W Y O M I N G   O I L   S H A L E   R E S O U R C E S

BY

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(Note to editor: Headings marked with an asterisk not included herein. Headings are of five ranks, arranged as follows:

PRIMARY HEADS

SECONDARY HEADS

Tertiary heads

Quaternary heads

Quinary heads

Numbers preceding the headings indicate ranks according to this classification. In the text, the rank of the headings is indicated in red pencil.)

PART II GENERAL

A. DEFINITION OF TERMS (D & M)

B. SOURCES OF INFORMATION

Many sources of information were utilized in conducting the survey. Geologists of the subcontractor have personal knowledge of the geology of the area studied. Much dependence was placed on the extensive geological literature pertaining to the general geology and to the occurrence of oil shales in Wyoming and adjacent states. Most of this information has been published by the U. S. Geological Survey but pertinent papers also have appeared in technical geological periodicals. Recent assay data were supplied by the Bureau of Mines Oil Shale Experiment Station at Laramie.

Companies and individuals who contributed information or authorized release of information for use in this survey are listed under "Acknowledgements", Exhibit No. ___. The publications containing specific data presented in this report are listed in the bibliography forming Exhibit No. ___, and the reference numbers indicated on this exhibit are referred to in the text of the report by number as (Ref. 1), (Ref. 2) etc.

C. SURVEY AREA

The area investigated and reported herein comprises the State of Wyoming and a small area in Colorado. [~~A portion of~~] The outcrop area of the Green River formation in the Washakie Basin straddles the Wyoming-Colorado border and its southern part, in the Sand Wash Basin, lies in Colorado. This area is also considered in this report since the Green River formation there [~~it~~] is more closely related genetically and stratigraphically to the Green River [~~formation~~] of Wyoming than it is to the Green River as developed farther south in Colorado.

PART III INVESTIGATION OF SURVEY AREA

A. INTRODUCTION

1. General Statement

The Green River formation, of Eocene age, is the only oil shale-bearing formation of possible economic importance in the State of Wyoming.

Minor occurrences of oil shale occur in other formations but these oil shales are too insignificant in areal distribution, richness and thickness to meet the minimum requirements of this survey. All pertinent data on the occurrence of oil shale in these other formations are summarized under the heading "Other Formations" in Exhibit No. ___ of this report.

The text of this report, therefore, is confined to the occurrence of oil shale in the Green River formation in the Green River Basin, the Great Divide Basin and the Washakie Basin, a portion of which extends into Colorado and is considered herein.

2. Survey Methods and Procedures

Prior to this investigation, geologists of the subcontractor had made detailed and reconnaissance examinations of most of the Green River, Great Divide and Washakie Basins. During the course of the investigation several days were spent in examining various oil shale localities which had been sampled by earlier workers. Samples were taken at one locality near the town of Green River.

All the geological publications bearing on oil shale occurrences in Wyoming were used in obtaining data on early assay results, in compiling stratigraphic sections and in developing an understanding of the general regional geology of the Green River and related formations. A geological map showing the areal distribution of the Green River formation was compiled from a map covering the Green River Basin issued by the Wyoming Geological Association in 1950, and from a map of the Washakie Basin issued by the U. S. Geological Survey in 1949 (Ref. 11). Older published maps ~~(Refs. ______.)~~ covering marginal areas were used to complete the final map. Geological structure sections across the basins were then prepared. Stratigraphic diagrams were made to show regional correlations and changes within the Green River formation, and various charts and index maps were constructed.

All available stratigraphic sections and assay logs were plotted to standard scale and correlations of the stratigraphic units from place to place were made. The assay data were reviewed and averaged in order to determine the thickness of those oil shale zones yielding more than 15 gallons per ton or more than 25 gallons per ton, as a basis for determining areas of primary reserves containing 100 million tons of oil shale within a 5 mile area representing beds aggregating 25 feet of thickness capable of yielding more than 25 gallons per ton, or areas of secondary reserves comprising a similar amount of shale capable of yielding between 15 and 25 gallons per ton. In the determination of reserve areas, oil shale was classed as measured, indicated, or inferred, depending on the availability of assay data.

Those areas on which no reliable assay data were available, or those regions where sampling and assays indicated that the reserves did not meet the minimum requirements of the survey, were then eliminated. Further attention was restricted to the areas on which adequate data were available to enable the estimation of reserves meeting the minimum requirements.

Tabulations were prepared to show the surface and subsurface data used in the elimination or establishment of reserves.

3. Previous investigations and developments

The Green River formation was named by F. V. Hayden in 1869 from its exposures near the present town of Green River, at which time he pointed out that one of the conspicuous features was "the great amount of combustible or petroleum slates" contained in the unit. Lesquereaux, in 1872, remarked that "the shales . . . may yield by distillation an amount of bitumen large enough to be remunerative" (Ref. 16, pp. 50-51).

The first real study of the Green River oil shales in Wyoming was conducted by Dean E. Winchester, of the U. S. Geological Survey, and his assistants, in 1915 in ~~the~~ Green River Valley and around the station of Fossil in westernmost Wyoming. The results were published in 1917 (Ref. 22).

Schultz carried on field work on the Green River formation in 1907, 1908 and 1915 and in his 1920 publication (Ref. 16) implied that he observed the oil shales and measured sections prior to the work of Winchester. Much of the information in Schultz's 1923 bulletin was given earlier in Winchester's publications, however.

During the period from 1918 to 1925, in the vicinity of the town of Green River, interest was shown in the development of oil shale properties. Claims were filed, or patented lands secured, and development work was undertaken by individuals and by corporations organized for that purpose, but activity was generally restricted to prospecting. There is no record of the production of any shale oil.

Schramm, prior to 1920, undertook a study of the Green River oil shales for the Union Pacific Railroad. In a paper published in 1920 (Ref. 13), he reported assay data on 117 shale samples from some 17 general localities in the Green River Basin, of which 66 samples were from the region about the town of Green River. Also, 12 generalized columnar sections were given which indicate the thickness of those oil shales yielding more than 15 gallons per ton. Some thicknesses were shown to be as great as 140 feet. Thin but rich units were listed which were reported to yield as high as 88 gallons per ton.

Duplicate cuts of 18 of the samples were later assayed in the laboratory of the Union Pacific Railroad. Schramm's assays of the 18 samples indicated yields ranging from 2 to 53 gallons per ton or an average yield of 14.3 gallons per ton, whereas the yield of the check samples ranged from 0.4 to 29.5 gallons per ton and averaged 7 gallons per ton, or about 50 percent of the yields reported by Schramm.

During the course of the present investigations, because of the indicated discrepancy in data, engineers and geologists of the subcontractors visited various localities around the town of Green River and south along ~~the~~ Green River Valley to the Utah line. This reconnaissance examination was made to observe the general distribution and thickness of the oil shales in that area and to obtain samples of the richest appearing shales in the vicinity of one of Schramm's sample localities. Samples were taken at Locality 6 from two shale zones in the upper part of the Laney, just below the Tower sandstone, which are relatively persistent throughout the Green River area, and were assayed by the Bureau of Mines Oil Shale Experiment Station at Laramie. The two oil shale sections are separated by a 9-foot sandstone bed. The upper shale bed, immediately below the Tower sandstone consists of about 15 feet of lean papery shale and a sample of the basal 4 feet of the 15-foot interval assayed 6.6 gallons per ton. This unit is underlain by 13 feet of richer massive shale, which yielded 17 gallons per ton. The lower shale bed, below the 9-foot sandstone, is 21 feet thick. The upper 9 feet yielded 12.5 gallons per ton and the lower 12 feet yielded 8.8 gallons per ton. The overall yield of the 21-foot section was 10.9 gallons per ton.

In view of the results of the assays made by the Union Pacific Railroad and those made on samples collected recently, the actual yields appear to be about 50 percent of those reported by Schramm. In addition, the assay results of samples collected by Winchester from the upper Laney oil shale zone in the area around the town of Green River do not indicate a richness as great as that presented by Schramm. The results of sampling this zone by Winchester at three localities around the town of Green River indicate average yields of 13.3 gallons per ton, 14.0 gallons per ton and 16.4 gallons per ton. Schramm's data, therefore, can not be considered as a reliable basis for evaluating the richness of shales in the Green River area and have not been used. The columnar sections and stratigraphic data given by Schramm, however, provide valuable information on the position of the oil shale zones within the stratigraphic succession and on their thickness.

Since this early work, there have been no detailed investigations of the oil shale resources of Wyoming. Later workers, such as Bradley, Sears, and Nace, were concerned mainly with the regional stratigraphic relations of the Green River, with its depositional environment and with the relations between contemporaneous stream deposits (fluviatile deposits) and the lake deposits (lacustrine deposits) which carry the oil shales. These studies, however, are of great value in any consideration of oil shale resources.

Since 1937 a number of wells, drilled for oil or gas, have penetrated the Green River formation. Other wells have been drilled for water or for mineral exploration. The Bureau of Mines has obtained samples of the cuttings and assayed them for oil yield.

The early workers failed to take samples through continuous sequences of beds and although the assay data on their selected samples may be reliable, it is difficult to evaluate the total thickness of rich shale in sections which may be hundreds of feet thick, and from which only a few intermittent samples were taken.

4. Amount and classification of data

Data are available on the oil yield of oil shales in the Green River formation from (23) localities in the Green River Basin and adjacent areas in southwestern Wyoming and from the Washakie Basin, which straddles the Wyoming-Colorado border. Pertinent data pertaining to these localities are contained in the attached tabulations. Early investigations, between 1910 and 1930, consisted of the measurement of stratigraphic sections and the sampling of selected beds, and was restricted to the region along the Green River, to the area north of the Rock Springs uplift, to the Fossil area, and to the Washakie and Sand Wash Basins. There are, therefore, large outcrop areas on which no data are available. During recent years, information on the oil yield of shales in the central part of the Green River Basin has been derived from assays of samples from deep wells or coreholes.

