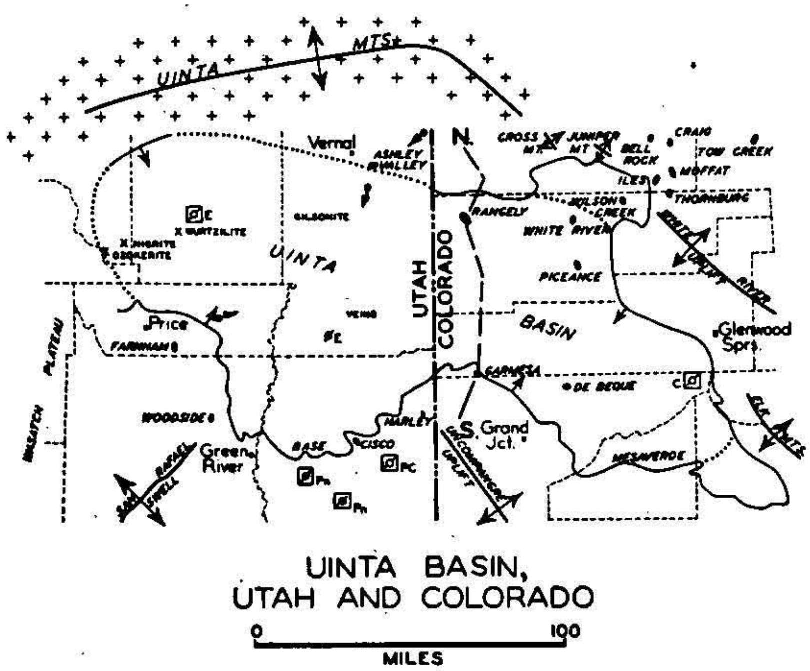


Figure No. 1 - Map Showing General Features of the Uinta Basin of Utah and Colorado. Reproduced from Page 64 of A. A. P. G.'s "Possible Future Oil Provinces of the United States and Canada"

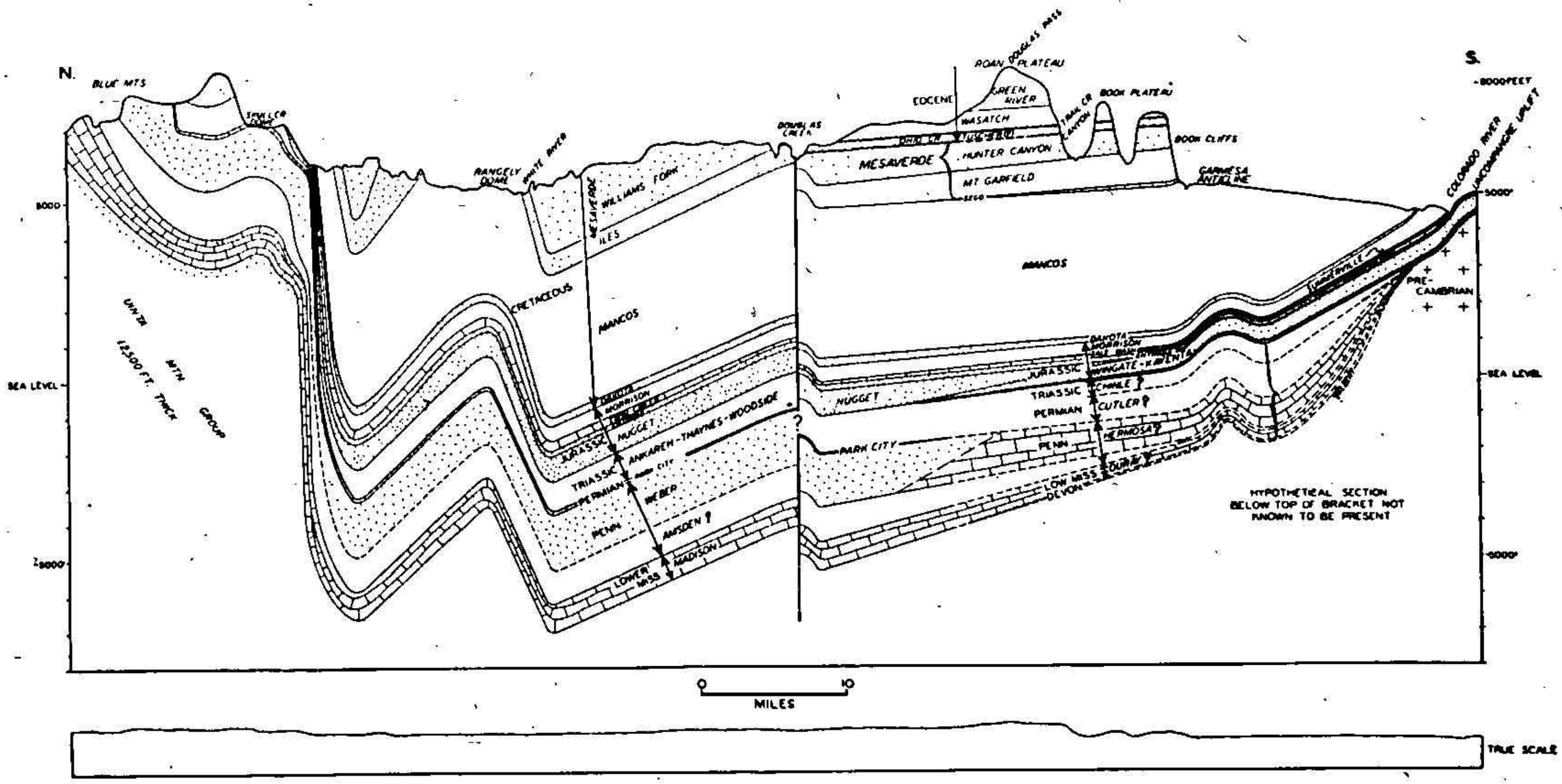


Figure No. 2 - Generalized Structural Cross-Section of the Uinta Basin in Northwestern Colorado. Reproduced from Page 65 of A. A. P. G.'s "Possible Future Oil Provinces of the United States and Canada."

Structural Geology
Surface Structure

The surface structure of the Rangely anticline has been studied in detail by the U. S. Geological Survey, and the results of this work have been published as Oil and Gas Investigations Preliminary Map 7. Map 7 is not reproduced for this report since it is now possible to show the subsurface structure of the field, on the top of the producing Weber sandstone, in considerable detail. In describing the structure of the Rangely anticline in connection with Map 7, it is stated:

"The surface expression of the Rangely anticline is typical of Rocky Mountain folds in that the crest is marked by a topographic basin. This basin, which is known locally as Raven Park, is formed in the soft Mancos shale, and is surrounded by a high rim rock made up of resistant sandstone members in the lower part of the Mesa Verde formation. The anticline, which trends west on the east end and northwest on the west end, is 20 miles long and 6 miles wide. The lowest closed contour line embraces an area of approximately 100 square miles and indicates structural closure of more than 2,300 feet. The dips of the beds on the southwest flank of the anticline increase from 13° near the axis to 21° at a distance of 1 1/2 miles south of the crest, and are thus steeper than those on the northeast flank where the dips average 6°.

Several short normal faults trending northeast and one trending northwest cut the basal rocks of the Mesa Verde formation low on the southeastern flank of the anticline. The rocks are downthrown on the southeast side of all of the faults except two, these being the most westerly of the northeast-trending faults, where the downthrown side is to the northwest, and the northwest-trending fault, where the downthrew is on the south side. On most faults the vertical displacement is less than 100 feet, but on one, in Section 11, T1N R102W, the vertical displacement is approximately 300 feet. The fault having the greatest lateral extent is low on the northwest nose of the anticline. It trends northeastward across the axis and northeastern flank of the anticline and may extend for a considerable distance beyond the anticlinal area."

Beyond the closed area of the Rangely anticline to the north and west, evidence of folding disappears, and near the Colorado-Utah state line the rocks dip normally southward away from the Uinta mountains. In like manner, the Rangely anticline appears to terminate to the southeast with no evidence of a continuation of folding in the gently dipping Tertiary rocks which make up the high escarpment known as the Cathedral Bluffs.

Subsurface Structure

The subsurface structure of the Rangely field on the top of the Weber sandstone is shown in Figure No. 3. Information now available indicates with reasonable certainty the existence of closure down to the water-oil contact which has been found in a couple of wells to be at a level of -1,150 feet. The highest well so far completed in the field is The Texas Company's Union Pacific No. 7-29, located in the SW 1/4 SW 1/4, Section 29, T2N R102W, which encountered the top of the Weber at an elevation of -230 feet. The effective closure so far determinable, therefore, amounts to 920 feet, and it is possible that this figure may be increased somewhat as more data become available.

Three-quarters of a mile to the northwest of Union Pacific No. 7-29, the top of the Weber was encountered only 6 feet lower, at -236 feet, in California Company's Emerald No. 1, located in the NE 1/4 SW 1/4, Section 30, T2N R102W. It is notable that the position of these two high wells, corresponds almost exactly to the highest point on the surface structure as mapped by the U. S. Geological Survey. Consequently, even though the fold is asymmetrical both at the surface and at depth, there certainly has been little shifting of the axis at the highest part of the structure from the surface rocks down to the top of the Weber sandstone.

Actually, there is really very little difference in the configuration of the structure at the surface and at the top of the Weber insofar as available subsurface information will permit interpretation of the folding. Some variation occurs at the northwest end where it appears that the subsurface axis, in Section 22, T2N R103 W, is shifted about a half-mile from where it is at the surface in Section 14, same township and range. Sufficient wells have not been drilled to indicate whether the several faults, known to exist at the surface, persist down into the lower rocks. This is a question which may never be solved, for it appears that the area in which the surface faults exist is beyond the presently defined limits of production, and thus probably will not be drilled.

As shown in Figure No. 3, the subsurface structure can now be outlined for a distance of about 10 1/2 miles and with a maximum width of about 5 miles. The area within the -1,150 foot contour line comprises some 26,000 acres. It is doubtful whether ~~development~~ drilling will extend much beyond this line, although future developments may cause some revision in minor details of the structure as it has been mapped presently.

Stratigraphy

Rocks Exposed at the Surface

The rocks exposed at the surface in the Rangely field are of Upper Cretaceous age and have been described by the U. S. Geological Survey as follows:

"The Mancos shale and the overlying Mesaverde formation, both of Cretaceous age, are the only rocks exposed at the surface in the Rangely field. The Dakota sandstone, however, crops out a short distance northwest of the field along U. S. Highway No. 40. The uppermost 2,000 feet of the Mancos shale, which has a total thickness of 5,200 feet, is exposed in the central part of the basin which marks the higher part of the anticline. This part of the formation consists mainly of gray calcareous shale, containing relatively few thin beds of calcareous sandstone, sandy shale, and concretionary, lenticular, sandy limestone. The beds of sandstone increase in number near the top of the formation and form a transition zone between the Mancos shale and the overlying Mesa Verde formation. Only the lowermost 1,000 feet, more or less, of the Mesa Verde formation is exposed in the rim rocks surrounding the field. This part of the formation consists of interbedded brown to light-brown sandstone, and gray to yellow-brown shale. It contains, in addition, a few beds of carbonaceous shale, coaly shale, and coal. The boundary between the Mancos shale and the Mesa Verde formation lies at the base of the lowest prominent sandstone in the transition zone. A more consistently outcropping horizon than the actual contact, which has been used as a datum for structural mapping, is a persistent bed of sandy limestone which is found about 15 feet above the base of the Mesa Verde and has an average thickness of about 3 feet."

Rocks Penetrated in the Drilling of Wells

The best record of the rocks found below the surface in the Rangely field is the formation log of the discovery well, Raven No. 1, which accompanies U. S. Geological Survey Map 7, and is copied exactly as follows:

Formation	Description	Thickness
	Upper Cretaceous Rocks	
Mancos shale	Gray to dark-gray shale, grading downward to black, calcareous shale. Contains a few thin beds of fine-grained sandstone and siltstone.	2,970'
Dakota sandstone	Fine-grained, gray sandstone interbedded with gray and greenish-gray shale.	280'
	Jurassic Rocks	
Morrison formation	Green and varicolored shale, white sandy limestone, and limy sandstone.	670'
Curtis formation	Dense, gray, limy shale; dense sandy limestone; and very fine-grained, dark gray, calcareous, glauconitic sandstone.	90'
Entrada sandstone	Light-buff, friable, calcareous sandstone, containing frosted and rounded grains.	130'
Carmel formation	Red to brown sandy shale; dark-gray, fissile limy shale; and very fine-grained, calcareous, buff sandstone.	70'
Navajo sandstone	Salmon-pink, very fine to fine-grained sandstone containing rounded and frosted grains.	480'
	Triassic Rocks	
Undifferentiated	Interbedded red, gray, and green shale; gray to brown, very fine-grained sandstone; and a few thin beds of gypsum.	820'
	Permian Rocks	
Park City formation	White, fissile shale, and reddish-brown shale, containing thin beds of hard limestone and very fine to fine-grained gray and light yellowish calcareous sandstone.	130'
	Pennsylvanian Rocks	
Weber sandstone	Upper 300 feet consists of fine to very fine-grained gray to buff sandstone containing three beds, 10 to 15 feet thick, of shaly micaceous red sandstone, and with parts of entire sequence calcareous. Lower 1,150 feet is similar to top 300 feet with an increase in red beds downward. Several oil-bearing beds which are mainly buff-colored occur from a depth of 5,704 to 6,320 feet.	1,450'

Below the Weber sandstone, in Raven No. 1, some 83 feet of undifferentiated Pennsylvanian rocks were encountered down to the total depth of 7,173 feet. These rocks consisted of very fine-grained, white to pink, calcareous sandstone; gray and red shale; and beds of dense limestone. Their lithology is very suggestive of the Amsden formation.

The Weber sandstone is regarded as being the stratigraphic equivalent of the Tensleep sandstone, an important oil-bearing formation in Wyoming. It is also believed to be equivalent to the Hermosa formation of southwestern Colorado, which is principally a limestone formation. The gradation from the hard, fine-grained, calcareous sandstone of the Weber to the limestone of the Hermosa is presumed to take place in the central part of the Uinta basin.

On Blue Mountain, to the north of Rangely, the Amsden formation overlies Mississippian limestone which varies in thickness from about 650 to 900 feet and has been correlated with the Madison limestone of Wyoming. The Madison, in turn, is underlain by rocks of what is known as the Uinta Mountain Group and which consists of over 12,000 feet of sedimentary rocks, chiefly limestones, which are believed to range in age from the Devonian to the Cambrian. None of these lower formations have been tested in the Rangely field.

Gas- and Oil-Bearing Formations of the Rangely Field

In the Rangely field, gas has been produced from the Dakota sandstone, and oil has been found in the Mancos shale, in the Morrison formation, and in the Weber sandstone. These horizons will be considered in their descending geologic order.