For the purpose of indicating the quantity and quality of data available for the determination of reserve areas and for the classification of reserves within these areas, the available data may be classified into five categories, according to useability; coreholes, the Westvaco shaft, well cuttings, stratigraphic sections accompanied by incomplete sample assay data on selected portions of the richer shales, and stratigraphic sections accompanied by visually estimated oil yields or sections which simply describe the rock succession without indication of oil shales.

(a) Coreholes.-

Although no coreholes have ever been drilled in Wyoming to specifically determine thickness and yield of oil shales, a number of coreholes have been drilled in the central part of the Green River Basin in exploration for trona (sesquicarbonate of soda) within the Green River formation. Assay data are avail ble on one corehole and lithologic data, without assays, are available on 6 coreholes which penetrated into, but not always through, the Green River formation. The data afforded by the samples taken from the cores constitute a reliable basis for evaluating the oil shale sections penetrated.

(b) Westvaco shaft.-

Samples were taken during the sinking of the 1,555-foot shaft of the trona mine of the Westvaco Chlorine Products Company, east of Granger. Although there are numerous overlaps of sample intervals which bring about difficulty in interpretation, the assays furnish reasonably reliable data on shale thickness and yield.

(c) Well cuttings.-

Assay data are available on well cuttings from (20) wells drilled in various placed in the Green River Basin. Most of these wells started above and passed completely through the Green River formation. The samples of well cuttings mainly represent 10-foot intervals. Well cuttings are somewhat less reliable than core samples for determining oil yield since cuttings from both richer and leaner beds are mixed together in the sample. Furthermore, some contamination occurs from caving of overlying shale zones. In addition, and perhaps of more importance, is the fact that in the areas where the wells were drilled, large amounts of trona are found associated with the oil shales as beds, as thin layers, or as disseminated crystals. Cores from some of the Union Pacific coreholes are estimated to contain as much as 50 per cent trona crystals intermixed in the shale and it is likely that similar large amounts occur in some of the shales in the areas in which wells were drilled, since all the wells encountered beds of trona. Because of the high solubility of trona it seems likely that the rock sample derived from such an interval would comprise an insoluble residue representing only a part of the total rock volume drilled up into cuttings. Assays of well cutting from shales containing an appreciable amount of trona would, therefore, indicate too great a richness for the rock interval drilled. Although the results derived from assays of cuttings do not show the details of individual oil shale beds, zones of richness and leanness are well differentiated and such zones may be correlated in wells as much as 8 to 10 miles apart. In general, the results obtained from assay of well cuttings may be used with a fair degree of confidence in determining reserves, and surely have much greater value than inadequate surface sampling.

(d) Stratigraphic sections with incomplete assay data.

Complete and partial stratigraphic sections of the Green River formation, accompanied by assay data on selected beds representing only a part of the oil shales, are available from 23 localities. The measured sections cover intervals ranging from less than a foot up to more than 1,000 feet and provide data on thickness, lithology and regional changes. Assay data are available only on selected parts of the sections and sampling was generally restricted to the richer-appearing beds. Rarely were samples taken from contiguous beds, and since sampling was not continuous the assay data are inadequate in providing a sound basis for the determination of the thickness and the yield of the various oil shale zones measured. Visual estimates are reported for some of the beds in a number of these sections.

(e) Stratigraphic sections without assay data

Data are available on 7 localities where stratigraphic sections have been measured and visual estimates only have been made of the expectable yield of different oil shales. Visual estimates of oil yields based on physical appearance and specific gravity afford only a general indication of the richness of oil shales, and it is known that estimated yields are at variance with actual assays. In other areas, stratigraphic sections were measured without taking samples for assay or without visually estimating the oil yield of shales. These sections, however, are valuable in that they provide important information on the regional changes within the Green River formation and enable the determination of trends of near-shore deposits in which oil shales are lean or absent, and thus serve to delineate the areas in which the richer shales may be expected.

5. Previous reserve estimates

No recent or reliable estimates have been made of the oil shale reserves of Wyoming. Winchester, in 1923 (Ref. 23, p. 122), pointed out that "the oil shale in southwestern Wyoming is in thin beds and that rich shale underlies a comparatively small area" and that because of insufficient knowledge of large parts of the area it seemed unwise to make estimates. He stated, however, that it was thought that the total quantity was not less than 7,176,000,000 short tons of shale that would yield at least 15 gallons per ton. He estimated that no more than 60 per cent of this tonnage would be recoverable. The estimated recovery, therefore, was placed at a minimum of about 1,567,000,000 barrels.

Later, in 1928, Winchester (Ref. 24) set up certain specifications for the estimation of reserves in which he considered that shales which would yield more than 3,000 barrels of oil per acre would constitute commercial oil shale, provided that any beds less than 1 foot thick or having a yield of less than 15 gallons per ton be excluded. He assumed also that no more than 60 percent of the shale would be mined. On these bases, his estimate for Wyoming was a total of 3,044,000,000 barrels of oil, of which 1,826,400,000 would be recoverable.

In the light of present knowledge, these estimates must be considered as no more than generalizations, especially when regarded in terms of the present survey requirements concerning classification of reserves.

6. Geography

(a) General statement

In Wyoming the Green River and related formations were deposited in a large Tertiary sedimentary province in the southwestern part of the State, bounded on the west by the Salt River Range and the Wyoming Range, on the north by the Wind River Range and the Sweetwater uplift, on the east by the Sierra Madre Range and the Park Range, and on the south by the Uinta Mountains.

Subsequently the Tertiary rocks were moderately deformed and the Green River formation has been eroded from the uplifted areas. Thus, the Green River formation, as it exists today represents only remnant of a once much more extensive rock unit now preserved in several downwarped basins which comprise the province.

The north-south trending Rock Springs uplift, extending nearly from the Wind River Range to the Uinta Mountains, divides the province into two parts. The western one is the Green River Basin; the eastern part comprises the Great Divide Basin on the north and the Washakie Basin on the south.

(b) Topography and drainage

Green River Basin.- The Green River Basin, sometimes called the Bridger Basin, is a topographic, structural, and drainage basin bounded on the south by the Uinta Mountains, on the west by the Wyoming Range and the Salt River Range, on the north and northeast by the Gros Ventre Mountains and the Wind River Range, and on the east by the Rock Springs uplift. It has a maximum east-west width of 140 miles, a length of 170 miles, and an area of about 12,500 square miles. Essentially it has the same area as that drained by the Green River, which heads in the mountains on the north, but one tributary, Bitter Creek, heads in the Washakie Basin and flows across the Rock Springs uplift to enter the Green River. Blacks Fork and Henrys Fork are the main tributaries which drain the north flank of the Uinta Mountains. Numerous short streams enter from the west, but no large tributaries enter from the east. Peripheral elevations range from 6,000 to 7,000 feet while elevations in the central part range from 5,000 to 6,000 feet.

Great Divide Basin.- The Great Divide Basin, sometimes called the Red Desert Basin, has an east-west length of about 100 miles, and a width of about 40 miles. It is bounded on the west by the Rock Springs uplift, on the north by the Wind River Range and the Sweetwater arch, and on the east by the Rawlins uplift. On the south it is vaguely bounded by an inconspicuous geological feature, the Wamsutter arch, but the Union Pacific Railroad serves to form a more definite southern limit. Its area of about 4,200 square miles, of which only some 1,400 square miles is underlain by Green River formation, is a region of low relief and internal drainage despite the fact that it is transected by the Continental Divide. Elevations in the northern part of the basin are between 7,000-8,000 feet; in the southern part they are between 6,000-7,000 feet.

Washakie Basin.- The Washakie Basin is a nearly circular structural depression but not a topographic one. Some 3,500 square miles in area, it is located principally in Wyoming but extends southward into Colorado and the southern part is called the Sand Wash Basin. It is bounded on three sides by relatively high outward-facing escarpments; on the north by the Laney Rim, on the west by the Kinney Rim, and on the southeast by the Vermilion Bluffs. The basin is bounded on the southwest by the eastern part of the Uinta Mountains and on the south by the ~~Axial Basin~~ Cross Mountain uplift. Drainage from the topographically high interior parts of the Washakie Basin flows southwest to enter the Little Snake River, a tributary of the Yampa River. Most of the Washakie Basin lies at elevations above 7,000 feet.

(c) Climate

The region is semi-arid with larger amounts of precipitation in the bounding mountains and smaller amounts, probably nowhere more than 10 inches per year, in the central parts of the basins. The Great Divide Basin approaches the character of a true desert.

(d) Culture

The region is traversed by the main line of the Union Pacific Railroad and the only towns of any size are located along it. The Great Divide and Washakie basins are virtually uninhabited, but where the railroad crosses there are a few small settlements. The coal mining town of Rock Springs is the largest in the area and the town of Green River, a division point on the railroad, lies about 15 miles to the west. Only small settlements are found in the central part of the Green River Basin, along the railroad and in regions where farming or ranching is carried on along the water courses.

U. S. Highway 30 crosses the region in an east-west direction. Although there are no main highways, most of the Great Divide and Washakie basins may be traversed by automobile on numerous trails used by sheep outfits. A surfaced highway extends from Rock Springs into the northern part of the Green River basin, and a north-south one traverses the west side of the basin. A number of dirt roads cross the basin and connect the two highways. Other graded roads extend south from U. S. 30 to the southern part of the basin and to the Uinta Mountains. An all-weather highway extends south from Rock Springs to the Hiawatha oil field, giving access to the Sand Wash Basin.

B. GEOLOGY OF THE GREEN RIVER FORMATION

1. Introduction

The Green River formation, named by Hayden in 1869 from outcrops in the town of Green River, Wyoming, is a complex assemblage of lake beds of Eocene age deposited in two great Eocene lakes, which now occupy the separate structural, depositional and topographic depressions known as the Green River, Great Divide and Washakie basins of Wyoming, and the Piceance Creek and Uinta Basin of Colorado and Utah. The index map, Exhibit No. ___, shows the distribution of the Green River formation in Wyoming, Colorado and Utah.

The Green River formation in Wyoming was once a continuous deposit in ancient Lake Gosiute but now occupies separate structural and topographic basins; the Green River Basin on the west and the Great Divide and Washakie basins on the east.

The Green River formation underlies both the Green River and Washakie Basins, but outcrops occur only along the flanks. In the central portions of these basins, the formation is overlain conformably by the Bridger formation. In the Great Divide Basin, the Green River has been eroded from all but the northwestern part.

The Green River formation is underlain by beds of sandstone, vari-colored clays and mudstone of fluviatile origin known as the Wasatch formation. The contact of the Green River with the underlying Wasatch is generally conformable and gradational and is ordinarily marked by the prominent color contrast of the red Wasatch beds below and the grey-colored Green River beds above. This contact is one of general intertonguing around the margins of the old lake basin, and the Cathedral Bluffs tongue of the Wasatch forms a wedge between Green River sediments throughout the Washakie Basin and most of the northern and western outcrop areas in the Green River Basin.

The Green River formation has been the subject of extensive regional and detailed study. In its type area it is divisible into an upper member, the Morrow Creek, the well known Tower sandstone next below, a middle Laney shale member and a basal Tipton shale member. Oil shales are restricted to the Tipton and the Laney. In the northern parts of the Green River and Great Divide basins, and in the Washakie Basin, the Tipton and the Laney are separated by the wedge of fluviatile sediments known as the Cathedral Bluffs tongue of the Wasatch. Because the Tipton in these areas lies between Wasatch-type sediments, it is known as the Tipton tongue of the Green River formation.

Structure

A series of three cross-sections which illustrate the structural and stratigraphic relationships of the Green River and related formations in the Green River, Wasakie and Sand Wash basins forms Exhibit ___ of this report. The attached map, Exhibit No. ___ also shows the location of the principal structural features of the region, and all dip information that is available.

The geologic structures of southwestern Wyoming are a series of anticlines and synclines of large magnitude and lateral extent, but are formed by strata of low dip, with the exception of the area west of the Green River Basin. The structural features ~~will be~~ are discussed in geographic order from west to east.

The rocks in Lincoln and Uinta Counties, Wyoming, are broken into a series of slices by low angle thrust faults that dip to the west. The faulting is extremely complex and is the eastern extension of a zone of similar structure in eastern Idaho and northern Utah. The easternmost thrust fault of this belt is the LaBarge thrust fault which forms the structural boundary between the overthrust belt and the adjacent Green River Basin.

The Green River formation in this area overlies the faulted rocks, and was not ~~affected by~~ deposited until the earlier period of movement had terminated.

The Green River Basin is a large, shallow syncline bounded on the west by the overthrust belt, and on the north and northeast by the Gros Ventre Mountains and the Wind River Range. The eastern margin is the Rock Springs uplift and the southern boundary is the Uinta Mountains of Utah and Colorado. The axis of the basin trends slightly east of north and passes near Granger Station on the Union Pacific Railroad. The dip of the strata into the basin is very low and ranges generally between 1° and 2° but flattens to even lower dip near the axis of the basin. Dips are somewhat steeper, ranging up to 5°, along the east flank of the basin and to even higher values in the faulted area along the northern flank of the Uinta Mountains. The Green River formation is affected by the Continental fault zone which parallels the Wind River Range along the northeast flank of the Green River Basin. The fault zone trends N 75° W and extends from near Big Sandy P.O., in T. 30 N., R. 105 W., to Lost Creek in T. 26 N., R. 95 W.

The Rock Springs uplift lies at the east margin of the Green River Basin and separates that basin from the Great Divide and Washakie basins to the east. The center of the uplift is located about ten miles east of Rock Springs, from which point the strata dip away in all directions. The uplift is about 60 miles long and 35 miles wide, and has raised the formations exposed at the crest to an elevation of over 10,000 feet above comparable units on either side. The dips along the flanks of the uplift average 10°-20° W on the west side and about 5°-10° E on the east side. The uplift is separated from the Uinta Mountains to the south by a low structural saddle that is occupied by the Green River formation. The strata exposed on the crest of the uplift are older than the Green River and contain commercial deposits of coal.

A compound ~~of~~ syncline lying east of the Rock Springs uplift is divided into three parts; the Great Divide Basin; the Washakie Basin and the Sand Wash Basin. This major syncline is bounded on the west by the Rock Springs uplift, on the north by the Wind River Range, on the east by the Rawlins arch and the Sierra Madre Range, and on the south by the eastward extension of the Uinta Mountains. The Great Divide Basin lies north of the Union Pacific Railroad, and structurally is due to downfolding to the east so that most of the strata dip eastward. The axis of the basin lies well to the east near the Rawlins arch, and apparently the basin is not as deep structurally as the Washakie Basin.

The Washakie basin lies south of the Great Divide Basin and is separated from it by the Wamsutter arch which trends east-west approximately along the line of the Union Pacific Railroad. The Washakie Basin is a roughly circular structural depression in which the strata dip toward the center from all sides at dips not exceeding 5° ~~five degrees~~, and for the most part ranging from 2° to 4°. The deeper portion of the basin is located near T. 13 N., R. 97 W., which is near the southern end and adjacent to the Cherokee Ridge fault zone paralleling the Wyoming-Colorado boundary. This fault zone separates the Washakie Basin from the Sand Wash Basin in a structural sense.

The Sand Wash Basin is the southward portion of the major compound syncline mentioned above. The axis of the basin trends almost north and south and extends to the Little Snake River in Colorado. The strata in the basin locally dip as much as 10° toward the basin center but the average dips range from

2^{o} to 4^{o}. Local folds and structural variations are more prevalent in this area than in the rest of the basins of southwestern Wyoming. The Sand Wash Basin is terminated at the south by a zone of faulting trending N 70^{o} W and extending from Sunbeam P.O., Colorado to the northwest corner of Colorado and thence westward along the northern front of the Uinta Mountains. The fault elevates older rocks on the south to form the Cross Mountain line of folding.

3. <u>Distribution and outcrop of the Green River formation</u>

The attached map, Exhibit No. ___, entitled

has been compiled from published maps of the Federal and State Geological Surveys and from unpublished maps obtained from private sources. The areal extent of the surface exposures of the Green River formation and associated rocks ~~appears~~ is shown on this map by means of symbols and patterns. The reader is referred to Exhibit No. ___ in order to follow the ensuing discussion.

The principal outcrop areas of the Green River formation in southwestern Wyoming are in the Green River and Washakie Basins, with less extensive exposures in the Great Divide Basin, and in the overthrust belt west of Kemmerer, Wyoming. In both the Green River Basin and the Washakie Basin the outcrop areas of the Green River formation completely circle the basins as a series of concentric bands. The outcrop width of any member of the Green River formation varies with the thickness of the unit and the amount of dip. In the central portion of the basins the Green River formation is overlain by the Bridger formation which has large areas of surface exposure, and which buries the Green River to depths of over 2,000 feet.

The outcrop of the Green River formation averages ten miles in width on the east flank of the Green River Basin from the Utah boundary northward to the Union Pacific Railway and then narrows to about five miles along the northwestern flank of the Rock Springs uplift. The outcrop band swings westward around the end of the basin and because of decreasing dips the outcrop band widens to as much as 25 miles for a distance of 50 miles. Along the western margin of the basin from the vicinity of Big Piney southward the width of the outcrop band is about six miles, ~~and~~ but thins to a very narrow ~~band~~ belt near Evanston.

The Green River formation along the western boundary of the Green River Basin is separated into two units by the intervening Cathedral Bluffs tongue of the Wasatch formation. The outcrop of this tongue extends southward from near Big Piney to near Evanston and parallels the bands of the Green River members. In this same locality the Tipton (lower) member of the Green River formation thins ~~to nothing~~ out, both at the north end and the south end of the area and the outcrop pattern forms a narrow individual band separated from the upper members of the formation.

Insert ¶ from following page

~~West of Kemmerer, Wyoming, near Fossil Station, the Green River formation outcrops in an elongate area 45 miles long and ten miles wide.~~ Isolated outcrops occur in northern Sublette County in the extreme northern end of the Green River basin.

The outcrop pattern of the Green River formation in the Washakie Basin is roughly circular with a much wider area of outcrop on the eastern flank than on the western flank. The outcrop width varies from five miles on the southwestern flank of the basin to a maximum in the southeastern portion where it covers a strip over fifteen miles wide. The Bridger formation forms the surface outcrop in the center of the basin and buries the Green River to depths approaching 1,500 feet. The Green River formation can be divided into two ~~members~~ units separated by the Cathedral Bluffs tongue of the Wasatch.

The outcrop band of the intervening Cathedral Bluffs tongue encircles the basin as a band parallel to the Tipton member (lower unit) and the Laney-Morrow Creek members (upper unit) above. The Tipton member which lies below the Cathedral Bluffs has a horseshoe pattern open to the south, since along both the southwest and southeast edges of the basin the Tipton tongue thins out and becomes unrecognizable.

The Green River formation outcrops in the northern portion of the Great Divide Basin and the ~~outcrops~~ exposures are continuous through a structural saddle between the Rock Springs uplift and the Wind River Range so that they join the main body of the Green River outcrops present in the Green River Basin. The true extent of the Green River formation has not been accurately mapped in the Great Divide Basin and may have a wider extent than indicated upon the geologic map, Exhibit ___.

Insert on preceeding page

A large area of Green River formation is present in the Fossil area centering around Fossil Station, west of Kemmerer, Wyoming. The outcrops occur as cappings on a series of flat, mesa-like topographic em~~m~~inences, extending for about 15 miles north and approximately 30 miles south of Fossil. The average width of the outcrop area is ten miles. The Green River in this area unconformably overlies the folded and faulted older rocks of the overthrust belt.

The outcrop pattern of the Green River formation in the Sand Wash Basin, Colorado is roughly triangular in shape with the apex situated near Powder Wash, in T. 12 N., R. 97 W. The eastern limb of the triangle extends southward to the

Little Snake River and the width of the outcrop band varies from one mile to over ten miles. The western leg of the triangle trends about S/ 60° W/ and the width of the outcrop varies from one mile at the southern end to about 12 miles in the vicinity of Powder Wash. The Bridger formation covers a limited area in the central portion of the triangle.