Mancos Shale

As mentioned in Chapter I, oil was first discovered in the Rangely field in the Mancos shale. Production has been found at depths of from 500 to 1,600 feet, with no one particular horizon serving as the reservoir. The relation of the occurrence of oil in the Mancos to calcite veins in the shale is unique and has been described by the U. S. Geological Survey as follows:

"One of the most striking features of the Rangely anticline is the association of oil with calcite veins in the Mancos shale. The outcrops of many of these veins, which occupy joints in the shale, are shown on the U. S. G. S. Map 7 of the field, and others undoubtedly are present beneath the mantle of alluvium and terrace gravel that covers much of Raven Park. The veins are most abundant near the crest of the anticline where folding was most intense. They generally mark strong zones of fracture and strike northwestward parallel to most of the faults and joint cracks. The oil that is found at shallow depths in the Mancos shale appears to be in porous parts of these veins or in crevices in the fractured shale near the veins. For this reason the dip of the veins should be taken into consideration in planning well locations. Inasmuch as most of the fault planes dip eastward, it is to be expected that the dip of the calcite-filled joints is in the same direction."

It is reported that in following the projection of veins from the surface in Section 31, T1N R102W, a fair measure of success has been attained in the completion of shallow wells.

Dakota Sandstone

The occurrence of gas in the Dakota has received some previous comment. Actually, it is doubtful whether the original reserve of gas in the Dakota was of any considerable magnitude, and it is certain that much of it has been wasted through uncontrolled wells. Apparently, only a minor part of the upper member of the Dakota is gas-bearing, and the gas pay is underlain directly by water which has coned upward and drowned out the wells when they were allowed to flow in large volume. From the behavior of the Dakota wells, the porosity and permeability of the gas pay section must be high.

Where exposed on the south side of Blue Mountain, the Dakota has a thickness of 483 feet, which is considerably greater than the thickness of 280 feet reported in the Raven discovery well. Along the lower slopes of Blue Mountain, the Dakota is made up about two-thirds of shale of various colors and one-third of brown and white sandstone and conglomerate. The topmost member consists of about 10 feet of brown, porous sandstone, which rests immediately above a series of black, slaty shales and tightly cemented conglomerate. This member is believed to be the source of the Dakota gas found in the Rangely field.

Morrison Formation

One well in the Rangely field, The Texas Company's Union Pacific No. 1-32, located in the NE 1/4 NW 1/4, Section 32, T2N R102W, has encountered a good showing of oil in the Morrison formation. Whether this horizon has been mudded off by rotary drilling in other wells is not known. It is, of course, possible that the sand encountered in Union Pacific No. 1-32 may be an isolated lentil which may not be present elsewhere. A study of electrical logs, which are made on most wells to provide geologic information, should reveal its presence or absence in other wells.

Weber Sandstone

It is natural that more attention has been given to the Weber sandstone, the principal oil-producing formation in the Rangely field, than to all of the other oil- and gas-bearing horizons. The Weber, in its oil-bearing sections, typically is a hard, fine-grained, usually calcareous in varying degree, sometimes cross-bedded and generally thin-bedded sandstone. Thin laminations of shale and shaley sandstone prevail throughout the greater part of the formation, and, because of their presence, vertical permeability is probably negligible. Small fragments of solid, black material, of gilsonitelike appearance, are common in the porous zones of the sandstone and suggest that the present accumulation of oil may have resulted from a second migration, the first migration having been dissipated during the course of geologic time leaving nothing but solid hydrocarbon residue.

Although no opportunity has been available for a study of the petrology of the oil-bearing rock, a cursory inspection reveals that calcium carbonate is the primary cementing material and clay minerals are subordinate cementing material. It would not be at all surprising to find that considerable secondary cementation has taken place.

The three beds of red, shaley sandstone, noted in the U. S. G. S. formation record of Raven No. 1, have been identified with reasonable regularity over various parts of the field, but it has not proved to be possible to correlate other individual members for any considerable distance. Electrical logs have been of little value for correlation purposes in the Weber.

Oil-bearing sandstone was reported in Raven No. 1 through the upper interval of 616 feet of the Weber (from 5,704 to 6,320 feet). Visual inspection of cores and drill-cuttings, and other "extractions" indicated that 30 per cent of this section or some 183 feet were oil-bearing. However, no information is available as to just how much sandstone out of this 183 feet possesses sufficient permeability to permit the effective movement of reservoir fluid under the conditions of pressure and temperature prevailing.

In the "Foreword" mention was made of the coring program now under way in the Rangely field, and regret was expressed that the preparation of this report could not be delayed until a complete series of core analyses should be available. Through the courtesy of various operators, the writer has been permitted to study the analyses of all cores taken in the field, except one, up to the end of April, 1946. This is the first instance that much of this information has ever been released, and for that reason none of the wells are identified specifically. Table No. 1, in Appendix I, presents a summary of all core information secured. In it the section in which the well from which cores were obtained is listed, and it is believed that this will prove to be sufficient information for the evaluation of the capacity and contents of the Weber reservoir as far as the limitations of scanty data permit.

From Table No. 1 it will be apparent that the best sand conditions so far discovered in the Weber reservoir occur in the northwestern part of the field, and that both porosity and permeability deteriorate to the southeast. Actually, only three of the wells listed have cored the upper part of the Weber completely, and for this reason conclusions regarding general sand quality are uncertain until more information becomes available. However, it can be pointed out that the best sand section so far cored was encountered in a well located in Section 23, T2N R103W. Also, the wells in Section 15 and Section 23, T2N R103W, and the well in Section 19, T2N R102W have cored over 100 feet of permeable sandstone capable of producing oil under the pressure prevailing in the reservoir, and it is believed that the same condition will exist in Section 20, T2N R102W. The permeable pay section appears to thin somewhat from Section 20 to Section 33, T2N R102W to around 80 feet, although all of the permeable pay section may not have been cored in Section 33. There is some reduction in the average permeability of the sand cored in the wells in these two sections. The section of sand encountered in Section 27, T2N R102W differs markedly from all of the others in that a thick section (over 400 feet) of sand possessing low porosity and very low permeability was [redacted] How extensive the occurrence of this very tight sand may be cannot be stated at present, but it is obvious that the effective recovery of oil from it may provide a difficult operating problem.

Even with limited information available, as presented in Table No. 1, it is evident that average figures for porosity and permeability cannot be applied to the field as a whole. Weighted averages have been listed for the purpose of showing the general tight character of the Weber reservoir. Certainly, its physical properties are inferior to the reservoirs of most Rocky Mountain fields, and they are similar in some respects to the tight sand bodies found in certain fields of New York and Pennsylvania.

Attention is called to the considerable thickness of oil saturated sand, having low porosity and negligible to zero permeability, which was cored in the well located in Section 15, T2N R103W. Sand of this type has been found in varying amount in all of the wells that have been cored, but generally it has been ignored by the analysts. It is doubtful whether such tight sections will contribute very much to the flow of oil under the pressure differentials now existing in the reservoir. However, as the pressure declines in the immediate periphery of the well bore, some oil may be produced from the less permeable sand sections, particularly if they are cracked with explosives.

Some check on the thickness and permeability of the producing sand section can be derived by applying the equation for fluid flow through porous media, now that some productivity index tests and subsurface viscosity determinations are available. Data from the well cored in Section 33, T2N R103W are used for this purpose, and the equation for the calculation and its solution are as follows:

$$K = \frac{u \times Q \times \log_e(r_1/r_2) \times 1{,}000}{2 \times pi \times t \times (P_1 - P_2)}$$

where

K = permeability in millidarcies

u = viscosity of oil in centipoises which for Section 33 at 2,445 lbs./sq. in. is 1.1 centipoises

Q = rate of flow from well in cc per second. On productivity index test the well in question produced at the rate of 98 barrels of oil per day with a pressure drop from 2,445 lbs./sq. in. to 2,260 lbs./sq. in. 98 bbls. per day = 4,116 gals. per day = 950,796 cu. in. per day = 15,580,694 cc per day = 180.3 cc per second.

$\log_e$ = Naperian logarithm

r_1 = radius of drainage area in feet = 660

r_2 = radius of hole diameter in feet = $\frac{\text{dia. in inches} \times 0.5}{12}$

$\log_e(r_1/r_2)$ = 7.35 (From tables by F. B. Plummer)

pi = 3.1416

t = thickness of pay in cm. = 70 ft. = 840 in. = 2,133.6 cm.

P_1 = static bottom-hole pressure = 2,445 lbs./sq. in.

P_2 = flowing bottom hole pressure when well was producing at rate of 95 bbls. oil per day = 2,260 lbs./sq. in.

$P_1 - P_2$ = 185 lbs./sq. in.

$= \frac{185.0}{14.7}$ = 12.6 atmospheres

Substituting the values given above in the equation, the determination of effective permeability is calculated as follows:

$$K = \frac{1.1 \times 180.3 \times 7.55 \times 1{,}000}{2 \times 3.1416 \times 2{,}133.6 \times 12.6} = \frac{1{,}497{,}391}{168{,}913} = 8.8 \text{ m. d.}$$

Referring to the average permeability of from 7 to 10 millidarcies reported for Section 33, T2N R102W and listed in Table No. 1, as determined from core analysis, it will be evident immediately that the results of the preceding calculation (8.8 millidarcies) provides an excellent check on the average accuracy of the core tests. Furthermore, it is certain that little more than 70 feet of pay formation is contributing to the production of oil with a pressure differential of 185 lbs./sq. in. as set up in the productivity index determination. If a greater thickness of sand were present, the calculated permeability would be less with all other factors remaining constant.

Occurrence of Gas, Oil, and Water in the Weber Sandstone

From several series of drill stem tests it has been determined that the gas-oil contact in the Weber sandstone reservoir at Rangely is at an average elevation of -320 feet, and has been shown as such on the subsurface structure map. Thus, from the highest known well on the structure, which is The Texas Company's Union Pacific No. 7-29, where the top of the Weber was encountered at an elevation of -230 feet, down to the gas-oil contact a maximum interval of some 90 feet of gas-bearing strata exist. The amount of gas pay, of course, diminishes going down dip to the contact, and the strata which is gas-bearing at high structural elevations is known to be oil-bearing at structural levels below the gas-oil contact. Because of the presence of the gas-cap, the thickness of oil pay section in the Weber is reduced proportionately within the limit of the -320 foot contour line.

The water-oil contact in the Weber sandstone at Rangely has been found in Continental Oil Company's Booth No. 1, located in the NW 1/4 SW 1/4, Section 15, T2N R103 W, and in Algord Oil Company's Guiberson et al No.1, located in the SE 1/4 NE 1/4, Section 18, T2N R102W, at an identical structural elevation of -1,159 feet. For convenience, this contact has been assumed to be at an elevation of -1,150 feet and has been so shown on the subsurface structure map. In large part, the position of the contact has had to be projected and it is, therefore, not drawn on the map as a continuous line.

The only well to be carried to the Weber outside of the designated water-oil contact is the controversial Cobb-Newton-Stringer Government No. 1-D, located in the SE 1/4 SE 1/4, Section 4, T1N R102W. At the time the writer visited the Rangely field, during the latter part of April, 1943, this well had just encountered the top of the Weber at a depth of 6,506 feet. With a surface elevation of 5,205 feet the datum elevation on the top of the Weber was -1,301 feet. Therefore, it was believed that Government No. 1-D would encounter water at the top of the Weber, and this conclusion was confirmed by cores from the top of the sand section which showed no evidence of oil or gas content.

With no showing of oil being found in the upper sections of the Weber, the operators decided to carry the well on deeper, and at a depth from 6,835 to 6,859 feet, some 329 feet below the top of the formation, they reported the recovery of 24 feet of oil saturated sandstone cores. On the basis of this showing, 7 inch casing was run and cemented to a depth of 6,816 feet, but, after drilling the plug, the well made water. Operators are now reported to have abandoned the well (June 29, 1946), so, apparently, they are satisfied that it will not produce oil in commercial quantity, if at all.

An unsuccessful attempt was made to plug off the water-bearing sand encountered in Continental's Rooth No. 1 with plastic. In the Algord well, no attempt was made to plug back from the water-bearing section of the Weber, and in course of time the production of water, which originally cut around 8 per cent, has decreased until it is reported to be negligible at the present time. Subsequently, Algord moved its rig to a location 1/4 mile north of No. 1, in down-dip direction, and, after drilling into the Weber for a distance of only 53 feet the second well is reported to be producing at the rate of 142 barrels of oil per day by flowing and swabbing. The first well penetrated the Weber for a distance of 241 feet. This experience would indicate that water is not encroaching up dip as oil is being removed from the reservoir.

In previous recovery calculations for the Weber sand reservoir at Rangely, the connate water content of 35 per cent, determined in the cores from the well drilled in Section 33, T2N R102W, has been used. From the data presented in Table No. 1, it is evident that this figure is too low for the field as a whole for cores taken with water-base mud. In general, the data in Table No. 1 is suggestive that the connate water content increases from higher to lower structural levels, which is not a surprising condition.

The connate water determinations on cores from the well drilled in Section 20, T2N R102W are of great interest and significance. These cores were cut with oil-base mud and samples were tested in the laboratory of the operator and by an independent service company. The operator's laboratory determined an average connate water content of 16.6%, and the independent service company reported a water content from 11.4% to 23.2% with a weighted average of 19.6%. It will be noted that the well under consideration is located at an intermediate structural position some distance from the water-oil contact, so the results of these tests cannot be criticized on the grounds that they were developed from samples derived from an unrepresentative part of the reservoir. Further confirmation from other cores cut with oil-base mud is, of course, most desirable. However, for the time being, and until other determinations have been made, it can be assumed that the actual connate water content of the Weber sandstone reservoir is less than half the weighted average content (43.9%), determined from cores cut with water-base mud and listed in Table No. 1. The existence of a lower water content in the Weber reservoir than that previously assumed, will serve to improve the results of recovery calculations by the volumetric method.

Chapter III
Drilling and Production Practice

Drilling

As mentioned previously, all wells that have been carried to the Weber sandstone in the Rangely field have been drilled with rotary rigs. Both standard derricks and jack-knife masts are used, and they are uniformly set on substructures. Rigs and pumps are operated with gas engines which use lease gas for fuel, supplemented with butane to provide for any deficiency. Water is obtained chiefly from White River, and is distributed through a pipe line system owned and operated by Stanolind Oil and Gas Company.

The uppermost bed-rock formation, below surface terrace gravels and soil, encountered by all wells is the Mancos shale which drills quite easily but is characterized by a system of fractures in which circulation may be lost at any point in the upper 2,500 feet of hole. Lost circulation may be a very serious problem, requiring a lot of fibrous material for the mud to correct, or an extra long string of intermediate casing to combat successfully.

Light mud weight, from 9.0 to 9.5 lbs./gal., is used down to near the top of the Dakota sandstone where the weight is increased to about 10.6 lbs./gal. in order to prevent a possible blow-out from gas which is sometimes found in the top part of this formation, and to control the artesian water that is found uniformly in it and in the underlying Morrison formation. The Jurassic sandstones, (See Chapter II, Page 21 for description), drill easily, but if the hole is pushed too rapidly it tends to deviate from the vertical. Beneath the Jurassic sands, the Triassic shales and sandstones have tendency to cave and must be drilled with care to keep the drill pipe from sticking. Also, the gypsum beds found in the Triassic contaminate the mud to an extent that some chemical treatment is generally required to maintain good condition.

Seven inch casing is usually set at the top of the Weber, or, if the well is located within the area of the gas-oil contact, at a depth from 10 to 20 feet below this level. The Weber is drilled customarily with low water loss, starch-base mud or with oil-base mud to prevent water enfiltration into the oil-bearing sandstone sections.

The time required to drill from the surface to the top of the Weber is variable, and is dependent largely upon the time which may be required to combat loss of circulation. On the average, from 85 to 100 days are consumed before the 7 inch casing point is reached. The time required to penetrate the Weber is, also, not constant, and depends a great deal on the amount of coring that is done. The minimum drilling and clean-out time for the hard rocks of the Weber is around 40 days, and may amount to as much as 70 days if the entire upper part of the Weber is cored completely. Therefore, the very minimum time for the drilling and completion of Weber sandstone wells at Rangely to average total depths of 6,300 feet has been around 3 months, which may be increased to as much as about 6 months if extended trouble from lost circulation is encountered and considerable coring is done. The prolonged time required to drill and complete wells at Rangely is the principal reason for the high development cost.

A minimum of around 80 hard-rock bits of the following sizes are required for each hole:

3 - 16 inch
3 - 13 3/4 inch
48 - 9 inch
26 - 6 1/8 inch

Because of the hardness of the Weber sandstone, coring cannot be done successfully with wire-line core barrels, and the time-consuming conventional type of core-barrel must be used. Additional time is, of course, required for reaming the hole after two or three cores have been taken, and the cost of coring in past operations has been estimated to be around $30.00 per foot in addition to the ordinary drilling expense. Coring is, truly, an expensive item when some 600 feet of formation must be cut, but no other technique is known whereby the true volumetric capacity of the reservoir can be determined.

There is a possibility that diamond mounted core-barrels, similar to the equipment used for prospecting for metallic ores, might reduce the Weber coring time substantially. It has been recommended to the Rangely Engineering Committee that the possible adaptation of diamond mounted core barrels to the Weber coring program is worthy of careful consideration.

Casing Program

From 60 to 200 feet of 13 3/8 inch surface casing is set and cemented, which is followed by from 500 to 2,700 feet of ~~10 3/4~~ 9 5/8 inch pipe, the amount used depending on the lowest point in the Mancos where circulation may be lost. It is customary to rat-hole ahead through the greater part of the Mancos section, and then ream the hole out to a diameter sufficient to accomodate ~~10 3/4~~ 9 5/8 inch pipe down to the lowest depth where circulation was lost. The 7 inch production string of casing, which is set on top of the Weber or below the gas-oil contact as the case may be, is cemented with from 800 to 1,300 sacks, sufficient cement being used to reach up on the outside of the pipe to a point above the water-bearing strata encountered in the Dakota.

Well Completion Technique

It has been proven beyond much question of doubt that the use of water-base drilling mud, even when treated with starch or gels to reduce the water loss into the oil-bearing formation, produces detrimental effects. After months of production, wells, located considerably above the water-oil contact, which were completed with water-base mud, and thoroughly swabbed, have accumulated several hundred feet of fresh water from drilling mud in the lower part of the hole. This enfiltered water has gradually worked its way back out from the oil-bearing sandstone, and its presence in contact with the reservoir cannot help but impede the free flow of oil and gas, and may actually kill the well, as has been the case in several instances. Most operators hold the opinion that oil-base mud, since it cannot produce a water-block in the oil sand, is preferable to water-base mud and gives better completion results.

Since the natural potential of most of the Rangely wells is not large, it should be possible to drill the entire Weber section circulating oil alone as the drilling fluid and using a drilling-in head of the Guiberson type or some other similar equipment to control circulation. After a few feet of the pay section is penetrated, it would probably not be necessary to add any make-up oil, for the well should produce almost enough to keep the bit clean, particularly if it is being pumped through reverse circulation. The pumps, under these conditions, would be used only as partial boosters. There are, of course, some fire hazards connected with the use of this method, but by the use of a closed system they can be reduced to a minimum. The considerable amount of oil that will be produced by this method while the Weber is being penetrated cannot be very successfully prorated, and can provide some immediate return on the considerable cost of drilling and completing the well. The great success resulting from the use of this method in the completion of wells in the Lost Soldier, Wyoming field, justifies a thorough trial in the Rangely field.

On account of the calcareous cementing material in the Weber, the thought had been held that acid treatment might improve the productivity of wells which have encountered very tight sand sections. The Texas Company acidized its Union Pacific No. 1-32 with unsatisfactory results. Subsequently, this well had to be shot in order to bring it on production. Therefore, the results obtained do not encourage the hope that acid treatment can be employed successfully elsewhere in the field.

About half of the Weber sand wells at Rangely have been shot with nitroglycerine, and it is the concensus that moderate shooting, where the pay section is tight, is beneficial. No advantage can be demonstrated, in the form of greatly increased oil production, for very heavy shots, and heavy shooting generally results in prolonged and costly clean-outs. Cleaning-out, after shooting, with reversed circulation is becoming common practice, and is reported to result in a substantial saving in clean-out time.

Production Equipment

External-upset, 2 inch tubing has ample capacity for the Rangely allowable well production, and is used generally. Surface connections need not be elaborate, with one-wing X-mas trees being favored, and since only about 50 pounds is generally carried on the gas-separators, high-pressure fixtures and surface production equipment are not needed. As long as the wells continue to flow, there is no serious production problem in the field. Some accumulation of paraffin has been reported in tubing which may have to be removed with a retractable knife or other form of cutting tool.

The central pipe line pumping station for the Rangely field is located at a low elevation near to White River, and oil from practically all lease stock tanks will flow by gravity to it.

Well Spacing

Since the deep development of the Rangely field was commenced during the time when the Petroleum Administration for War had virtual control of oil field development, a spacing of 1 well to 40 acres was adopted in accordance with the general well-spacing order. After PAW's control was eliminated, there has been no disposition to go to a closer pattern, and certain companies, for the present, are drilling 1 well to 80 acres on staggered locations except where off-set requirements enforce drilling on 40 acre units. Several unitization agreements have been concluded to cover some of the smaller tracts which came into existence on account of errors in the original land survey.

The effect of the spacing of 1 well to 40 acres on ultimate recovery remains to be determined. Already, it has been questioned on the grounds of the low average permeability of the Weber sandstone. However, until some method can be developed to reduce substantially the cost of drilling and completing wells or to increase materially the anticipated oil recovery, it is doubtful whether any informed operator could find justification for closer well spacing.

Chapter IV
Production of Oil and Gas in the Rangely Field

Operators in the Field

The principal lease owners and operators in the Rangely field, with their percentage ownership of the presently proven area are listed as follows:

Company	Ownership
The California Company	35.0%
Stanolind Oil and Gas Company	21.5%
The Texas Company	18.4%
Idaho-Sharples-Wasatch	8.3%
Phillips Petroleum Company	5.1%
Newton Oil Company	4.7%
Continental Oil Company	0.9%
Minor Interests	3.1%

About 60 per cent of the land in the Rangely field is owned individually in fee. The remainder is Federal and State School lands.

Production of Oil and Gas

The production of shallow oil from the Mancos shale, up to the end of 1945, has been slightly over 1 1/2 million barrels of oil. The production from the Weber sandstone, up to the first of June, 1946, has amounted to 3,992,088 barrels of oil. Currently (June, 1946) the Weber production is around 13,500 barrels of oil per day. The oil production from individual wells is tabulated in Appendix II, Table No. 2 and Table No. 3.

Except for a minor amount used for drilling, gas produced from the Dakota has not been utilized. The total production of gas from the Weber has amounted to 2,222,257 M cu. ft. The gas production from individual wells is tabulated in Appendix II, Table No. 2 and Table No. 3. The average gas-oil ratio for the entire Weber sand production up to the first of June, 1946 is 557 cu. ft. per barrel. If the excessive production of gas from The California Company's Emerald No. 1 and from Idaho-Sharples-

Wasatch's McLaughlin No. 1-32, and the oil production from these wells are eliminated from the calculation, the produced gas-oil ratio becomes 293 cu. ft. per barrel, which is a moderate and reasonable figure.

<u>Oil and Gas Analyses</u>

A sample of Weber crude from The California Company's Raven No. 1, the deep discovery well in the Rangely field, has been analyzed by the U. S. Geological Survey with the following results:

Specific Gravity at 60° F	0.848
Per cent sulfur	0.72
Saybolt Universal Viscosity at 70° F	53 secs.
Saybolt Universal Viscosity at 100° F	46 secs.
Cleveland Open Cup:	
Flash: Below 60° F	
Fire: Below 60° F	
A. P. I. Gravity at 60° F	35.4
Color	Brownish-Green
Pour Point	Below 5° F
Carbon Residue of Crude	2.69%

<u>Approximate Summary</u>

	Percent	Sp. Gr. 60/60° F	°A. P. I. @60° F.
Light gasoline	5.4	.706	68.9
Total gasoline and naptha	24.6	.747	57.9
Kerosene distillate	11.2	.812	42.8
Gas-oil	14.5	.849	35.2
Nonviscous lubricating distillate	13.0	.864-.895	32.3-26.6
Medium lubricating distillate	7.3	.895-.923	26.6-21.8
Viscous lubricating distillate	—	—	—
Residuum	25.8	.958	16.2
Distillation loss	2.6	—	—

Some comments from the refinery of a major oil company on the quality of the various fractions in Weber sand crude from the Rangely field are as follows:

"No 90-100 octane aviation base stock is present in the Weber crude, but from 18 to 20 per cent premium motor fuel with a rating of 80 octane can be obtained by selective refining or desulfurization to improve the susceptibility to lead treatment. A recovery of 80% of regular motor gasoline with a rating of 72 octane can be secured by straight run distillation, and an additional recovery of 29% of the same grade can be obtained by cracking. The cost of lead treating for the regular gasoline is higher than average. Yields of from 20% to 23% of kerosene, requiring treatment for the reduction of sulfur content, can be obtained, and a yield of from 28% to 32% of high quality diesel fuel is possible, depending on the refining schedule for lighter fractions. From 14% to 16% of asphalt and heavy road oils can be manufactured. Some of the heavier fractions might be used in the production of lubricating oils, but at a probable high cost. The oil contains a comparatively high content of sulfur. However, gasolines are sweet, and the sulfur remains in the residuum so that this crude can be regarded as a sweet oil and refined for gasoline, kerosene, and fuel oil. A total yield of approximately 60% of gasoline is obtainable. Treating costs are estimated to be slightly higher than for average sweet crude products∀

Gas analyses from several Weber wells show considerable variation. The Nitrogen content varies from 11 to over 27 per cent. Analysis of a gas sample from Stanolind Oil and Gas Company's Rector No. 1, Section 34, T2N R102W is as follows:

Oxygen	0
Nitrogen	25.15%
Carbon Dioxide	0
Methane	52.43%
Ethane	9.36%
Propane	6.15%
I-Butane	1.66%
N-Butane	2.59%
I-Pentane	1.01%
N-Pentane	0.69%
Hexanes plus	0.96%
Gross BTU by Pod	1159
Specific Gravity by Pod	0.887
Specific Gravity by weight	0.888
GPM	
Actual pentanes	1.059
Calculated at 15 lbs.	1.119
Calculated at 26 lbs.	1.458

Vapor pressure of pentanes plus fraction is 12.31 lbs./sq. in.

Allocation of Production

A Subcommittee of the Rangely Engineering Committee has made a study of equitable allocation of production from the Weber reservoir, and has submitted its report to the Operators, which is included herewith as Appendix III. The allocation formula which was recommended considers the factors of acreage, bottom-hole pressure, and gas-oil ratio. Particular emphasis has been placed on the conservation of gas, and the gas-oil ratio factor has been designed to accomplish this objective.

Subsequently, the formula developed by the Engineering Committee was adopted by the Rangely Operators with the following modifications:

1. Assign 80 acres to each well located not less than 1,867 feet from any drilling or producible well, and assign 40 acres to each well having a direct offset, and

2. Allocate no more than 500 barrels per day and no less than 100 barrels per day to any one well, and

3. Distribute underages to wells able to make the production but no well to exceed 500 barrels per day.

With recognition being given to these changes for the governing of the application of the formula, a Production Allocation Schedule was developed for the Second Quarter of 1946 which is reproduced to accompany this report as Appendix IV, Table No. 4. The allocation of production in this schedule is based on a total field outlet of 18,500 barrels per day, of which 17,323+ barrels per day were allotted to 67 wells completed at the time the schedule was prepared, and 1,157 barrels per day were allotted to 8 wells in process of being drilled which were estimated would be completed during the quarter.

The range of well allowable for the 67 wells, as set forth in Appendix IV, Table No. 4, is from 50 to 433 barrels of oil per day with an average of 258.5 barrels per day per well.

Economic Factors Affecting Current Rangely Development

Assuming no more than a 1/8th royalty, an average well in the Rangely field should yield an operator a net production of 6,780 barrels of oil per month under the existing allocation schedule. Even with the high costs of from $125,000.00 to $150,000.00 for a completed well, the indicated pay-out under existing allowables, of within around two years has certainly been far more attractive than the extended payouts which can be expected in many MidContinent and Southwestern fields. However, the present capacity of the pipe line outlet from the field is only 20,000 barrels of oil per day, and from Appendix II and Appendix IV it will be apparent that the line is already approaching capacity operation. It is understood that its capacity can be increased to 30,000 barrels of oil per day by the installation of an intermediate pumping station between Rangely and Wamsutter, Wyoming. However, there is no assurance that additional markets are available for an increase of some 50 per cent in field production.

With the prospect of from 30 to 35 rigs running in the field at the beginning of the Third Quarter of 1946, it is reasonably certain that there should be some 125 wells completed at Rangely by the end of the current year. With no increase in the outlet for crude, the average allowable production per well, by necessity, will decline to around 160 barrels of oil per day. As development in the field is continued, it can be forseen, even with a possible increase in the capacity of the pipe line outlet, that the average daily allowable per well will probably decline to around 100 barrels of oil per day by the end of 1947. Under such conditions, the time required for pay-out of a completed well will increase correspondingly to from 4 1/2 to 5 years. Consequently, it is obvious, if the current rate of pay-out at Rangely is to be preserved, some drastic changes must be effected, among which the following might be considered:

1 - Improved drilling performance, thereby reducing development cost.