2. Geological history

After the period of folding and faulting which gave rise to the present mountain ranges of Wyoming, Colorado and Utah, the downwarped region extending from the northern part of the present Green River Basin southeastward into northwestern Colorado and from there westward into Utah, was the site of deposition of fluviatile sediments (Wasatch) made up of material derived from the adjacent mountain uplifts. After the deposition of these early Eocene stream-laid sediments, fresh water lakes began to form, and at one time large parts of southwestern Wyoming, northwestern Colorado and eastern Utah were occupied by lakes. Gosiute Lake lay to the north of the Uinta Mountains; Uinta Lake was situated to the south. A third smaller lake, according to Bradley (Ref. 7, p. 640), occupied the Fossil area in southwestern Wyoming. The lacustrine deposits constitute the Green River formation, which contains the oil shales. Subsequently, lake conditions terminated and younger fluviatile deposits were spread over the Green River lacustrine deposits during later Eocene time.

The lake history was not a simple one for in Wyoming there is evidence that the lake reached an early stage of maximum spread, during which time the Tipton tongue was laid down as a widespread lacustrine deposit. As the lake spread, the zone of fluviatile deposition peripheral to the lake migrated progressively outward from the original lake basin and as a result there is a replacement of the upper part of the fluviatile Wasatch beds by the lacustrine deposits of the lower Tipton.

After the lake had reached its maximum extent in Tipton time, a regression of the shore caused the spreading of fluviatile deposits over the previously deposited Tipton. The lake at this time was restricted essentially to the present Green River Basin, and in that area lacustrine deposition went on continuously. The tapering wedge of fluviatile sediments which penetrated the lake basin constitutes the Cathedral Bluffs tongue of the Wasatch.

A second time of widespread lake conditions followed after the maximum retreat during Cathedral Bluffs time and lacustrine sediments again accumulated in the expanding lake. As the lacustrine environment migrated outward, lake beds constituting the Laney member were spread over the fluviatile deposits of the Cathedral Bluffs tongue.

After the second maximum expansion was reached, during Laney time, a second period of recession ensued and the subsequent history was that of a continuously shrinking lake. Following Laney time, at the beginning of Morrow Creek time, lake conditions remained widespread, but a marked change in physical conditions resulted in the cessation of oil shale formation and in the deposition of sediments quite different from those laid down in earlier Green River time. Sands which make up the Tower sandstone in the vicinity of the town of Green River were spread over the southern part of the Green River Basin and over the southwestern part of the Washakie Basin. Over the remainder of the area, lake beds were deposited which carry abundant plant remains and which lack the distinctive character of earlier lake deposits. These plant-bearing lacustrine beds constitute the Morrow Creek member. Concomittent with the deposition of the Morrow Creek within a shrinking lake basin, the peripheral zone of fluviatile deposition migrated basinward, and with the final extinction of the lake these fluviatile deposits, representing the Bridger formation, were spread completely over the old lake basin.

Because the Green River and related formations were deposited in a great many sedimentary environments, it is obvious that there are many intergrading rock types which reflect the differences in the physical, chemical and biological factors which prevailed in the different environments. As based on the environment of deposition, the different rock types which are being deposited contemporaneously may be referred to as facies. The two major facies are the fluviatile facies, made up of sediments deposited by streams and the lacustrine facies, comprising those sediments deposited in the lake.

Within the lacustrine facies are minor variations in rock types determined by the specific lake environment in which they were deposited. Some of these are the shore facies, such as beach deposits, the near-shore shallow water facies, the deep water basin facies and the saline facies representing a super-saline water environment. The distribution of oil shales within the Green River formation was directly controlled by facies distribution. This relationship is discussed at length as a separate topic.

3. Fossils of the Green River formation

Microfossils are abundant in the Green River formation and include such plant remains as bacteria, fungi, algae, fern spores, and pollen and such animal remains as protozoans, crustaceans and fragments of insects. These are known primarily from the oil shales. Larger fossils are commonly represented by small crustaceans, called ostracods, which in favorable shallow-water environments flourished to such an extent as to form beds of limestone. Snails were abundant, especially the genus Goniobasis, and some shallow-water beds are made up largely of their remains. Reef-building algae, which differ from the micro-algae, flourished in warm shallow waters. Larvae of aquatic insects were also abundant. A great variety of fish inhabited the lake and the beautifully preserved articulate skeletons have been quarried for many years, especially in the Fossil area. The shore environment and the fluviatile environment were the habitats of turtles, crocodiles and insects. Rich mammalian faunas are known from the fluviatile equivalents of the Green River formation.

Relation of Facies to Distribution of Oil Shales

Bradley's detailed studies of the lithology of the Green River formation pertaining to the occurrence of algal limestones, oolites and various fossils, as well as the physical and chemical structure of the sediments, such as lamination, mud cracks and shale breccias, have revealed much regarding the environment under which the deposits accumulated and the depositional history of the formation (Refs. 2,4).

These relationships are of direct interest in that the occurrence of certain lithologic types and structural features are related to barren shore facies which were unsuitable for the formation of oil shales. Other characteristics tend to indicate deposition in shallow water or in near-shore areas where the occurrence of appreciable thicknesses of rich shale are unlikely. Thus, even though assay data are lacking in many areas, certain valid inferences and assumptions can be made with regard to the occurrence and distribution of oil shales.

The remarkable regularity and persistence of rich oil shale beds in the central parts of the depositional basin and the varved sequences of thin laminae make it seem likely that they were formed in a lake deep enough for thermal stratification of its waters to persist for sufficiently long periods of time to allow putrification of organic matter in its cool stagnant depths.

Deposits along the shore line of the lake basin are characterized by coarser sediments, including sandstones, silts and silty shales and by the occurrence of algal reefs, oolitic limestones, ostracods and shell marls. Similar sediments characterize the basal member of the formation. Algal reefs and oolites formed at relatively shallow depths along the shore line where fresh water containing considerable lime was present. These conditions were distinctly unfavorable for the formation of oil shale which requires stagnant water conditions for putrification of organic matter to take place. It is significant that oil shale is practically absent in the basal member, the shore facies and other sections containing algal deposits, and that such few beds as do occur are thin and extremely lean.

Mud cracks, mud curls and well preserved insect larvae on the surface of shale beds formed during temporary exposures of the lake bottom at low-water stages. Lenticular shale beds appear to be related to shallow water conditions and some appear to have formed in residual ponds during withdrawal of water from portions of the lake.

Glauberite, trona and other salts, occurring in disseminated crystals, in beds or in lenses, formed when extremely saline water conditions built up during low-water stages or during periods when the lake had no outlet and evaporation balanced precipitation.

The occurrence of lenticular shale beds or oil shales associated with mud cracks, mud curls and soluble salts in the section are not alone indicative of lack of rich beds averaging over 15 gallons per ton. They are indicative, however, of fluctuating lake conditions and although a few thin rich shales are noted in such sections, there are extreme variations in the thickness, richness and distribution of the oil shale beds. The occurrence of silty shales, silts or sands in the same section would suggest proximity to the shore line, and corresponding decreases in thickness and richness may be expected.

The occurrence of sandstones, silts and silty shales in oil shale-bearing sections is generally indicative of barren to low-grade shales and of proximity to the shore line. In some instances, thin persistent sandstones occur interbedded with persistent rich shales. As these sandstones increase in thickness and number toward the shore line, corresponding decreases in richness and thickness of the oil shales may be expected.

The lithology of the Green River formation is typically one of changing facies. Contemporaneously with the formation of oil shales in the central part of the lake, streams were depositing sands and silts along the shores of the lake. Some students of the problem consider that all the lake deposits comprising the Green River formation are somewhere represented by fluvial deposits of sand, mudstone and shale and that the Green River formation is, in effect, a lens of lake beds enclosed by stream deposits of the Wasatch and of the Bridger.

Many gradations in lithology may occur between the shore line and the deep part of the lake basin. Starting at the shore line and progressing basinward are coarse sands, silts and silty shales which are in association with algal limestones in the shallow water slightly offshore. Basinward, the beds become finer grained and contain silty shales, nearly barren shales and thin beds of sandstone, and grade into sections containing thin oil shale beds which increase in richness and thickness toward the center of the lake basin.

During continued periods of stabilized conditions when the equilibrium of the lake was not upset by major fluctuations in water level or by influxes of sand and silt from the shore line, or in other ways, thick sequences of rich shale were formed in the central portion of the lake basin. During initial stages of the cycle, formation of oil shales was limited to a small area in the central portion of the basin but as deposition continued, succeedingly higher zones of oil shale expanded areally toward the margins of the lake basin, and during periods of sustained stability and equilibrium, widespread deposits of shale extended outward toward the margins of the lake. As a result, the base of an oil shale zone is often an interfingering contact which crosses time lines.

This upward and outward expansion of the oil shale zones toward the margins of the basin continued until the environment suitable for oil shale deposition was upset by influxes of sand and fresh water from the margins of the lake, by variations in water level, or in other ways. At the same time, deposition of rich shale beds was restricted to the central portion of the lake basin and zones of sand, silt and barren to low-grade shales were deposited shoreward.

If these fluctuations were the result of low-water stages of the lake, mud cracks and mud curls may have formed and fly larvae may have accumulated on the exposed portions of the lake bottom, while lenticular shale bodies may have formed in residual ponds. Shale breccias, and salt crystals may have formed in the shallow water of the lake. As conditions again became favorable, widespread deposition of oil shales may have again been resumed until the stable conditions were again upset by various factors.

In general, the thick continuous sequences of oil shale beds of relatively uniform richness were deposited under long-continued static conditions in the lake. On the other hand, sections containing alternating beds of barren, lean and rich shale beds which show considerable variation in distribution and richness were formed under fluctuating conditions.

3. <u>Stratigraphy</u>

a. <u>Introduction</u>.- The stratigraphy of the Green River formation involves an understanding of the lateral changes within the formation, such as differences in lithology, in thickness, and in terminology. The relations of the individual units to older and younger units are also considered. The chart showing stratigraphic relations (Exhibit ___) will be found to be a useful adjunct to the written discussion.