2 - Enlarged markets for Rangely crude with the construction of additional pipe line facilities to transport the increased production.

3 - A curtailment of drilling activity by agreement among all the operators, should such procedure be legal, with the temporary enforcement of a spacing of 1 well to 80 acres.

It is believed confidently that definite economies in the cost of drilling and completion are possible, and the saving that will result from such improvement combined with some curtailment in drilling activity appears to offer the best present solution to the immediate problem of diminishing returns. However, in arriving at this conclusion, monetary return alone has received consideration, and if consideration is given to what may be the maximum efficient production rate, it may become evident that some of the high well allowables now existing may prove to be an extravagant waste of reservoir energy.

With the need for some form of artificial lifting equipment in prospect in the not too distant future for certain parts of the field, thereby adding to an already high development cost, it would certainly seem to be the part of prudence for the Rangely Operators to consider seriously the conditions which will likely result from the expanding development now under way.

Chapter V
Reservoir Conditions and Performance in the Weber Sandstone Rangely Oil Field

Specific Gravity of Gas

The specific gravity of produced gas from the Weber sandstone reservoir in the Rangely field has been determined for four wells by the U. S. Bureau of Mines as follows:

Company	Well	Location	Sp. Gr.
Stanolind Oil and Gas Co.	Hagood No. 1	Sec. 23, T2N R103W	.842
The California Company	Fee No. 3	Sec. 29, T2N R102W	.904
The California Company	Gray "B" No. 2	Sec. 18, T2N R102W	.856
The California Company	Fee No. 1	Sec. 30, T2N R102W	.720

The wide variation in the specific gravity of the produced gas is believed to be due to differences in the percentage content of inert gases which are reported to range from 11 to 27 per cent. An average specific gravity of .867 has been used in calculations relating to the performance of the reservoir.

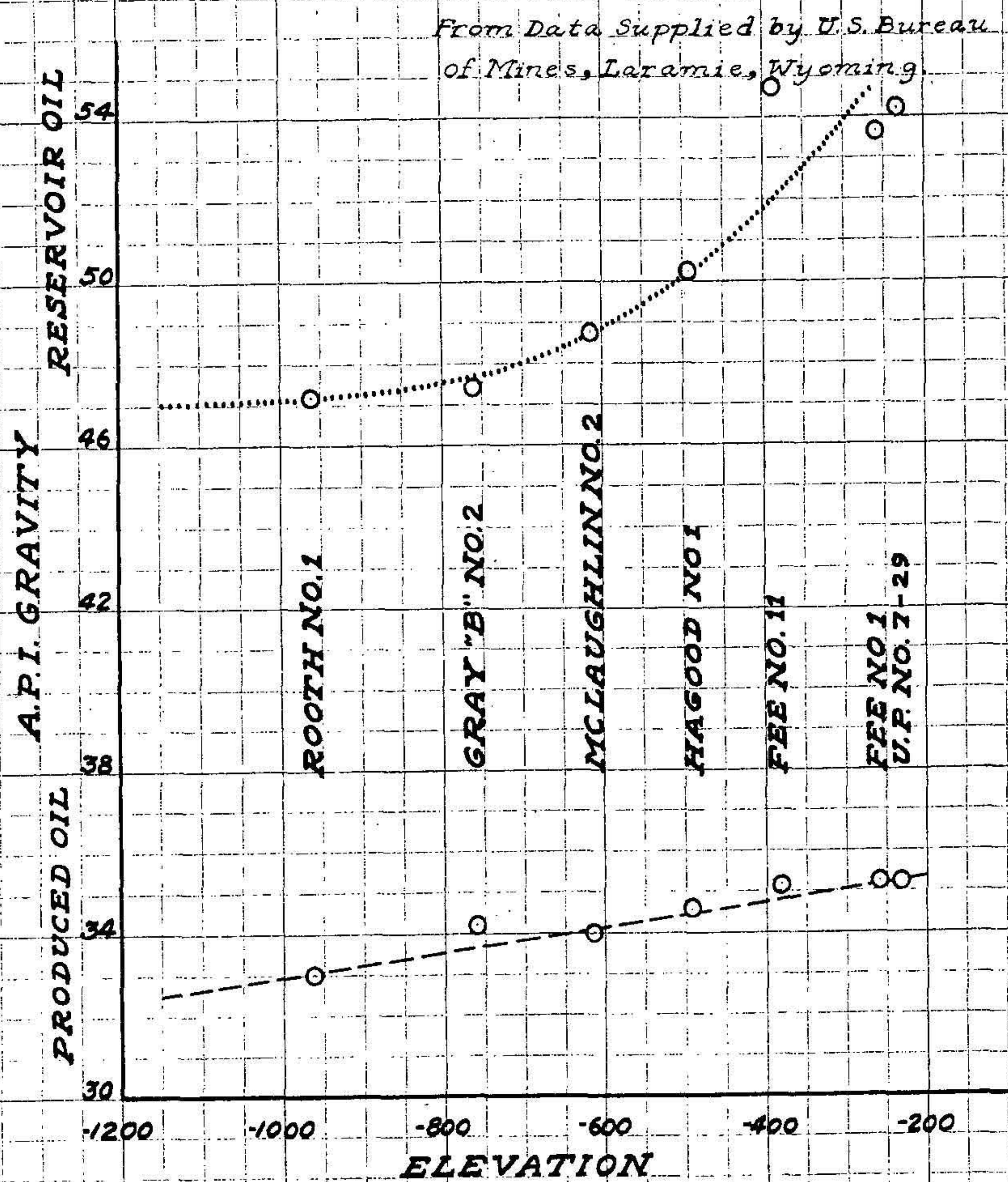
The considerable inert content of the produced gas from the Weber sandstone will, of course, serve to reduce its heating value, and will effect the supercompressibility factor for the pressure differential existing between the reservoir and the atmosphere.

A. P. I. Gravity and Specific Gravity of Crude

The A. P. I. gravity and specific gravity of Weber sand crude from several wells in the Rangely field have been determined precisely by the U. S. Bureau of Mines, and are listed in Appendix V, Table No. 5.

The relation between the A. P. I. gravity of produced oil and of reservoir fluid to structural position has been determined by the U. S. Bureau of Mines, and is shown graphically in Figure No. 4, Page 45-A. From this illustration, it is very evident that the A. P. I. gravity of the oil increases consistently from lower structural positions toward the gas-oil contact.

RELATION OF A.P.I. GRAVITY OF WEBER PRODUCED CRUDE AND RESERVOIR FLUID TO STRUCTURAL POSITION RANGELY FIELD, RIO BLANCO COUNTY, COLO.



Paul D. Torrey
July 11, 1946

Figure No.4

Reservoir Temperature and Temperature Gradient from the Surface to the Weber Sandstone

The temperature of the Weber reservoir has been determined in most of the wells in the Rangely field in connection with bottom-hole pressure surveys, and the temperature gradient from the surface to the top of the Weber has been determined in several wells. Some of these data have been plotted in graphical form and are shown in Figure No. 5, Page 46-A. From the data presented in this graph and from other surveys, it has been determined that the temperature in the reservoir varies from 154° F on top of the structure to 166° F near the water-oil contact. The perceptible "elbow" in the gradient curve, at a structural elevation of approximately +1,750 feet, marks the position of the uniformly water-bearing Dakota sandstone. Both above and below this point, the trend of temperature increase is quite consistent, although at different rate.

Shrinkage Factor

In Appendix VI, Table No. 6, the volume increase from oil at the surface to the oil as it occurs in the reservoir, and the expansibility factor, which is the change in volume for each pound decline in pressure, for 6 representative wells, producing from the Weber sandstone in the Rangely field, are listed. The average shrinkage factor, determined from these 6 wells, is 1.173 barrels of reservoir fluid = 1 barrel of surface oil. In Figure No. 6, Page 46-B, the relation between the shrinkage factor of crude and structural position is shown in graphical form. From this curve, it will be apparent that the loss in volume from the reservoir to the surface increases from low to high structural positions in the Weber reservoir. This is a good example of certain unusual relations in the Rangely field, where structural

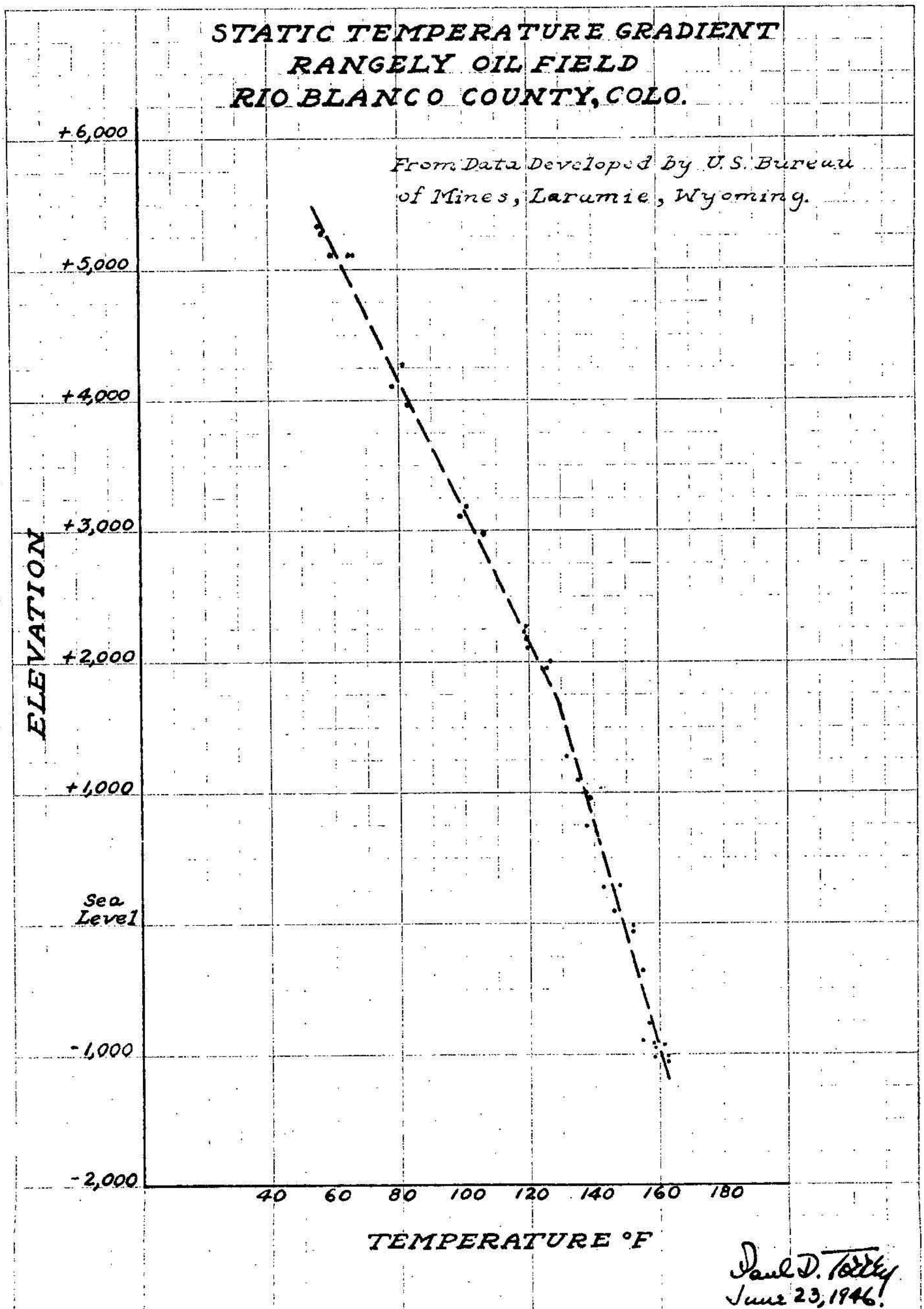
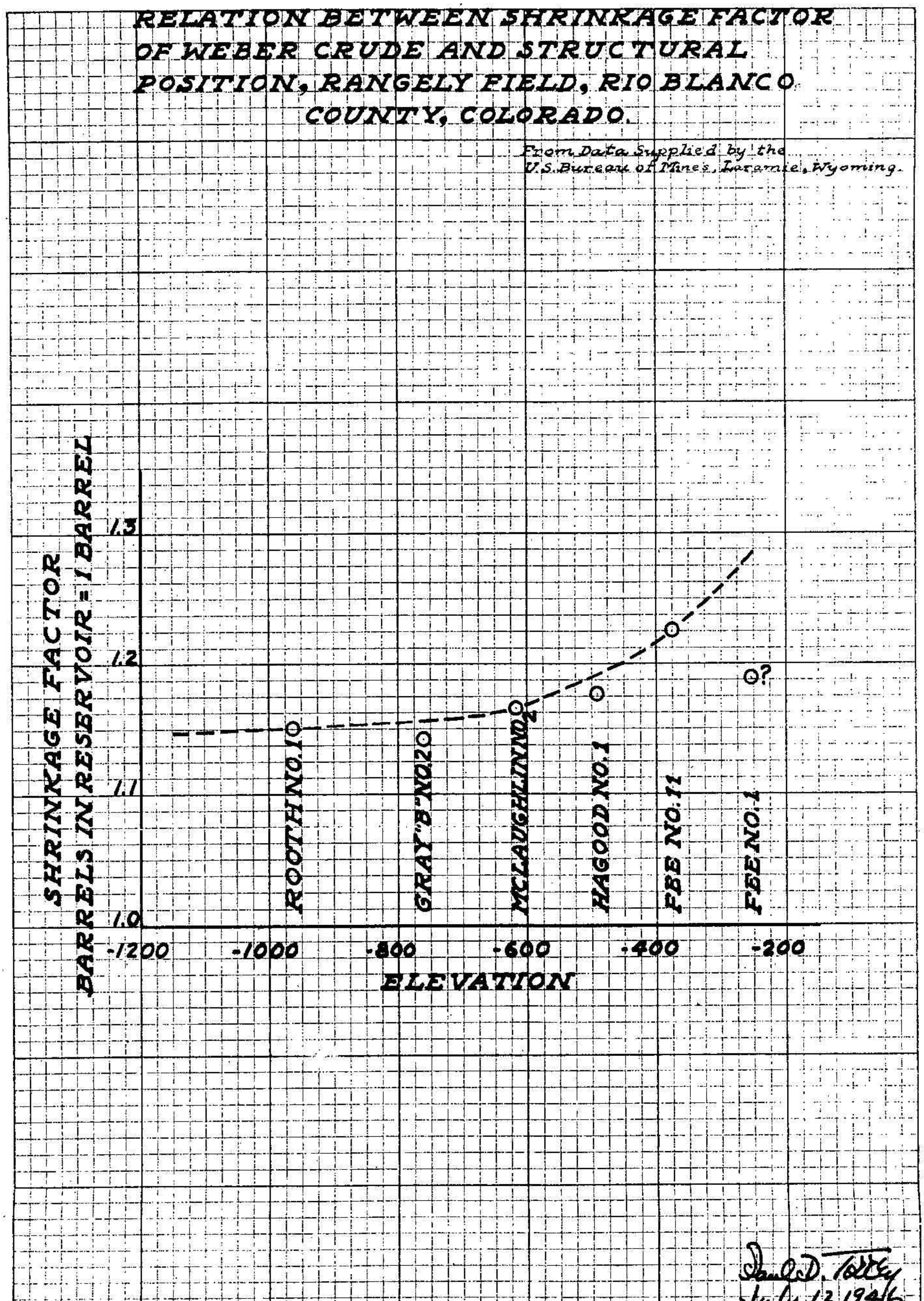

STATIC TEMPERATURE GRADIENT
RANGELY OIL FIELD
RIO BLANCO COUNTY, COLO.
From Data Developed by U.S. Bureau of Mines, Laramie, Wyoming.
ELEVATION
+6,000
+5,000
+4,000
+3,000
+2,000
+1,000
Sea Level
-1,000
-2,000
40
60
80
100
120
140
160
180
TEMPERATURE °F
Paul D. Torrey
June 23, 1946.