The names of the Eocene formations of southwestern Wyoming were given in the early days and the Wasatch, the Green River and the Bridger were named by Hayden in 1869. During the last 30 years, as more detailed studies were undertaken, it became necessary to apply formal names to minor stratigraphic units, and such tongues and members as Tipton, Cathedral Bluffs, Laney, Morrow Creek and others have been named.

The oldest Eocene formation, the Wasatch, rests unconformably above rocks ranging in age from pre-Cambrian to Paleocene. Fluviatile deposits make up the entire formation and it is characterized by conglomerates, sandstones and clays, predominatly red in color, which may be as much as 5,000 feet thick. In the Great Divide Basin and the Washakie Basin, where the Wasatch is split by the Tipton tongue of the Green River, the name Hiawatha member has been used for the lower, or main, part of the Wasatch and the upper part has been named the Cathedral Bluffs tongue. The name Hiawatha member has not found universal usage and many geologists still refer to this part of the formation simply as Wasatch. The Cathedral Bluffs tongue of the Wasatch is made up of brightly colored clays and sandstones of fluviatile origin. It ranges in thickness from a featheredge to as much as 1,500 feet or, in other words, the Laney member and the Tipton tongue of the Green River may be separated by as much as 1,500 feet of Cathedral Bluffs beds in some places, and in other places the Laney may rest directly on the Tipton.

Along the western margin of the Green River Basin, along the boundary of the Overthrust Belt, the Wasatch ranks as a group, with the basal formation known as the Almy and the upper one as the Knight. The Almy is primarily a conglomerate and the Knight comprises finer-grained reddish clays and sandstones. A fluviatile tongue which penetrates the Green River formation on the northwest margin of the Green River Basin recently has been named the New Fork tongue of the Wasatch (Ref. 10, p. 64). It is the lithologic equivalent of the Cathedral Bluffs tongue elsewhere.

The Green River formation constitutes the lacustrine beds of early Eocene age and the total thickness, where the formation is well-developed, may be as great as 2,000 feet. Over large parts of southwestern Wyoming, it is divisible into a basal unit, the Tipton tongue, which is overlain by the Cathedral Bluffs tongue of the Wasatch. Ordinarily the Tipton rests on the Wasatch, but in a few rare instances overlaps the Wasatch and rests on older rocks as in sec. 25, T. 22 N., R. 115 W., where it rests on Jurassic rocks. The remaining upper part of the Green River formation comprises the Laney shale at the base, the Tower sandstone next above and the Morrow Creek member at the top. Along the west side of the Rock Springs uplift the Cathedral Bluffs tongue is lacking and there the Tipton is directly overlain by the Laney. Along the northwest margin of the Green River Basin, a lacustrine unit within the Wasatch which probably represents the Tipton has recently been named the Fontenelle member of the Green River (Ref. ___, p. 63).

The Laney shale occurs in all the basins and retains the same name everywhere. The Tower sandstone, next above the Laney in the area about the town of Green River, is a local deposit restricted to the southeastern part of the Green River Basin and to parts of the Washakie Basin. Where the Tower sandstone is lacking, the Morrow Creek members rests directly on the Laney. The Morrow Creek is widely distributed and retains the same name throughout its extent. Oil shales are present only in the Tipton and in the Laney members of the Green River.

The Bridger formation, a sequence of fluviatile beds of Middle Eocene age, overlies the Green River, or in rare localities where no lacustrine beds are present, may overlie the Wasatch. In the central part of the Green River Basin, as shown by deep wells, the Bridger is nearly 2,000 feet thick. The formation is characteristically made up of sombre gray and tan clays and sands. A great part of the Bridger is made up of material of volcanic origin, part of which accumulated as ash-falls and part was transported and redeposited by streams. The name Blacks Fork member for the lower part of the Bridger and Twin Buttes member for the upper part have been proposed but are rarely used except by vertebrate paleontologists.

It should be emphasized that the formations here described are lithologic units and not time units. Parts of the Wasatch are contemporaneous with parts of the Green River, and parts of the Green River are contemporaneous with parts of the Bridger.

The discussion of the units making up the Green River which follows, treats them from oldest to youngest.

Tipton tongue.- The type locality of the Tipton tongue is immediately south of Tipton station on the north flank of the Wasakie Basin. It was originally named by Schultz in 1920 (Ref. 16) who described it as consisting of "whitish shales, clays and sandstones" with an oolitic limestone 20-50 feet thick near the bsse. A thickness of from 200 to 250 feet was given for the unit. Bradley (Ref. 6) has more recently given the thickness in this area as 350 feet and states that the Tipton is made up primarily of "soft, brown, papery, varved organic shale and low-grade oil shale, in which somewhat harder beds of gray, flaky marlstone and thin, regular beds of brown limy sandstone are interbedded". The Tipton retains a thickness of about 350 feet to the southwest of the type locality, along the west flank of the Washakie Basin, to secs. 5 and 6, T. 15 N., R. 100 W. Farther south the sandstone beds become thicker and more numerous and beds of greenish-gray shale and gray mudstone replace much of the papery shale. Schultz (Ref. 16) has described "great escarpments of yellow sandstone, about 200 feet high, containing a small amount of conglomerate" along Canyon Creek, in about T. 12 N., Rs. 101 and 102 W. Within a few miles to the south, toward the Uinta Mountains, the size of the boulders increases to as much as two feet in diameter. The change from fissile and papery shales at the north to sandstones and conglomerates toward the Uinta Mountains indicates the transition from off-shore to near-shore to shore and fluviatile environments.

West and northwest of this area, however, oil shales reappear in the section. In sec. 15, T. 12 N., R. 102 W. (Locality 34) a section measured by Bradley and Sears (Ref. ____) shows the Tipton to be made up predominantly of sandstone, but a few beds of papery shale and low-grade oil shale are present. The thickness of the Tipton is given as 509 feet. Thin oil shales persist on to the northwest and were sampled by Winchester in T. 13 N., Rs. 103 and 104 W. (Localities 32 and 33).

Along the southwest margin of the Washakie Basin, the Tipton maintains a thickness comparable to that along the northern part of the basin and the lithology is similar. South of the Wyoming border, at Locality 35, it is 385 feet thick and is made up of an upper part which is predominantly sandstone with sandy shales and low-grade oil shales, and a lower part composed mainly of shale, some beds being papery low-grade oil shales. About 10 miles farther south, at Locality 36, it has thinned to 227 feet, where it is made up mainly of sandstone with beds of carbonaceous shale carrying abundant plant fragments. The Tipton cannot be recognized south of T. 10 N., R. 100 W.

From Tipton station, along the east side of the Basin, the Tipton retains a thickness of about 350 feet to T. 16 N., R. 92 W., where it begins to thin noticeably through replacement of the lower part by Wasatch beds and of the upper part by Cathedral Bluffs beds. In the northern part of T. 14 N., R. 92 W., it has thinned to 115 feet. Farther south, in the southern part of T. 14 N., R. 91 W., the Tipton is made up mainly of regular beds of light-gray well-sorted cross-bedded sandstone with thin beds of sandy shale and carbonaceous shale. This local sandy phase apparently marks the site of the mouth of a stream which entered the lake from the east. South of this point the Tipton continues to thin but changes to a papery shale phase. In T. 13 N., R. 91 W. the Tipton is entirely papery shale and is 75 feet thick. A constant thickness of 75 feet is retained for some distance to the west, on the southeast margin of the basin, but the shales become carbonaceous and sandy and the Tipton loses its identity in sec. 4, T. 12 N., R. 93 W.

On the east side of the Green River Basin, the Tipton is well developed in the vicinity of the town of Green River, where it shows the greatest amount of oil shale, but changes strikingly both north and south from that area. East of the town of Green River, along Bitter Creek, at the southern end of White Mountain (Locality 3), the Tipton is about 150 feet thick and is directly overlain by the Laney. The lower half is made up of an alternation of beds of sandstone, limestone and shale. The upper part is primarily shale and shows thin beds of papery shale alternating with thicker beds of lean to barren flaky to papery shale. Near the top of the Tipton in this area there is a persistent zone of relatively rich shale, composed of thin rich massive shales interbedded with somewhat thicker beds of paper shale.

Northward from this area, along the east face of White Mountain, a persistent limestone unit makes its appearance at the base of the Tipton in the southern part of T. 21 N., R. 105 W. This limestone is oolitic and is characterized by abundant ostracode shells with scarcer snail shells and fresh-water clam shells. North of this point the fissile shales which are so characteristic east of the town of Green River begin to give way to fine-grained even-bedded sandstones and still farther north these are replaced by massive cross-bedded coarse-grained sandstones, locally conglomeratic, which suggest stream-channel deposits. The change in lithology from near the town of Green River to the area north of the Rock Springs uplift indicates a change from the off-shore to the near-shore and shore environments. It is pertinent to note also that in T. 24 N., R. 104 W., the Tipton and the Laney are separated by the wedge-edge of the Cathdral Bluffs tongue, and that the fluviatile deposits characterizing that tongue become more conspicuous to the northward and eastward.

The sandy facies of the Tipton characterizes the region north of the Rock Springs uplift, and at Localities 17-21 the tongue is made up principally of sandstone and limestone.

To the east of a line joining Localities 20 and 21, the sandy character is lost and the Tipton is made up of finely laminated shales, ostracodal limestones, algal limestones and oolitic limestones, as at Locality 25. East of locality 25, the Tipton extends for an unknown distance. The area has never been mapped in detail, nor have stratigraphic sections been measured, but geologists of the subcontractor have personal knowledge of the wide distribution of ostracodal limestones through the northern part of the Great Divide Basin which suggests that the near-shore environment was widespread through this area during Tipton deposition.

South of Bitter Creek the Tipton persists for about 15 miles but loses its identity south of T. 16 N., R. 106 W. In T. 17 N., R. 106 W. (Locality 10) it is 324 feet thick and as along Bitter Creek is made up principally of shale, but there are thin sandstones in the upper part. Here the zone of richest shale lies about 114 feet below the top and is about 16 feet thick. The oil shales of the Tipton are discussed at greater length in the section dealing with the east flank of the Green River Basin.

So far as known, the Tipton is lacking around the northern margin of the Green River Basin, but it appears in the southern part of T. 29 N., R. 111 W., and extends southward along the west margin of the basin for a distance of about 100 miles, thinning out again in T. 15 N., R. 117 W. The U. S. Geological Survey (Ref. ___) indicates that throughout this area the Tipton is separated from the Laney by the Cathedral Bluffs tongue of the Wasatch, with the exception of a few places in and adjacent to T. 25 N., R. 112 W., where it is overlain by the Laney member. Conversely, Donovan (Ref. ___), in discussing the stratigraphy of the Green River formation in the area about the point where Sweetwater, Lincoln and Sublette counties adjoin in T. 26 N., R. 111 W., states that in this region the Tipton, which he calls the Fontenelle member of the Green River, rests on the Laney but that north of sec. 14, T. 28 N., R. 111 W., the Tipton and Laney are separated by a fluviatile tongue which Donovan has called the New Fork tongue of the Wasatch. Regardless of this discrepancy, the lithology of the Tipton of this region shows an alternation of buff-brown sandstones and green and gray mudstones. The sandstones are strongly cross-bedded and there are thin local pebble conglomerates near the top of the unit. The lithologic character suggests shore-line delta deposition and the unit appears to be devoid of organic shales.

Laney shale member.- The Laney shale member of the Green River formation was named by Schultz (Ref.___) from the Laney Rim on the north flank of the Washakie Basin. Along the northern part of the basin, in the type region, and along the western margin of the basin, the Laney is between 400 and 500 feet thick and is made up principally of buff marlstone and limy mudstone and light-gray to brown shale. The middle part of the formation contains a considerable amount of papery low-grade oil shale and a few beds of moderately rich shale. Certain layers in the Laney which are now altered to the mineral analcite, a hydrous sodium aluminum metasilicate, probably originated as layers of volcanic ash. Analcite layers are found in the Laney throughout the Washakie Basin, as are thin oolites and algal limestone layers, especially in the lower part of the unit.

On the eastern margin and along the Wyoming-Colorado border, the Laney contains much less organic matter and the shales are softer and more nearly mudstones. Locally, however, varved organic marlstone and low-grade oil shale are present, particularly in the area along the Colorado-Wyoming border.

In the Sand Wash Basin the Laney shale makes up the major part of the Green River formation. In the area south of the wedge-edge of the Tipton, the Laney rests directly on the Wasatch. The thickness ranges from 1,100 to 1,200 feet, which is considerably greater than the thickness of the Laney in the Green River area. This discrepancy is explained by the fact that the beds called Laney in this area actually include equivalents of the Tower sandstone and the Morrow Creek at the top, since in the Sand Wash Basin the so-called Laney is directly overlain by the Bridger. Lithologically, the member may be divided into three units, as indicated by the section south of Lookout Mountain (Locality 38). The lower 250 feet is characterized by limy sediments including limy shales and thin crystalline, algal, and oolitic limestones. The middle 500 feet is predominantly shale, much of which is classed as low-grade oil shale. A few thin ostracodal limestones and shell marls lie within the shales. The upper 450 feet is about half sandstone and half clay shale. Interspersed there are thin beds of limestone made up mainly of snail shells or of ostracode shells. A conglomerate in the upper part of the Laney on the west side of the basin suggests deposition fairly close to the source. In the southeast part of the basin thin coal beds lie in the lower part of the formation and many beds contain abundant coalified plant remains.

The lithologic features of the Laney through the Washakie Basin suggest that a great part of the unit was deposited in shallow near-shore waters and for that reason the shales are relatively low in organic matter. Most of the beds which can be classed as oil shale are low grade, although a few beds of moderately rich shale have been noted in the northern part of the region.

The Laney is conspicuously exposed in the area about the town of Green River and outcrops both to the north and to the south as a broad belt on the east flank of the Green River Basin. Near the town, the Laney is about 750 feet thick and is made up principally of finely laminated shale, with thin interbeds of sandstone and limestone, resting directly on the Tipton member. The entire unit weathers to a conspicuous bluish-white color. The fissile shales of the Laney in this area are of many sorts but may be divided into barren shales and oil shales. The barren shales are commonly gray in color and many of them are sandy. The oil shales are dark in color and vary from tough, hard and massive to papery. They range from lean to rich, but the rich shales are generally thin. Some of the richer shales are strikingly lenticular in character. Barren shales and oil shales are interspersed throughout the section. Some of the oil shales show casts of salt crystals. In the area about the town of Green River, at the top of the Laney, and just below the overlying Tower sandstone is a well-defined zone of oil shale, herein called the Upper Laney oil shale zone, which has been traced for a considerable distance southward along the valley of ~~the~~ Green River.

Not far to the north, in T. 19 N., R. 107 W. (Locality 1), the Laney contains a much larger proportion of sandstone than it does around the town of Green River, but the overall thickness appears to remain the same. Farther north, however, there is marked thinning. In the southwestern part of T. 24 N., R. 104 W., it has thinned to 200 feet. Northward thinning persists and the Cathedral Bluffs tongue is introduced between the Tipton and the Laney in this same township. Farther north green claystone makes up a major part of the Laney and finally, in sec. 3, T. 25 N., R. 102 W., the Laney merges with the fluviatile sediments of the Cathedral Bluffs.

Little is known of the Laney along the north margin of the Green River Basin, but in the northwestern part it has been differentiated and mapped by Donovan (Ref.____). Here it is much thinner than in the region about the townoof Green River but lithologically it is very similar, being composed of marlstones, shales and oil shales which weather to the characteristic bluish-white color. The maximum thickness is 131 feet in T. 25 N., R. 112 W. Not far to the west, in T. 24 N., R. 112 W., the Laney has thinned to the point where it is not definitely recognizable. Farther north, in T. 29 N., R. 110 W., the basal member is an algal limestone 40 to 50 feet thick suggesting near-shore shallow water deposition. The overlying beds are platy siltstones, thin-bedded shales and oil shales. The thinness of the Laney in this region and the presence of algal limestone suggest that the Green River lake did not extend far beyond this area.

In the southwestern part of the Green River Basin, in T. 14 N., R. 117 W., east of Evanston, the entire Green River is but 300 feet thick. The lower part of the Green River here is probably the Laney equivalent and is made up of white-weathering marlstones and shales with thin beds of sandstone and limestone. It is of interest to note that basinward the Green River thickens from 300 feet here to over 1,500 feet in the Church Buttes field 30 miles to the east.

Tower sandstone lentil.- The Tower sandstone is a local sandstone unit which is conspicuous in "The Towers" near the town of Green River and southward along the Green River valley and along the western margin of the Washakie Basin. The contact of the Tower with the underlying Laney shale in the Green River area is peculiar. The shales immediately below the Tower are strikingly contorted in an undulatory fashion with the contortion dying out downward below the contact. The sharp contact of the shale with the overlying sandstone is likewise contorted and there are dike-like extensions of sandstone penetrating the Laney shale. Rude-bedding in the lower part of the Tower suggests that it, too, is strongly contorted in the lower part. This contortion may be a feature of sub-aquesous gliding, or subsolifluction, developed through the slumping of deltaic deposits.

The Tower is a brown resistant massive cross-bedded medium- to coarse-grained sandstone about 250 feet thick. Southward it persists as a distinctive unit in the cliffs bordering ~~the~~ Green River until it passes under water level not far north of the Wyoming-Utah border. Northward along the west side of the Rock Springs uplift, the Tower sandstone is replaced by beds of Morrow Creek lithology and finally loses its identity along the northern part of the uplift. The Tower has not been recognized in wells drilled in the central part of the Green River Basin.

On the western margin of the Washakie Basin, the Tower seems to represent a complex widespread system of channel sandstones. The channel sandstones are 50 to 75 feet thick and from 150 to 300 feet wide. The Tower sandstone can not be recognized in the

~~in the~~ eastern and southern parts of the basin, but it may be represented by one of the numerous sandstones in the upper part of the Green River in those areas.

Morrow Creek member.-The youngest and uppermost member of the Green River is the Morrow Creek member. The name Morrow Creek was applied to exposures of lacustrine plant-bearing beds north of the Rock Springs uplift. In the type region it rests on the Laney shale or, where the Laney has been replaced by fluviatile beds, it rests on the Cathedral Bluffs. It consists of about 500 feet of buff sandy limestones and buff sandstones which are poorly bedded. Some thin light-brown paper shales and algal limestones lie within the member. ~~Some~~ Thin beds of low-grade oil shale lie within the paper shale units. Farther north, near the Wind River Range, the Morrow Creek thins and changes to Bridger lithology so that it is no longer recognizable.

The Morrow Creek extends southward along the east flank of the Green River Basin to White Mountain and to the region about the town of Green River, where it is 600 feet thick. In this area and southward along ~~the~~ Green River valley the Morrow Creek lies above the Tower sandstone.

In the northwestern part of the Green River Basin, the Mowwor Creek rests on the Laney and is much thinner than in the area around the town of Green River. It comprises buff and brown sandstones, shales, clays, mudstones and limestones and grades upward into the Bridger in such a fashion that the two are not readily differentiated.

In the Washakie Basin, where the Tower sandstone is present along the western margin, the Morrow Creek may be readily differentiated from the lower beds of the Green River and in this region the member is about 300 feet thick. It consists of buff platy marlstones and brown silty sandstones with interspersed beds of soft laminated organic shale and papery low-grade oil shale, mainly in the lower part. To the east and south the Morrow Creek is difficult to separate from the Laney and is represented at the top of the beds called Laney at Lookout Mountain (Locality 37) and through the Sand Wash Basin to the south (Exhibit ___).