Figure No. 5.



RELATION BETWEEN SHRINKAGE FACTOR OF WEBER CRUDE AND STRUCTURAL POSITION, RANGELY FIELD, RIO BLANCO COUNTY, COLORADO.
From Data Supplied by the U.S. Bureau of Mines, Laramie, Wyoming.
SHRINKAGE FACTOR
BARRELS IN RESERVOIR = 1 BARREL
1.3
1.2
1.1
1.0
ROOTH NO.1
GRAY "B" NO.2
MCLAUGHLIN NO.2
HAGOOD NO.1
FBE NO.11
FBE NO.1
?
-1200
-1000
-800
-600
-400
-200
ELEVATION
July 12, 1946

Figure No. 6

position appears to control important physical properties of the reservoir fluid.

Solution Gas Content of Crude and Produced Gas-Oil Ratio

Information on the gas in solution in the Weber reservoir fluid is listed in Appendix VI, Table No. 6. These figures are compared, as follows, with produced gas-oil ratios measured at approximately the same time that subsurface samples were procured or determinations of bottom-hole pressure made.

Well	From Table No. 6 Gas in Solution Cu. ft./Bbl.	Produced Gas-oil Ratios Date and Cu. ft./Bbl.	Date and Cu. ft./Bbl.	Date and Cu. ft./Bbl.
U. P. No. 7-29	212?			June 1946 259
Fee No. 1	324?	9/17/45 324	2/22/46 339	June 1946 302
Fee No. 11	406	9/28/45 427		June 1946 784
Hagood No. 1	299	9/20/45 236(1)	2/22/46 260(3)	June 1946 260
McLaughlin No. 2	310	10/3/45 341	2/22/46 160	June 1946 243
Gray "B" No. 2	224	9/15/45 [illegible](2)	[illegible]	June 1946 169
Booth No. 1	246			June 1946 271

(1) Average of 6 previous determinations
(2) Average of 2 previous determinations
(3) Estimated
? Data from U. P. No. 7-29 and Fee No. 1 may not be reliable on account of unfavorable production conditions at time tests were made

From these data it is apparent that no definite trend in produced gas-oil ratios has developed for the group of wells in which the solution gas content of crude has been determined. Except for Fee No. 11, it seems evident that none of these wells have been produced at a rate which would lower the bottom-hole pressure consistently below the saturation pressure.

Although it may not be a fair comparison because many of the recently completed wells have been at intermediate and lower structural positions, it is notable that the produced gas-oil ratio of the Rangely field has declined slightly between the time of the first and second general bottom-hole pressure surveys. Eliminating the oil and gas production from both Emerald No. 1 of The California Company and McLaughlin No. 1-32 of Idaho-Sharples-Wasatch from consideration because of excessive gas production, the field had produced up to the time of the first pressure survey 1,640,606 barrels of oil and 517,200 M cu. ft. of gas for a produced gas-oil ratio of 315 cu. ft./bbl. With the same wells eliminated, the production from the time of the first survey to the time of the second survey has been 2,022,882 barrels of oil and 555,824 M cu. ft. of gas for a produced gas-oil ratio of 275 cu. ft./bbl. With no general increase in produced gas-oil ratio being evident, it may be concluded that there has been no considerable expansion of the gas cap, and that gas is not breaking out of solution in any quantity in the reservoir. Locally, exceptional conditions, such as the increase in gas-oil ratio reported for Fee No. 11, may be indicative of a developing condition which could have a damaging effect on ultimate oil recovery. However, the trend of produced gas-oil ratio for the field as a whole cannot be considered to be dangerous up to the end of the Second Quarter, 1946.

The relation between gas in solution in the Weber sand reservoir fluid to structural position is shown in Figure No. 7, Page 48-A. From this curve, it can be seen that the solution gas content of the crude increases from lower to higher structural positions, and here again, as previously noted, it is evident that

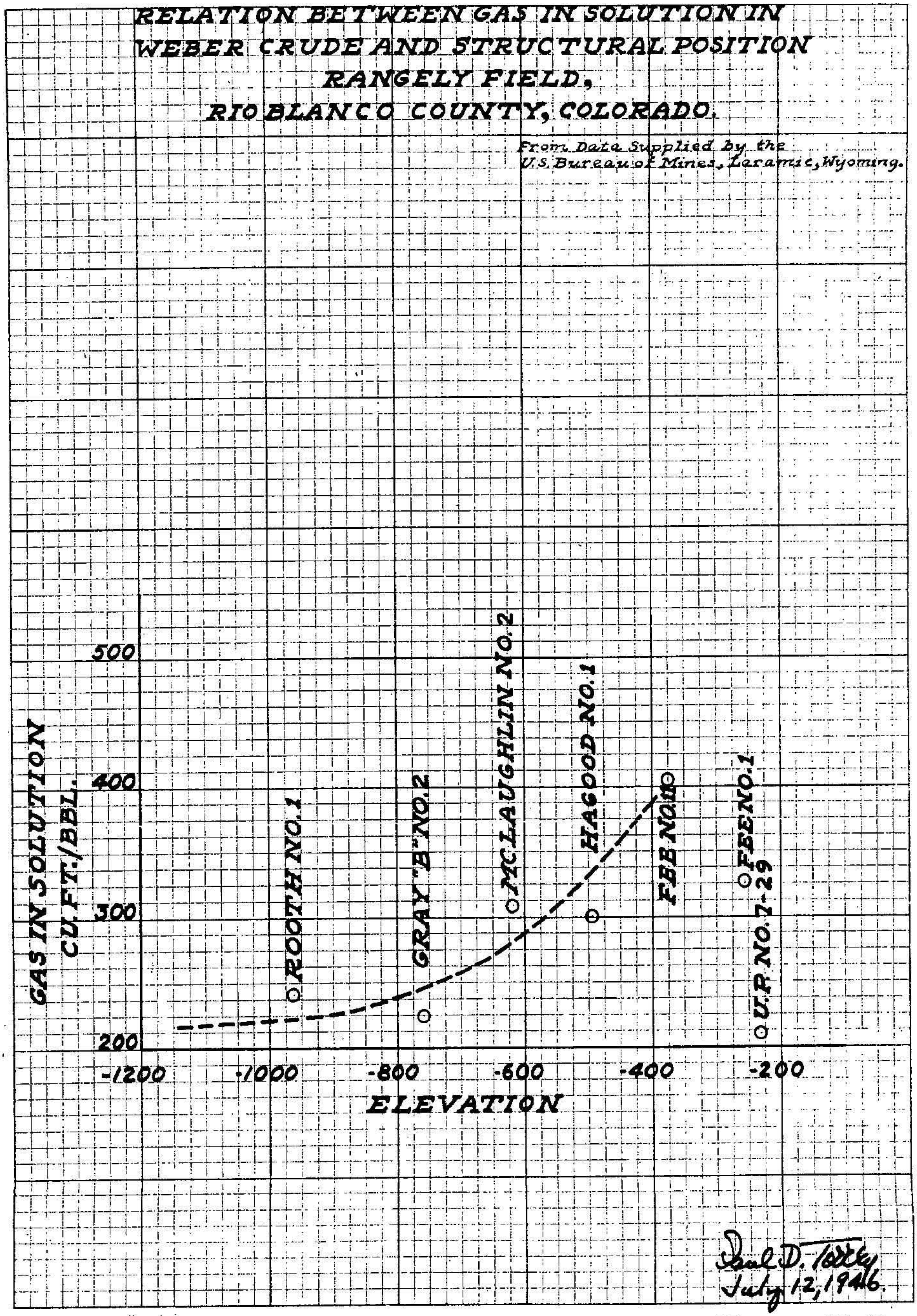

RELATION BETWEEN GAS IN SOLUTION IN
WEBER CRUDE AND STRUCTURAL POSITION
RANGELY FIELD,
RIO BLANCO COUNTY, COLORADO.
From Data Supplied by the
U.S. Bureau of Mines, Laramie, Wyoming.
GAS IN SOLUTION
CU.FT./BBL.
500
400
300
200
-1200
-1000
-800
-600
-400
-200
ELEVATION
ROOTH NO.1
GRAY "B" NO.2
MC LAUGHLIN NO.2
HAGOOD NO.1
FEE NO.8
FEE NO.1
U.P. NO.7-29
Paul D. Torrey
July 12, 1946.

Figure No. 7

structural position has influenced the physical characteristics of the reservoir fluid.

Saturation Pressure

The saturation pressure of the Weber sand crude from several wells in the Rangely field is listed in Appendix VI, Table No. 6, and the relation between the saturation pressure and structural position is shown graphically in Figure No. 8, Page 49-A. In this illustration, data from Fee No. 1 and from U. P. No. 7-29 are purposely omitted because, for Fee No. 1, although the subsurface sample was found to be saturated completely under the pressure prevailing, it is known that the bottom-hole pressure had declined about 250 lbs./sq. in. prior to the time the sample was taken; and for U. P. No. 7-29, it was discovered, after the subsurface sample had been taken, that this well had been produced at a high rate, probably sufficient to lower the bottom-hole pressure below the saturation pressure, for one week before the sample was taken.

Figure No. 8 indicates that the crude in the Weber reservoir is completely saturated with gas in that part of the structure above the gas-oil contact, under the existing conditions of temperature and pressure. It is believed that this condition may prevail for a vertical distance of from 50 to 100 feet below the gas-oil contact, and therefrom the saturation pressure decreases going down dip. The relation between the bottom-hole pressure and depth, as shown in Figure No. 8, is consistent, but the low saturation pressure encountered in Gray "B" No. 2 does not conform with results from the other wells.

Three separate bottom-hole samples from Gray "B" No. 2 have been tested by the Bureau of Mines with closely checking results, so the accuracy of the work cannot be questioned. Without

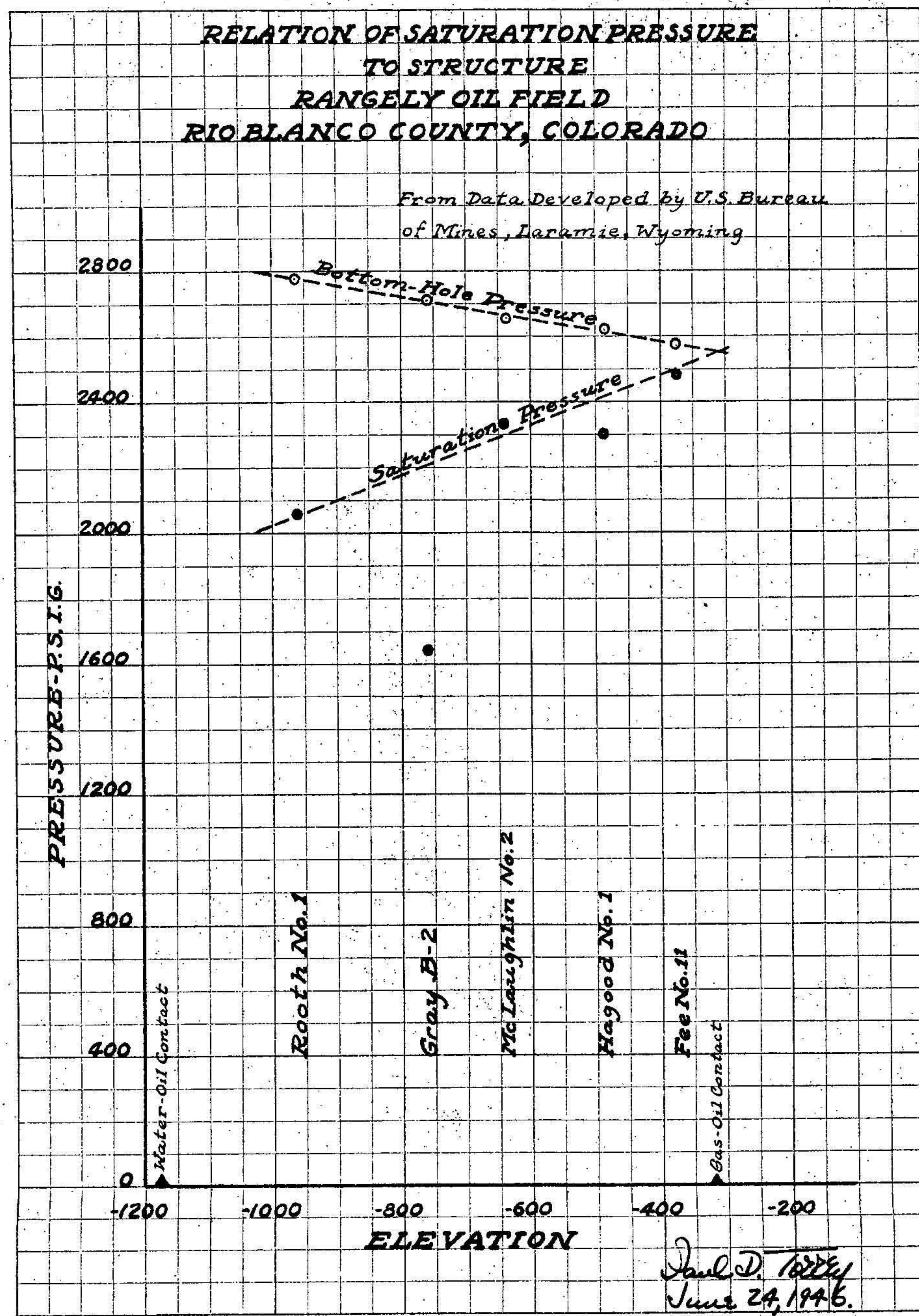

RELATION OF SATURATION PRESSURE
TO STRUCTURE
RANGELY OIL FIELD
RIO BLANCO COUNTY, COLORADO
From Data Developed by U.S. Bureau
of Mines, Laramie, Wyoming
Bottom-Hole Pressure
Saturation Pressure
PRESSURE-P.S.I.G.
2800
2400
2000
1600
1200
800
400
0
Water-Oil Contact
Rooth No.1
Gray B-2
McLaughlin No.2
Hagood No.1
Fee No.11
Gas-Oil Contact
-1200
-1000
-800
-600
-400
-200
ELEVATION
June 24, 1946.