Green River formation of the Fossil area.- The Green River formation of the Fossil area is not subject to subdivision into the Green River units recognized elsewhere. Bradley (Ref. 7) believes it to have been deposited in a separate lake. In the buttes near Fossil the contact with the subjacent red shales of the Knight (Wasatch) is sharp. About 200 feet of Green River is exposed and is made up mainly of sandstones and sandy shales. The basal 80 feet is primarily sandstone but next above is a 65-foot shale unit which contains thin beds of hard brown rich shale and thin-bedded lean shales, with interbeds of sandstone. The upper part of the section of shaly sandstone. These beds may represent the Tipton tongue, since they lie just above the Knight, but ~~this~~ there is no other evidence to support such a correlation.

(Tertiary head)

Composition and Character of Oil Shales

Bradley (Ref.___) defines oil shale as "a fine-grained sedimentary rock containing organic matter which was derived chiefly from aquatic organisms or waxy spores and pollen grains, which is only slightly soluble in ordinary petroleum solvents, and of which a large proportion is distillable into artificial petroleum."

Technically, most oil shales are not shales and do not contain oil. Actually, they are marlstones which give up only small amounts of oil in solvents and yield oil principally on destructive distillation. A few of the oil shales, however, are true shales.

The marlstones and most of the oil shales of the Green River formation are impure fine-grained calcareous sedimentary rocks containing up to 50 percent organic matter. The inorganic constituents are predominantly dolomite and calcite with varying amounts of clay minerals and soluble salts and small amounts of volcanic ash, chert and pyrite. The organic matter is of two types; one is massive and structureless, and is the matrix of the other which has a definite form and consists of organisms or fragments of them.

The amount of organic matter present controls the color of the oil shales. On fresh surfaces, rich shales grade from grayish-brown to brown to jet black and display a dull to waxy or satiny luster. On weathered surfaces, most rich oil shale beds have a distinctive light bluish-gray to bluish color. The presence of a thin white residual film of mineral constituents over the dark organic matter lends the bluish tint.

Lean oil shale beds are usually light gray, brownish gray, buff and generally weather light brown or gray.

For the most part, the oil shales are thin-bedded and regularly bedded. Many oil shales are finely laminated, containing thousands of separate laminae ranging from paper-thinness to about ½-inch thick. This lamination is due to alternating layers rich and lean in organic matter. In some beds, the laminations form a rhythmic varve-type sequence but in others they are unsystematic.

The organic matter in some lean to rich shale beds is homogeneously distributed through the rock and lamination is generally obscure. Rich shales of this type are brown or black to jet black with a high lustre and tend to have a sub-concoidal fracture. Thinly laminated beds which weather into masses of paper-thin flexible sheets are known as "paper shales". These "paper shales" are generally deeply weathered, whereas in the more massive beds, the apparent zone of weathering is shallow.

All gradations in physical character, richness and coloration may exist in individual beds or groups of beds. Not all oil shale beds are as evenly bedded and laminated as those described above. Some are exceedingly irregular in thickness, distribution and structure. Some lenses of rich oil shale often occur in relatively thick units of lean shale and taper off to thin but well-defined edges.

Mud cracks, mud curls and fly larvae which occur in some of the oil shale beds are regarded as representative of

6. Occurrence of oil, gas, water, and saline brines

A review of the occurrences of ~~crude~~ petroleum, natural gas, and saline brines as well as potable water has been made to determine the relative abundance of these materials, their distribution, and their possible effect upon any contemplated mining operations conducted for the recovery of oil shale as a raw material. No wells drilled in this area have found ~~crude~~ petroleum in the Green River formation but minor showings of natural gas have been encountered. Non-commercial quantities of methane gas have been encountered in the shaft of the Westvaco Chlorine Products Company at depths of 1,000 feet.

Saline brines are present in the Green River formation and have been encountered in wells drilled in the vicinity of Eden, the town of Green River (Ref. 14), ~~Station,~~ Westvaco, Granger, and in the Church Buttes area. The saline brines consist predominantly of sodium carbonate and sodium bicarbonate ranging in concentration from 20,000 to 75,000 parts per million total dissolved solids. The saline brines have been encountered at depths of about 125 feet in the vicinity of the town of Green River ~~Station~~ on the margin of the Green River Basin; at depths of 450 feet in the Eden area a slight distance out in the basin; and at depths 1,200 feet plus in the Westvaco and Church Buttes areas in the deeper portions of the Green River Basin. It appears that the saline brines are associated with the oil shale-bearing and the trona-bearing portions of the Green River formation, and that the occurrences of such brines is fairly widespread in the basin. The yields of these wells encountering the saline brines has not been large except in the Eden area where flowing wells with a capacity of 5,000 barrels per day have been reported. To date, only limited commercial use has been made of the brines.

Potable water has been scarce in the wells drilled in the Green River Basin. The exception is the local occurrence of potable water in sands of the Wasatch formation, such as have been encountered at the town of Green River and in the vicinity of Eden.

C. ELIMINATION OF AREAS NOT MEETING REQUIREMENTS OF SURVEY

As a result of this survey four areas in southwestern Wyoming are deemed to meet or approach the minimum requirements for oil shale reserve areas as set forth in this report. The four areas are the Green River area centering around the town of Green River; and three areas in the deeper portion of the basin, namely Eden, Westvaco, and Church Buttes.

A review of all data available indicates that the following areas in southwestern Wyoming and northwestern Colorado should be eliminated from consideration either because of lack of information or because the available assay data or interpretation of geologic data suggests that shales meeting the minimum requirements do not exist. The eliminated areas are; the Washakie and Sand Wash basins; the Great Divide Basin; the Fossil area; Sublette county areas; the area between Big Piney and the Utah-Wyoming boundary, and much of the area in the central portion of the basins ~~which are~~ covered by the Bridger formation. The Washakie and Sand Wash basins lie south of the Union Pacific Railroad in southeastern Sweetwater County and southwestern Carbon County, Wyoming, and in central Moffat County, Colorado. The Great Divide Basin lies north of the Union Pacific Railroad in Sweetwater County, and extends from near Wamsutter to the Wind River Range. This area lies contiguous to the outcrop areas of Green River formation northwest of the Rock Springs uplift in Sublette County, Wyoming. The Sublette County areas of Green River exposures are in turn connected with those extending southward from Big Piney toward Opal, Evanston, and the Utah-Wyoming boundary, and extending through northwest Sweetwater County, eastern Lincoln County, and eastern Uinta County.

The Fossil area lies west of Kemmerer and extends north and south of the Oregon Short Line Railway.

The areas in the central portion of the basin covered by the Bridger formation have been in adequately tested by borings to fully outline the potentialities of the covered and deeply buried Green River formation. The geologic map Exhibit ____, accompanying this report best illustrates the extent of the Bridger formation, and thus the amount of underlying Green River formation that is penetrated only by a few ~~tests~~ wells.

(Secondary head)

DESCRIPTION OF AREAS SELECTED FOR DETAILED RESERVE STUDY

The available information indicates that within the Green River Basin there are four areas which meet or approach the minimum requirements of the survey. These are the Green River area, which is a region of surface outcrops, the Eden area, the Westvaco area, and the Church Buttes area. The last three areas are in the central part of the Green River Basin where the oil shales lie at depths from 300 to 2,000 feet below the surface.

(Tertiary head)

The Green River area

The Green River area is defined as the outcrop belt of the Green River formation along the eastern margin of the Green River Basin extending southward from T. 24 N., R. 104 W., opposite the Eden area, to the Wyoming-Utah border. The town of Green River is centrally located in this belt of exposures and Green River flows through its southern part. That part of the area near the town of Green River and south along Green River is herein referred to as Green River Valley. White Mountain is a conspicuous cuesta made up of Green River beds extending 30 miles northward from the town of Green River, and that part of the general area lying north of the town is referred to herein as the White Mountain area.

Assay data pertaining to the area are limited to 48 assayed surface samples representing 14 localities. Because sampling was limited to selected beds, and was not continuous, the assay data do not afford a complete basis for the appraisal of the reserves of the area.

OPTIONAL ADDITION

If added, should go at bottom of page 63 and constitute the third paragraph under The Green River area, under DESCRIPTION OF AREAS SELECTED FOR DETAILED RESERVE STUDY

Not included in the 48 assays are four made on random samples of rich-appearing shales taken from talus in the SE$\frac{1}{4}$ sec. 9, T. 18 N., R. 107 W., about 0.8 mi. northwest of the town of Green River. The samples may represent one of the thin rich beds of the middle Laney or may have come from the upper Laney and, of course, have little value since nothing is known of the thickness of the beds represented. Two samples assayed 32 gallons per ton, one assayed 38 gallons per ton and one assayed 61.7 gallons per ton. The last is the richest sample reported from the Green River area based on a reliable assay.

by K. E. Stanfield, of the Bureau of Mines

There are three main oil shale-bearing intervals in the Green River area - - in the Tipton member, in the middle Laney, and in the upper Laney. The Tipton oil shale zone and the upper Laney oil shale zone are most important.

(Quaternary head)

<u>Tipton oil shale zone</u>.- The Tipton outcrops as a narrow north-south band along the east margin of White Mountain and southward parallel to Green River Valley. The Tipton dies out about 15 miles south of the town of Green River.

Data pertaining to oil shale in the Tipton member are scanty. Schram indicates that in the vicinity of the town of Green River, (Locality 3) the upper part of the Tipton carries an appreciable amount of oil shale. Geologists of the subcontractor observed that the lowest oil shale beds, 2 to 3 feet thick, lie 80 feet above the base and are separated by a barren interval 42 feet thick from a higher interval made up of 18 feet of paper shale and leaner shale in 3-foot beds overlain by 36 feet of paper shale with some thin rich seams.

Schultz and Winchester reported 7 samples from Localities 9 and 10 southeast of the town of Green River. Reliable assay data, however, are available only at Locality 9, where 5 samples representing 21.6 feet of a 26.6-foot interval yielded an average of 15 gallons per ton. The highest yield was 19 gallons per ton for an 11.6-foot interval. The location of the sample point as given by Winchester does not place it on the Tipton outcrop, yet in the stratigraphic section it is definitely stated that the samples were taken from the Tipton. At nearby Locality 10, two samples representing 13.6 feet of a 15.8-foot interval averaged 17.1 gallons per ton.