Figure No.8

additional supporting information, the only logical inference that can be made at present is that Gray "B" No. 2 may produce from an isolated reservoir, cut off from the main part of the field by faulting, by sealed joints, or by variable sedimentary lithology. With the possibility that no communication may exist between Gray "B" No. 2 and the other wells that have been sampled, the phase relations between the liquids and gases could be quite different from those encountered elsewhere in other parts of the field.

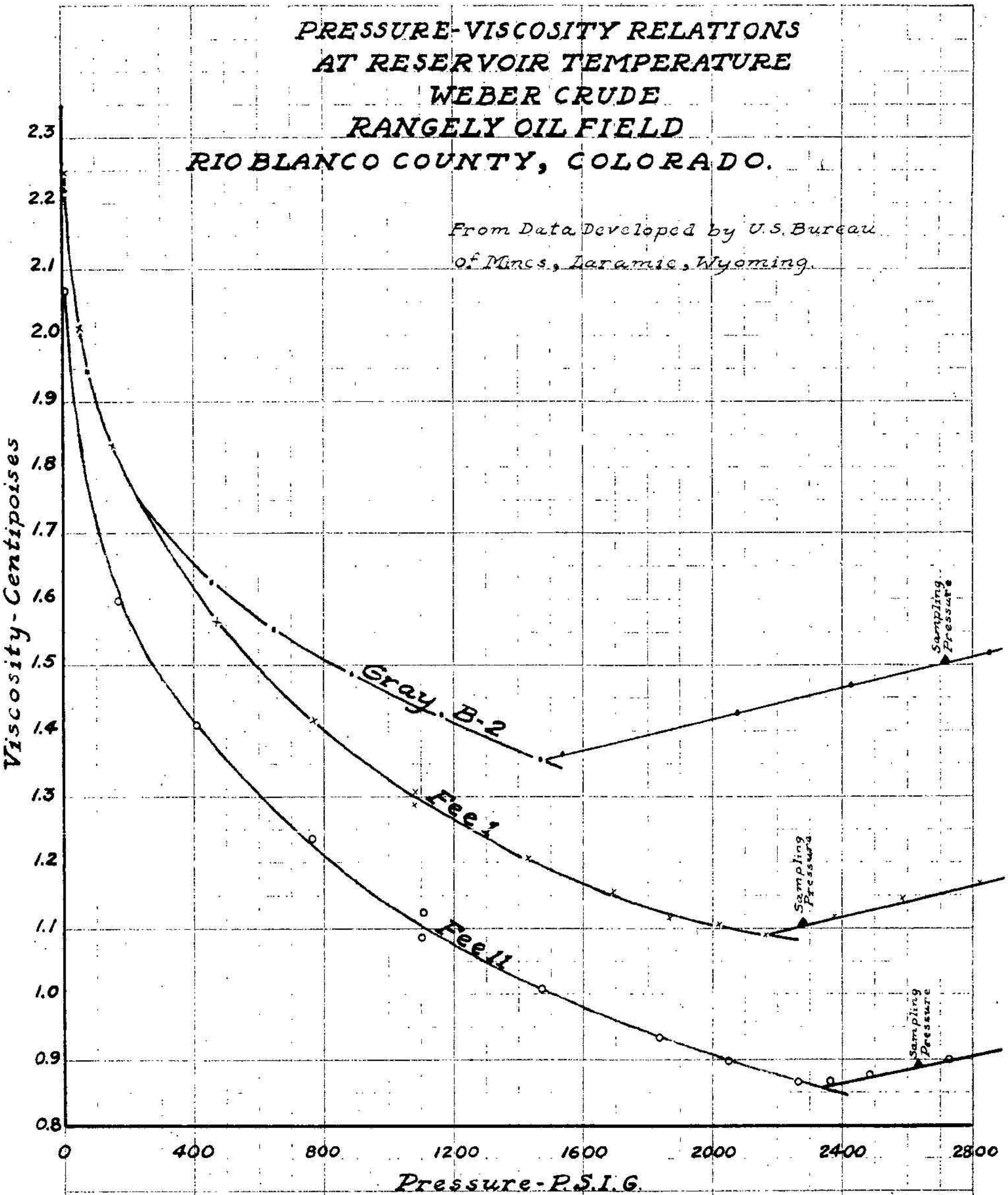
Variations in the saturation pressure within a single reservoir are most unusual, the only other occurrence of this type known to the writer being the Elk Basin field, Wyoming. There is certainly a surplus of virtually dry gas available in the gas-cap of the Weber reservoir at Rangely, and if free intercommunication existed throughout the entire gas and oil saturated sand section the amount of gas in solution in the oil should not vary appreciably. Excepting the anomalous condition found in Gray "B" No. 2, the saturation pressure decreases progressively rather than abruptly going from high to low structural levels. The only likely explanation which can be offered for the unusual conditions found in the Weber reservoir at Rangely is that most of the gas which has accumulated therein originated from the source beds and migrated to the higher part of the structure prior to the migration of oil and prior to any reduction in permeability brought about by secondary cementation in the sandstone or compaction of the entire sedimentary column. Subsequently, after the migration of oil took place, the low vertical and horizontal permeability in the Weber has prevented the formation of a state of complete equilibrium in the reservoir, and it is conceivable that minute adjustments were still in progress up to the time when the withdrawal of reservoir fluid was commenced.

The detrimental effects which accompany the lowering of the bottom-hole pressure below the saturation pressure will be considered in detail in a following part of this Chapter. However, it may be noted at this point that at structural levels near to the water-oil contact a much higher production rate can be maintained during the early life of the field with no harmful reaction in the form of increased gas-oil ratios and reduced permeability of the reservoir to oil than would be the case at higher structural positions.

Subsurface Viscosity of Cruse and Pressure-Viscosity Relations

It will be recognized that the subsurface viscosity of the oil will vary in accordance with the amount of gas in solution. Consequently, it will not be surprising to note in Appendix VI, Table No. 6, and in Figure No. 9, Page 51-A, that the viscosity of the reservoir fluid is lower at high structural positions and higher at low structural positions in the Weber reservoir. The unfavorable conditions under which the sample from Fee No. 1 was secured have been emphasized previously, and for the reasons already stated the data developed from this well are not considered to be representative of the original reservoir conditions and have not been used.

Keeping in mind that the effect of oil viscosity on its mobility is an inverse function, in contrast to the effect of permeability on the rate of flow of oil which is a direct function, it will be immediately apparent, from Figure No. 9, as the bottom-hole pressure declines, that wells located on the higher part of the structure will have a distinct advantage over wells having a lower structural position insofar as the influence of viscosity on the efficiency of fluid flow is concerned. As an example, it may be cited that the bottom-hole pressure could drop from the



Location of Wells

Gray B-2 - SW¼ SE¼ Sec. 18, T2N R102W, Datum Elev. -761'.
Fee 1 - NE¼ SE¼ Sec. 30, " " " " -256'.
Fee 11 - SW¼ SE¼ Sec. 28, " " " " -374'.

Figure No. 9

Paul D. Torrey

saturation pressure of about 1,500 lbs./sq. in. with a loss of only about 0.1 centipoise of viscosity in Fee No. 1 and with a loss of only about 0.15 centipoise of viscosity in Fee No. 11. However, in the case of Gray "B" No. 2, at the same pressure of about 1,500 lbs./sq. in., the viscosity is 0.35 centipoise higher than in Fee No. 11, even though its crude is less viscous at this point than at any other.

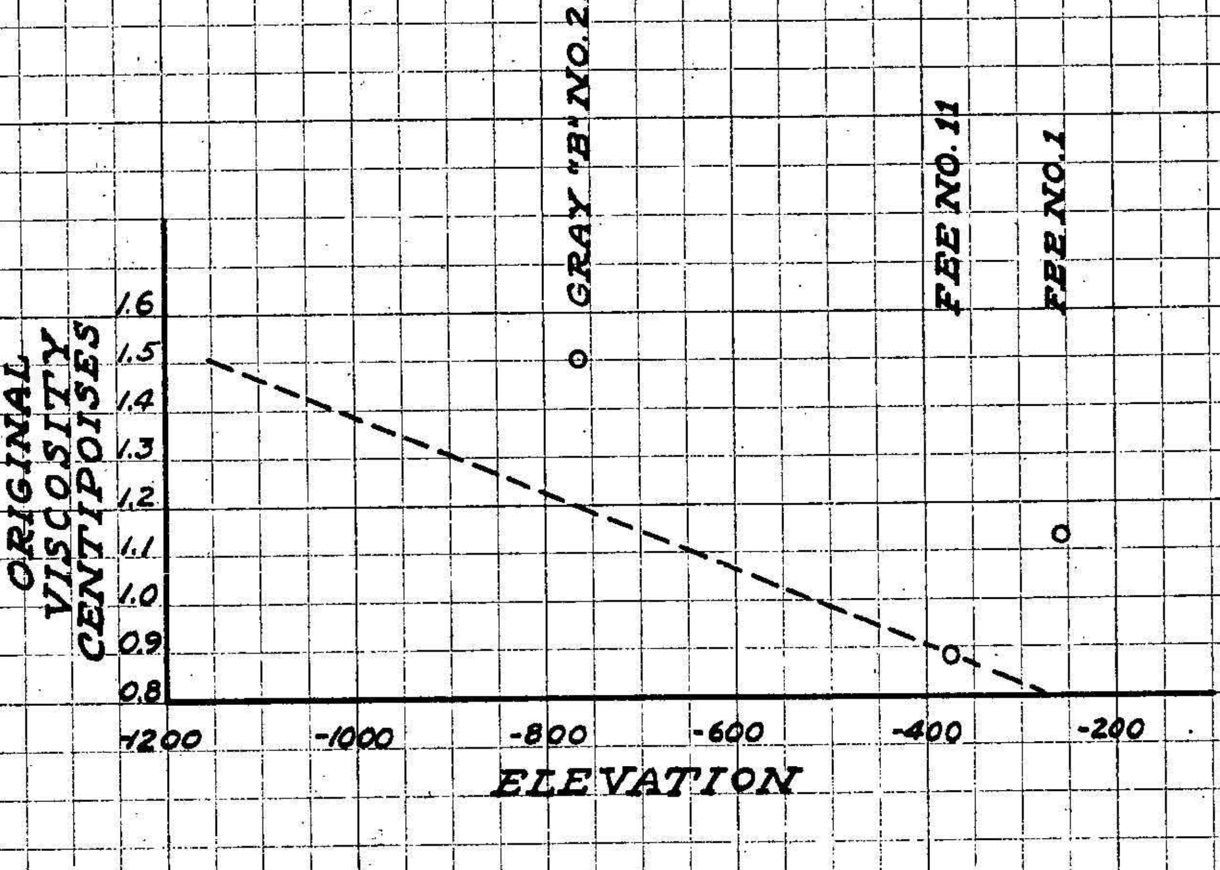
As mentioned previously, the crude sample from Gray "B" No. 2 has anomalous characteristics, and may not be representative of other parts of the field at equivalent structural position, so additional data, to confirm or disprove the effects now indicated, are particularly desirable. However, with the relation between structural position and gravity of crude, solution-gas content, and saturation pressure established with reasonable certainty, it may be assumed that the initial viscosity of crude found at higher parts of the structure was somewhat less than at lower elevations. Figure No. 10, Page 52-A, has been prepared to show what is believed to be the initial subsurface viscosity of the Weber reservoir fluid in relation to structural position.

Productivity Indices

A total of 57 productivity index determinations have been made on wells producing from the Weber reservoir in the Rangely field by the U. S. Bureau of Mines and by the Rangely Engineering Committee. Certain of these tests were made on the same well at different times, and on certain wells a series of tests have been made at different flowing rates in sequence. All information available on the build-up characteristics of the Weber sand wells and their productivity indices are listed in Appendix VII, Tables No. 7, No. 8, and No. 9.

PROBABLE RELATION BETWEEN SUBSURFACE VISCOSITY AND STRUCTURAL POSITION WEBER RESERVOIR, RANGELY FIELD, RIO BLANCO COUNTY, COLORADO.

From Data Developed by the U.S. Bureau of Mines, Laramie, Wyoming



Paul D. Torrey
July 11, 1946.

Figure No.10

When more complete core analyses become available a comparison of the results of this work with productivity indices should provide an interesting and probably profitable study. It is quite possible that a fairly accurate deduction on average permeability should be possible from productivity index tests combined with other engineering information on the reservoir. For the present, the limited amount of information at hand will permit only a certain amount of surmise on these relations.

Productivity indices have been made on 5 of the 6 wells on which core information is presented in Appendix I, Table No. 1. Using the same formula employed in Chapter II, page 28, and with an estimation of subsurface viscosity from Figures No. 9 and No. 10, the average permeability of the sand sections encountered in these wells has been calculated, and, for the sake of comparison, is tabulated below along with the average permeability from core analyses and other pertinent data relating to the productivity index test.

Well - As Identified in Table No. 1 by Section	15	23	18	20	33
Datum Elevation - Top Weber	-364	-617	-564	-516	-290
Oil Pay Section Cored Ft.(1)	108.0	122.3	104.5	52.5	70.0
Average Permeability from Core Analyses - M. D.	13.0	28.2	15.7	7.8	7 to 10
Calculated Avg. Permeability from P. I. Tests - M. D.(2)	21.4(4) 23.4(5)	24.2(5)	5.3(5)	3.8(5) 10.4(5)	8.8(3) 8.7(5)
Flowing Pressure at P.I. Test Lbs./sq. in.	2,482(4) 2,492(5)	2,420(5)	1,690(5)	1,947(5)	2,260(5)
Estimated Saturation Pressure	2,060	2,320	2,360	2,400	2,520
Lbs. Flowing Pressure is below Saturation Pressure	none	none	670	453	260

(1) Having a permeability of over 1 millidarcy.
(2) By formula from M. Muskat, Gulf Research and Development Co.
(3) From calculation in Chapter II, page 28
(4) From tests by Bureau of Mines
(5) From tests by Rangely Engineering Committee

It was thought that some relation between the effect on the permeability of the reservoir to oil and the flowing of the wells below the saturation pressure, as that might be the case, might be established. From consideration of the data that are given in the preceding table, this does not appear to be possible, but some comment relative thereto and to other pertinent points may serve to guide the proper application of more complete information when the same may be available at later time.

The calculated average permeability of the sand from the well in Section 20 is considerably higher than the determined average permeability. However, only about one-third of the total upper Weber section was cored, and if there is more permeable sand below the cored section, which is probable, the average calculated permeability will be reduced accordingly. In this well the flowing pressures are substantially above the saturation pressure.

There is reasonably close agreement between the determined average permeability and the calculated average permeability for the well in Section 23. Here again the flowing pressure is above the saturation pressure.

For the well in Section 19, the calculated average permeability is only about one-third of the determined permeability, and in this well the flowing pressure is substantially below the saturation pressure. It is known that the complete Weber pay section was cored in this well with good recovery so the divergent results cannot be attributed to incomplete core information. The only explanation that can be offered for the wide variation in results is that the permeability of the reservoir to oil is being diminished appreciably by producing the well at a rate which lowers the flowing pressure considerably below the saturation pressure.

With two separate productivity tests, enabling a double check, there is fairly good conformity between the determined average permeability and calculated permeability for the well in Section 20. However, it is known that not all of the producing pay section was cored in this well, which would serve to increase the calculated average permeability, and at the same time the flowing of the well at a pressure materially below the saturation pressure should tend to reduce the calculated average permeability. Consequently, there is a distinct possibility that these two variables may have balanced each other and thereby produced what appears to be a reasonably close check.

For the well in Section 33 there is little difference between the average permeability as determined from core analysis and the calculated average permeability from two separate productivity tests. In this well the flowing pressure, when the tests were made, was not seriously below the saturation pressure, so the permeability of the reservoir to oil may not have been affected to any extent.

All of the foregoing discussion should be regarded as being suggestive rather than conclusive, but there can be no doubt that when the point is reached where the bottom-hole pressure declines appreciably below the saturation pressure, gas will tend to break out of solution with the inevitable result that the permeability of the reservoir to gas will increase and the permeability to oil will decrease. Diminished oil production accompanied by greatly increased gas-oil ratios may be expected to accompany these changes as they take place in the reservoir.

In the July, 1946 report of the Rangely Engineering Committee it is suggested that some of the high productivity indices reported in Appendix VII, Tables No. 8 and No. 9 are du to a fractured condition in the reservoir. This is a reasonable assumption when consideration is given to the mode of shallow oil accumulation in the Mancos shale. The relations which have been described herein between determined and calculated permeability do not indicate any effects which require an assumption of fracturing to explain, but it will be recognized that this small group of wells, listed in Appendix I, Table No. 1, could not be regarded as being representative of the large and in many parts still undrilled area of the Rangely field.

The Rangely Engineering Committee has recently conducted a series of interference tests to determine whether the production of oil from a well will have any detrimental effects on off-set wells which are shut in. The results of these tests are given in Appendix IX, Table No. 10. These tests were conducted for periods of from 3 to 4 days, and it is evident that no interference developed during this time. In U. P. No. 9-29 and Associated No. 2 the bottom-hole pressure remained virtually constant while offset wells were being produced at the normal rate. In U. P. No. 1-32 the bottom hole pressure actually increased during the shut-in period, and this increase was checked by two different crews using different types of equipment.

If open fractures extended from the shut-in wells to the producing wells used for the interference tests, it could be expected that the bottom-hole pressure in the shut-in wells would decline while the offset wells were flowing. However, just because interference cannot be demonstrated by these tests does not mean that open fractures do not exist. They could be present and still not have a length of from 1/5th to 1/4th of a mile, which would be necessary to provide easy communication from the shut-in well to the producing well.

There can be no doubt but that the production of oil in one part of the Rangely field will have an eventual effect on the pressure in other parts of the field. This is shown conclusively by the fact that wells recently completed at what has been fairly isolated locations do not encounter the original bottom-hole pressure but rather find that the pressure has declined to approximately the pressure which exists in the nearest wells. A case in point is Stanolind's A. C. McLaughlin No. 1, located in the NE 1/4 NE 1/4, Section 5, T1N R102W and approximately 1 mile from the nearest producing well, which was completed during the second quarter of 1946 and which showed a bottom-hole pressure decline of over 300 lbs./sq. in. from the original bottom-hole pressure of the field after producing only 3,897 barrels of oil. It appears evident that the first wells completed in the field will derive the greatest benefit from the maximum pressure which existed in the Weber reservoir.

<u>Mechanics of Reservoir Performance</u>

All information so far developed indicates that the greater part of the Weber reservoir at Rangely has been yielding oil by dissolved gas drive, which is the most ineffective recovery process known. Mention has already been made, on page 48, of lack of evidence to date of any appreciable expansion of the gas-cap, and previously, on page 31, evidence indicating lack of effective water encroachment in the northern part of the field has been presented. The second bottom-hole pressure survey of the Rangely field, Appendix II, Table No. 3, reveals that the bottom-hole pressure on the Algord lease, which was discussed on page 31, is already some 250 lbs./sq. in. below the original bottom hole pressure of the field. Such decline in bottom hole pressure is further confirmation of the lack of effective water-drive in the northern part of the field.

In contrast to the conditions which have been determined to exist on the Algord lease, Continental Oil Company's Rooth No. 1, located in the NW 1/4 SW 1/4, Section 15, T2N R103W, in the extreme northwestern end of the field, had produced 30,457 barrels of oil from the time of its completion up to June 1, 1946 with a decline in bottom hole pressure of only 6 lbs./sq. in. This recorded decline is within the range of error in reading the instruments, so, actually, no decline in pressure may have taken place. Simultaneously, Rooth No. 1 produced some 2,680 barrels of water and currently is producing around 312 barrels of oil and 22.3 barrels of water per day. There is no evidence, so far observed, of any water exhaustion, such as has taken place on the Algord lease, so it appears likely that water is encroaching in this part of the field at a rate sufficient to maintain the bottom-hole pressure with little or no decline.

Unfortunately, the general low permeability of the Weber reservoir at Rangely will preclude the encroachment of water at a rate sufficient to replace the oil that is being withdrawn under current production schedules. In consequence, as will be most apparent from Appendix II, a continued decline in bottom-hole pressure is accompanying the production of gas and oil.

The relations between pressure decline and oil and gas production will be considered in the following section of this Chapter, but it is appropriate to emphasize at this point that a continued increase in the pressure differential between water-saturated and oil-saturated parts of the Weber may cause water to move into the field at later time with beneficial effects on oil recovery. However, at the present time such possible future benefits from water encroachment must remain in the range of conjecture and can only be doubtfully relied upon. Likewise, unless vertical fracturing exists in the Weber reservoir on a much larger scale than now suspected, it is dubious whether much benefit can be expected from an expansion of the gas cap, for it is not believed that fluid can move with freedom across the bedding planes of the formation. In consequence, the inferior recovery from dissolved gas drive, unless assisted by some form of pressure maintenance, is all that can be anticipated.

The characteristic of greatly increased gas-oil ratios, which accompanies the production of oil by dissolved gas drive, is not yet manifest at Rangely because the crude is undersaturated with gas over a greater part of the field. The produced gas-oil ratios, as previously mentioned on page 48, have not increased generally, and conform rather closely to the solution gas content.

Pressure-Volume Relations in the Weber Reservoir

The original bottom-hole pressure in the Weber reservoir, at a depth of 900 feet below sea level was 2,750 lbs./sq. in. Some early determinations of bottom-hole pressure were made by the U. S. Bureau of Mines and are listed in Appendix VII, Table No. 7. The first general bottom-hole pressure survey was made by the Rangely Engineering Committee in February, 1946 and was followed by a second general survey in June, 1946. The results of these surveys are listed in Appendix II, Tables No. 2 and No. 3. Isobaric maps have been prepared to show variations in bottom-hole pressure throughout the field as determined by the two general surveys and are included herewith as Figures No. 11 and No. 12. In both maps the position of the maximum pressure at the water-oil contact, and of the gas-oil contact is constant.

Much more information, of course, has been available for the preparation of Figure No. 12 than for Figure No. 11. The minimum pressure measured in the survey of February, 1946 was 2,221 lbs./sq. in., and the weighted average field bottom-hole pressure, from the isobaric map, was 2,630 lbs./sq. in. In the survey of June, 1946, the minimum pressure measured was 2,050 lbs./sq. in. and the weighted average field bottom-hole pressure, from the isobaric map, was 2,575 lbs./sq. in. The weighted average field bottom-hole pressure, therefore, declined 55 lbs./sq. in. between the elapsed time of the two surveys. The two areas of low bottom-hole pressure, shown in Figure No. 11, which correspond to the regions where early field development was most active, are somewhat expanded in Figure No. 12. (Note: All pressures here referred to are for a depth of 900 feet below sea level which has been accepted as the datum elevation for bottom-hole pressure tests in the Rangely field.)

Some general relations between the production of oil and decline in bottom-hole pressure are listed as follows:

Initial Field Bottom-Hole Pressure at -900 ft.	2,750 lbs./sq.in.
Weighted Average Field Bottom-Hole Pressure at -900 ft. from First Pressure Survey	2,630 lbs./sq.in.
Decline in Average Field Bottom-Hole Pressure from Initial Pressure to First Survey	120 lbs./sq.in.
Total Production of Oil to February 1, 1946	1,889,852 bbls.
Oil Produced for each Pound Pressure Decline	15,749 bbls.
Weighted Average Field Bottom-Hole Pressure at -900 ft. from Second Pressure Survey	2,575 lbs./sq.in.
Decline in Average Field Bottom-Hole Pressure from Initial Pressure to Second Survey	175 lbs./sq.in.
Total Production of Oil to June 1, 1946	3,992,086 bbls.
Oil Produced for each Pound Pressure Decline	22,811 bbls.

Decline in Average Field Bottom-Hole Pressure from First Survey to Second Survey	55 lbs./sq.in.
Oil Produced from 2/1/46 to 6/1/46	2,102,234 bbls.
Oil Produced for Each Pound Pressure Decline	38,222 bbls.

The lack of consistency in recovery efficiency indicated by the preceding tabulation, which shows that considerable improvement has taken place in the period between the First and Second Pressure Surveys over that of the time preceding or for the total productive period, may be attributed to the fact that the more recent development and production of the field has been more removed from the area where reservoir energy has been dissipated by high gas production. Consequently, more oil is now being recovered for each pound decline in weighted average bottom-hole pressure than was the case formerly.

It will be obvious that recovery efficiency will not be constant throughout the large area of the Weber reservoir in the Rangely field on account of variable thickness of permeable pay section, due to variations in average permeability, and because of the variable effects of gas waste. In order to provide some clue as to possible recovery trends throughout various parts of the field, a study has been made of the performance of all wells, in which the bottom-hole pressure was determined in February, 1946, during the time interval from the First to the Second Pressure Surveys and during the entire productive period. The results are tabulated as follows:

Well	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Hagood No. 1	121,840	338	360.5	34,481	168	205.2	0.90
Hagood No. 2	70,547	240	293.9	35,673	110	324.3	0.86
Hagood No. 3	60,270	170	354.5	43,193	80	539.9	0.77
Hagood No. 4	51,409	214	240.2	45,128	99	455.8	0.55
Lacy No. 2	44,831	365	122.8	39,141	150	260.9	
McLaughlin "B" No. 2	101,947	170	599.6	45,311	83	545.9	2.61
McLaughlin "A" No. 3	101,933	220	463.3	44,864	106	423.4	1.24
McLaughlin "A" No. 4	75,101	240	312.9	50,586	79	643.7	2.20

Continued on Page 62

Well	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Gray "A" No. 5	98,514	270	264.9	38,955	110	[illegible]	0.41
Gray "A" No. 9	84,189	310	311.8	37,517	68	551.7	
Gray "A" No. 10	88,563	270	520.9	49,719	22	2,259.9	1.18
Emerald No. 2	89,133	204	436.9	42,348	52	814.4	
Rigby No. 1	54,689	374	146.2	47,992	86	558.0	0.62
Raven "A" No. 1	183,944	332	554.0	31,763	121	262.5	0.49
Gray "B" No. 2	113,953	260	438.3	43,225	18	2,401.4	1.45
Fee No. 2	94,592	670	141.2	40,416	141	286.6	
Fee No. 4	121,482	246	493.8	47,298	(8)		1.18
Fee No. 5	49,835	280	178.0	39,691	80	496.1	
Fee No. 3	101,971	360	283.2	44,759	100	447.6	0.26
U. P. No. 1-32	58,297	492	118.5	21,286	28	760.2	0.56
U. P. No. 4-29	62,135	456	136.2	40,070	173	231.6	0.81
U. P. No. 2-20	44,195	293	150.8	32,090	160	200.5	0.43
McLaughlin No. 1-28	51,590	360	143.3	49,904	180	277.2	0.90
McLaughlin No. 1-33	100,298	606	165.5	39,568	151	262.0	
McLaughlin No. 2-33	77,241	270	286.0	29,012	45	644.7	0.37
Unit No. 1-34	37,868	499	75.9	29,846	144	207.2	
Fee No. 9	49,225	520	94.7	30,723	90	341.3	
U. P. No. 5-28	41,899	488	85.8	30,625	198	154.6	
U. P. No. 3-34	72,402	559	129.5	36,446	130	280.3	0.145
Lacy No. 1	83,792	255	328.6	40,741	105	388.0	
McLaughlin No. 1	125,544	330	380.4	39,711	102	389.3	
Fee No. 1	110,867	341	325.1	38,344	112	342.3	0.46
Fee No. 7	87,828	290	302.8	37,906	61	621.4	0.45
Emerald No. 1	182,869	230	795.0	37,206	30	1,240.2	
Fee No. 8	34,000	331	102.7	29,376	109	269.4	
Fee No. 10	39,330	335	114.4	39,330	135	291.3	

(1) Total [illegible]
(2) Total Decline in Bottom-Hole Pressure - Lbs./sq. in.
(3) BBls./Lb.
(4) Total Oil Production from 2/1/46 to 6/1/46 - Barrels
(5) Total Decline in Bottom-Hole Pressure from First to Second Pressure Surveys - Lbs./sq. in.
(6) Bbls./Lb.
(7) Productivity Index
(8) Actual Build-Up in Bottom-Hole Pressure from time of First Survey to time of Second Survey

The total production of oil per pound drop in bottom-hole pressure from the original pressure to the pressure measured at the time of the second survey is shown on Figure No. 12. It is obvious, from examination of Figure No. 12, that the areas which have shown the most rapid pressure decline correspond to the areas where the efficiency of reservoir performance has been inferior. It is also evident, that the older wells and the wells less surrounded by offsets are giving, generally, the best performance. No correlation can be made between productivity indices and the recovery per pound pressure decline. However, it was not expected that such correlation could be made since the normal productivity indices have been affected by the shooting of some of the wells and by wasteage of gas from others. However, it may be assumed that better productivity indices and better reservoir performance may be expected from the thicker, more permeable sand sections.

The Maximum Efficient Production Rate

Almost a year ago, the writer proposed that no wells in the Rangely field be produced at a rate whereby the flowing bottom-hole pressure would decline appreciably below the saturation pressure. This suggestion was not accepted because there was not agreement at that time as to whether the crude in the reservoir was completely saturated under the conditions of temperature and pressure originally prevailing. Also, data at that time were not available to show how the saturation pressure varies with structural position. However, in view of the alarming decline in bottom hole pressure which is taking place in the Weber reservoir, as described in the preceding section of this Chapter, it would seem the part of wisdom to enforce such a restriction until a consideration of plans for some form of pressure maintenance can be made. If the bottom-hole pressure is permitted generally to drop below the saturation pressure, serious and possibly irreparable damage may be done to the future recovery possibilities of the field.

In Appendix VII, Tables No. 7 and No. 9, the results of productivity index tests at variable flowing rates and pressures are listed. Of 13 wells so tested, 8 showed more oil produced per pound drop in pressure when flowing was at a low rate; 5 showed more oil produced per pound drop in pressure when flowing was at a high rate; and in 1 well the rate of flow seemed to have little effect on the productivity index. It is believed in a great majority of the wells that a production rate considerably lower than permitted by the present allocation formula would result in much more efficient recovery of oil. However, individual conditions should govern in all cases, and for this reason productivity tests at variable flowing rates on all wells, to determine the most effective production rate, are most desirable.

The effect that the waste of gas will have on the recovery of oil from the Weber reservoir has been recognized by the Rangely Engineering Committee and a penalty for gas wasteage was included in the allocation formula. (See Appendix III and Appendix IV) Notwithstanding this fact, of the total average daily gas production during May, 1946 of 7,113 M cu. ft., it is estimated that 2,403 M cu. ft. were wasted. The Rangely Engineering Committee has attempted to hold the production of gas to approximately the solution gas content of the oil produced, but has not had authority to control the large removal of gas from the gas-cap. Out of the total gas production from the Weber reservoir, up to the first of June, 1946, of 2,222,257 M cu. ft., two wells, Emerald No. 1 of The California Company and McLaughlin No. 1-32 of Idaho-Sharples-Wasatch, have produced 1,149,233 M cu. ft. or approximately one-half of the total production. Most of this gas, unfortunately, is believed to have come from the gas-cap and, although much of it is reported to have been used for drilling fuel, its loss represents a volume equivalent to some 957,000 barrels of oil. There can be no question but that oil will tend to migrate up dip, from higher pressure areas, to occupy the part of the gas-cap from which gas has been lost, and in so doing it will wet dry sand and become unrecoverable by any known production process. That such movement of oil into the gas-cap is actually taking place is indicated by the fact that there is no indication of gas-cap expansion.

The loss of gas from the gas-cap may not effect oil recovery on the properties on which the two large gas producers are located as seriously as adjacent properties farther down dip, except for the general detrimental effect brought about by the rapid lowering of the bottom-hole pressure. This condition has been emphasized by the writer repeatedly, but until the results of the recent bottom-hole pressure survey were available it was not possible to evaluate properly the effects which the waste of gas from the gas-cap might have on oil recovery. Unless the waste of gas is arrested, the loss of millions of barrels of otherwise recoverable oil can be expected.

The plans now proposed by the Rangely Engineering Committee for the conservation of gas and for the possible utilization of gas from the Dakota and Morrison formations should receive all possible support. It is feared that the amount of gas now being produced which can be returned to the Weber reservoir per day may not be sufficient to arrest the continued decline in bottom-hole pressure, but if this procedure should serve only to preserve the gas-cap and prevent the loss of additional oil into it, it will have served a most useful purpose.

The Recovery of Oil from the Weber Reservoir

The relation between oil production and decline in bottom-hole pressure in the Weber reservoir of the Rangely field has been considered in a previous section of this chapter, and some of the general facts relating thereto, which were developed from the results of the two bottom-hole pressure surveys, are listed on pages 60 and 61. For reasons previously discussed, it is believed that the recovery performance of the Rangely field during the interval from the time of the first pressure survey to the time of the second pressure survey is more representative and, therefore, is more reliable as a guide to future recovery. During this period 38,222 barrels of oil were produced from the field for each average pound of pressure decline.

It may be assumed that 5 per cent of the original bottom-hole pressure of 2,750 lbs./sq. in. at a depth of -900 feet or 138 lbs./sq. in. will not be effective in the recovery of oil. Subtracting this figure from 2,575 lbs./sq. in., the weighted average bottom-hole pressure determined during the second pressure survey of the field, gives a pressure of 2,437 lbs./sq. in. which is believed should be effective in oil recovery. Multiplying 2,437 by 38,228 gives an indicated future production from the field of 93,147,024 barrels of oil. Adding the production up to the first of June, 1946 of 3,992,086 barrels of oil to this figure gives an indicated total recovery from the Rangely field of 97,139,110 barrels of oil. This indicated recovery is so inferior that it would hardly pay back the complete development of the field on a well spacing of 1 to 40 acres.

Actually, the facts at hand on production trends reveal that the general figures for the field can hardly be applied fairly to individual conditions, and that there will be wide variation in per well recovery. From the statistics presented on pages 61 and 62, it is evident that the better wells, which, have been producing in the range of around 500 barrels of oil for each pound decline in bottom-hole pressure, have recovery possibilities, if reservoir conditions are not altered materially, of around 1 million barrels. From the same statistics, the very poorest performing wells have recovery possibilities in the range of 1/2 million barrels of oil, which should be sufficient to insure development and operation without actual loss. However, in this connection it should be pointed out that the behavior of the wells studied might have been somewhat different had the well density been greater, and it remains to be determined how trends of production will react after several hundred more wells may be completed in the field. For the present it is evident that the oldest wells have the best past record, since they have been able to utilize more effectively the total reservoir energy. Also, the wells which are not closely offset are producing a great deal more oil for each pound decline in pressure, a result which certainly seems to favor a wide well spacing pattern. A careful study of the economics of the well spacing problem might reveal that a spacing of 1 well to 80 acres will prove to be much more profitable than 1 well to 40 acres.

Although estimations of future well production based upon recent individual pressure-volume relations are believed to be more reliable than any prediction that may be based upon general field figures, it should be emphasized that the well recoveries ranging from 1/2 to 1 million barrels of oil are probably somewhat optimistic. These estimations depend upon production conditions where there can have been little increase in the subsurface viscosity of the oil or little decrease in the effective permeability of the reservoir to oil. If the pressure in the reservoir can be maintained generally above the saturation pressure, it is believed that the well recovery indicated by recent pressure-volume relations will be obtained. If the pressure is not maintained above this point, it is reasonably certain that the recovery that has been indicated should be discounted from

25 to 80 per cent depending on the structural position of the well which, in turn, controls its saturation pressure.

Previous estimations of the recovery possibilities of the Rangely field made by the writer and by other engineers, using the volumetric equation, have been similar to the individual well recovery figures indicated by recent pressure-volume relations. Giving consideration to all available core information, and assuming no great increase in subsurface viscosity or decrease in effective permeability, the average recovery of oil per acre foot from the Weber reservoir by dissolved gas drive is estimated as follows:

$$\frac{\overset{(a)}{7,758} \times \overset{(b)}{.108} \times \overset{(c)}{.80} \times \overset{(d)}{.30}}{1.173(e)} = 171.4$$

(a) = barrels per acre foot
(b) = determined average porosity
(c) = determined connate water factor
(d) = estimated recovery factor
(e) = determined average shrinkage factor

It should be understood definitely that all estimations of oil recovery made in this report are subject to the elimination of the waste of gas from the Weber reservoir. Unless the conditions now existing are corrected in the near future, very damaging results, the extent of which cannot be predicted exactly at the present time, may be expected.

<u>Possibilities of Pressure Maintenance in the Rangely Field</u>

Plans are now being considered for the return to the Weber reservoir of all waste gas now being produced in the Rangely field. Although this is a most laudable objective, it should be recognized that such a program is inadequate to maintain pressure in the reservoir and can only serve to arrest partially the current rate of pressure decline. With an average daily production of 7,113 M cu. ft. of gas per day and 19,538 barrels of oil per day during May, 1946, the amount of gas necessary to maintain pressure alone under such production rate will amount to some 30,500 M cu. ft. per day. Since the gas produced from the Weber will be available for return to the reservoir at generally low separator pressures and since the average permeability of the sand is very low, a considerable installation of high pressure compressors will be required. It is also evident that the whole program of pressure maintenance by gas injection will be dependent upon the development of a supplemental source of gas supply, and for that reason the Rangely Engineering Committee has recommended that several cores be taken in the Dakota and Morrison formation to ascertain their volumetric capacity and contents. Should the supply of gas from these formations prove to be insufficient for the purpose desired, it is uncertain whether another nearby source of adequate gas supply might be developed.

In any consideration of pressure maintenance in the Weber reservoir at Rangely, the possibilities of water injection certainly should not be overlooked. Of course, there can be no question concerning the desirability of maintaining the gas-cap in such condition that the loss of oil into it will be prevented. To do this will require the injection of only about 1 3/4 million cu. ft. of gas per day, which should not prove to be such a formidable undertaking in conjunction with a main program of water injection.

It is a well known fact that sands having a low average permeability, such as the Weber reservoir, have responded much better to water injection than to gas injection in various Eastern and MidContinent oil fields. It is also probable that the injection of some 25,000 barrels of water per day into the Weber pay sections for pressure maintenance should be much less expensive and far more effective than the compression of 30 1/2 million cu. ft. of gas per day for the same purpose. Furthermore, it is known that an abundant subsurface water supply, which might require some treatment to make it suitable for injection purposes, is available, whereas it is not yet demonstrated that an adequate gas supply can be developed. However, the most important consideration is that past experience would suggest that oil recovery should be doubled by the injection of water over the recovery which could be expected from dissolved gas drive supplemented by gas injection. The possibilities for recovering an enormous additional production are so promising that all necessary engineering and scientific research essential for a study of the feasibility and cost of pressure maintenance by water injection is clearly justified.

Whether the lithology of the Weber sandstone will reduce the effectiveness of pressure maintenance either by gas or water injection remains to be determined. Laboratory studies of capillary and surface tension phenomena, undoubtedly, would be most helpful in predicting the success of such a program and in the selection of the best method. However, the evidence which has been developed recently indicating a more or less general communication throughout the reservoir serves to encourage the hope that pressure maintenance can be applied with measurable success and with appreciable benefit to the recovery of oil.

Chapter VII
Conclusions

The abstract preceding the text of this report will serve to review its contents in summary form and need not be repeated.

It is acknowledged freely that much remains to be learned about Rangely. However, there can be no question that the Weber reservoir contains one of the very large oil accumulations of the United States, which, very possibly, may amount to around 1 1/2 billion barrels of oil. The writer is convinced that unless some form of pressure maintenance is employed, only a small part of this tremendous reserve will be recovered. The problem of oil recovery is so important that no measures should be neglected which might jeopardize the maximum efficient and at the same time profitable recovery of oil.

Chapter VIII
Acknowledgements

In the preparation of this report the writer has depended greatly on information developed by the U. S. Bureau of Mines, Laramie, Wyoming. Had it not been for the pioneering work of the Bureau at Rangely, information on the conditions prevailing originally in the Weber reservoir would be virtually unknown. The work of the Bureau of Mines is commended, and it is unfortunate that facilities and resources have not been available to permit its investigations to be carried on in a more extensive manner.

Information developed by the Bureau of Mines has been supplemented by the reports of the Rangely Engineering Committee, and by data generously supplied by its Chairmen. The work of the Committee has been of a high order of technical excellency, and it is deplored that its functioning had to be delayed for such a protracted period.

Appreciative recognition is due to engineers and officials of various companies operating in the Rangely field who made available heretofore confidential information. An effort has been made to use this information properly and in a manner conforming to its owners' directions.

The writer has studied all available publications relating to the Rangely field. Both ancient and recent publications of the U. S. Geological Survey have proved to be a valuable source of information and have been utilized extensively.

Most of the articles on Rangely that have appeared in trade publications have tended to exaggerate production possibilities and reserves and are considered to possess questionable reliability. One exception is the contribution by Bernard N.

Bench on "The Rangely Oil and Gas Field and Uinta Basin" which appeared first in the 10th Annual Petroleum Number of "The Mines Magazine", published by the Colorado School of Mines, and subsequently was reproduced in other periodicals. Mr. Bench gives a very complete review of the information contained in various government publications in addition to his own observations on conditions in the field. His statements are considered and reflect a proper scientific approach to the problems involved.

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State of Texas Serial No. 6236,
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Addenda

During the time this report was in progress of preparation, a new producing horizon was discovered in the Rangely field. While Continental Oil Company was drilling its Rooth No. 2, located in the SW 1/4 SW 1/4, Section 15, T2N R102W, it blew out unexpectedly during the early part of June, 1946 at a depth of 6,110 feet. This depth was about 600 feet above the expected top of the Weber sandstone. The well sprayed some oil in addition to making considerable gas.

Rooth No. 2 was brought under control, and it was decided to run a protection string of casing before resuming drilling to carry the well on down to the Weber. However, after reaming of the hole was commenced preparatory to running 9 5/8 inch pipe, the well continued to try to blow out, so, after making an electrical survey, pipe was set at a depth of 5,966 feet, 114 feet above the bottom of the hole. When the plug was drilled, Rooth No. 2 immediately kicked-off and flowed 133 barrels in the first hour. It began to sand up and averaged 73 barrels of oil per hour for the next 6 hours. The well was then killed in order to make preparation for the running of a liner so that a more effective production test can be made.

The electric log indicates that the entire section from 6,060 to 6,110 is saturated with oil, with the best pay section occurring in the upper and lower 10 feet respectively. The producing horizon has been identified as the Shinarump conglomerate of Triassic age. How extensive the productive area in this new horizon will be cannot be predicted at present. As far as is known, no other well has encountered the spectacular showing which was found in Rooth No. 2.

The oil from the Shinarump is reported to have a gravity of 38° A. P. I., somewhat higher than the Weber crude.

Further testing of this horizon will be followed with great interest. Idaho-Sharples-Wasatch's Larson No. 1-16, located in the NE 1/4 SE1/4, Section 16, T2N R103W, a direct offset to Rooth No. 1 and a diagonal offset to Rooth No. 2, which was spudded on June 19th, 1946, should be the first close-in well to reach the Shinarump. Every effort should be made to secure complete information on the reservoir characteristics of the Shinarump should it be found to be oil- or gas-bearing in Larson No. 1-16.

Continental's discovery of production in the Shinarump has very intriguing possibilities when consideration is given to the size of the Rangely structure and the large areas on it which have not been tested. It is entirely possible that the reserve position of Idaho and Wasatch might be improved substantially if a second producing horizon, in addition to the Weber, should be found on their holdings in Sections 16, 22, 26, 35, and 36, T2N R103W.