Because the base of the section measured at Locality 9 lies within the oil shale zone which gave an average yield of 15 gallons per ton, and because there are no assay data to limit the thickness of the 17 gallon per ton shale at Locality 10, it is possible that in Tps. 17 and 18 N., R. 106 W., there are oil shales in the Tipton of such quality and thickness that they would meet the minimum requirements of this survey.

In the section near the southern end of White Mountain (Locality 2), the Tipton is quite sandy, and, as is shown in the discussion of the stratigraphy of the Tipton, it becomes progressively more sandy northward. Although there are no assays to support the belief, it appears that there are no thick rich shales at Locality 2 or farther north in the White Mountain area.

(Quaternary head)

Middle Laney oil shale zone.- Thin but rich oil shales lie in the middle of the Laney shale member. These are reported by Schramm and were observed in the field by geologists of the subcontractor. It was noted that these shales are usually less than two feet thick and are interbedded with thicker intervals of lower grade papery to flaky shale. In addition, they are very lenticular. In one area southeast of the town of Green River a zone of lenticular massive shale bodies was observed, some of which are more than 5 feet in thickness and less than 10 feet in length. The shales in the middle Laney commonly contain glauberite salt crystal casts. Although many of the middle Laney oil shales appear to be rich, their thinness and non-persistence eliminate them from consideration.

(Quaternary head)

Upper Laney oil shale zone.- In the upper part of the Laney, just below the Tower sandstone, is an oil shale zone which can be recognized along Green River Valley from the town of Green River southward almost to the Wyoming-Utah border. Assays of 29 samples from this zone at 12 localities are available. The zone is made up of oil shales of varying nature and thickness with interbedded sandstones, and ranges in thickness from 50 to 120 feet.

The best section representing continuous sampling is that at Locality 6, where a 47-foot interval containing 38 feet of oil shale was measured and sampled by geologists of the subcontractor. At the top of the section, just below the Tower sandstone, is 15 feet of papery shale and a sample of the lower 4 feet yielded 6.6 gallons per ton. A 13-foot shale next below yielded an average of 17 gallons per ton. Next below is a barren 9-foot sandstone. The 21-foot shale section just below the sandstone yielded an average of 10.4 gallons per ton. The yield of the best 25-foot interval includes the sandstone and averaged 10.32 gallons per ton.

Samples taken at 11 localities along Green River Valley and reported by Winchester show that the richest shale yielded 34 gallons per ton from a 2.6-foot interval at Locality 15. Five samples assayed more than 20 gallons per ton from beds ranging from 0;9 to 5.25 feet in thickness. Nine samples gave yields ranging between 15 and 20 gallons per ton, but all represented thin sampled intervals. In this group of assays, 5 samples assayed 19 gallons per ton and represented intervals ranging from 3 to 8 feet thick.

An analysis of the assay data pertaining to the 11 localities sampled by Winchester suggests that from 10 to 15 feet of the richer part of the upper Laney oil shale zone will yield about 15 gallons per ton and that a few thin beds, from 1 to 5 feet thick, will yield 25 to 35 gallons per ton.

In the southern part of Green River Valley, a single group of beds in the upper Laney oil shale zone is exposed along the valley for about 12 miles, in Tps. 13 and 14 N., R. 108 W., and Winchester (Ref. 22, pp. 168-169) and Schultz (Ref. 16, pp. 52-53) noted the change in lithology and yield of the group of beds from place to place. The interval is made up of interbedded harder black rich shale and softer brown leaner shale. The total thickness is about 3 feet. In places the interval is predominantly rich shale, in others it is mainly lean shale and in others shows an interbedding of the two types. Three samples from the interval, taken at different points by Winchester, showed yields of 19, 32 and 34 gallons per ton. A fourth sample, reported by Schultz, gave a yield of 7 gallons per ton.

Because of the lack of continuous samples taken through the upper Laney oil shale zone, there are no places where the data indicate shales which approach the minimum standard of richness and thickness set as the requirement of this survey, yet a study of the available data suggests that some intervals in the upper Laney oil shale zone might approach, or meet, the minimum requirements if there were adequate information available to allow them to be discriminated.

Even less information is available on the White Mountain area. But one assay has been reported from this outcrop belt over 30 miles in length. Bradley (Ref.___, p. 127) reports a yield of 35.5 gallons per ton from a thin bed in the Laney at Locality 18. About 10 miles due west of the White Mountain outcrop belt of the Laney, in the Eden area, about 360 feet of oil shale-bearing section lies at a minimum depth of about 330 feet. In some wells up to 45 feet of section yields 25 gallons per ton or better, and up to 262 feet yield 15 gallons per ton. In view of the proximity of the outcrop to the thick oil shale sections drilled in the Eden area, it appears that fairly rich and fairly thick oil shales may be present in the outcrop belt. Because the evidence suggests that on the east flank of the Green River Basin, there is a decrease in richness and thickness of the oil shales from the basin toward the outcrop, shales as rich and thick as those in the subsurface are not to be expected in the outcrop.

2. Deep Basin areas

Within the Green River structural basin numerous wells have been drilled in the exploration for ~~crude~~ petroleum, natural gas, water and trona. These tests are widely distributed but somewhat concentrated in three areas; Eden, Westvaco, and Church Buttes, in the central portions of the basin. The geologic data obtained from these wells in the form of cores, samples, electrical resistivity logs, and water analyses together with the assay of samples for oil yield reveal that oil shales exist throughout much of the central portion of the basin. A comparison of the assays of samples of oil shale from the deep basin area with the assays of the surface outcrops indicates that oil shale from the basin area may be thicker and may have higher oil yields than the surface exposures of comparable rock units. Continuous sections of oil shale-bearing Green River formation up to   feet thick have been encountered in the basin areas, and the yields in these sections have ranged from   to   gallons per ton. Surface sections nearby have ~~had~~ either no reported oil shale, as in the case of the outcrops adjacent to the Eden area, or have ~~had~~ lesser thicknesses, as in the case of outcrops near Green River in comparison to the Westvaco area. The sampling of the exposed surface sections has been inadequate, hence the above comparison may not be valid.

Sufficient information from wells has been reviewed in this survey to evaluate the reserves of three specific areas in the deep basin portion of the Green River syncline. From north to south these areas are the Eden area, the Westvaco area, and the Church Buttes area. The Eden area contains primary and secondary reserves but the Westvaco and Church Buttes area contain only secondary reserves as defined in this survey.

EDEN AREA

The ~~area~~ district ~~to be~~ described ~~under the name of~~ as the Eden area lies in T. 23 N., and T. 24 N., Rs. 106 and 107 W., near Eden Post Office, Sweetwater County, Wyoming, in the drainage of Sandy Creek as is shown on the attached map and graphic section Exhibit ___.

Geological background.- Geologically the area is situated on the east flank of the Green River Basin, and the rock units rise gently at an average dip of 3° toward the southeast onto the Rock Springs Uplift. The surface rocks are a part of the Bridger formation. The oil shale-bearing units of the Green River formation outcrop at the surface in a north-south band across T. 23 N., R. 105 W., approximately seven miles east of the Eden district.

The units present in the outcrop area include from base upward ~~to~~ the Wasatch formation, the Tipton member (80-100 feet thick), the Laney shale member (200 feet thick) and Morrow Creek member (325 feet thick). The Green River is in turn overlain by the Bridger, for which no accurate thickness is available. These strata named above dip westward toward the Eden area and can be recognized in the wells which began in the Bridger formation and penetrated the Green River formation. One test passed through the Green River formation into the underlying Wasatch formation.

Well data.- In the Eden area John R. McDermott, of Rock Springs, Wyoming drilled five wells in an attempt to find commercial quantities of bedded trona at shallow depths. The wells are shown on the geologic map Exhibit ___, and on the Tabulation Sheet Exhibit ___, as Localities A, B, C, D, and E. The wells range in depth from 477 feet to 1,095 feet and encountered an oil shale-bearing section approximately 360 feet thick. The area outlined by these wells embraces approximately ten square miles in the northwest portion of T. 23 N., R. 106 W., Sweetwater County, Wyoming.

Samples from the five wells drilled in the Eden area were assayed for oil yield by the U. S. Bureau of Mines Oil Shale Experiment Station in Laramie, Wyoming. A chart ~~prepared~~ based on ~~this~~ these data, and on data obtained from the operator, forms Exhibit ___ of this report. The chart illustrates graphically the location of the wells, the correlation of the geologic formations present, the correlation of yields based on assay data, and the occurrence of saline brines in these wells. Correlatable zones of oil shale are indicated by dashed lines on the chart. The overall thickness of oil shale is approximately 360 feet and the top lies between ~~the~~ depths of 330 feet to 710 feet dependent upon the topography at the well site. The oil shale zone contains shales which on assay yielded from 0 to 35 gallons per ton. Penetration is not equal in all wells, and only one completely passed through the Green River formation and into the underlying Wasatch formation.

Exhibit ___ demonstrates the general correlation of the individual oil shale zones encountered in these wells but it also demonstrates the extreme variability of yield within the individual zones. The thickness of shale yielding an average of twenty five gallons per ton or better varies from 15 feet to 45 feet in individual wells within the short distances between the wells. The thickness of shale yielding an average of fifteen gallons per ton varies from 133 to 262 feet in individual wells which is somewhat more constant than for the richer shales. In order to more clearly show the relationships existing between the wells in terms of thickness of shales of varying yields the attached tabulation has been prepared.

The method of sampling the drilled formations in these tests was by collecting cuttings from the ditch circulating the drilling fluid. In the Eden area brines rich in sodium carbonate and bicarbonate were encountered in the wells. Trona, a highly soluble sesquicarbonate, is known to occur in layers and as disseminated crystals in oil shale elsewhere in the Green River Basin and presumably occurs here also. The removal of the disseminated carbonates by the drilling fluid may explain to a certsin extent the variability in yield in individual zones. Assays of samples from the Eden area may indicate greater thicknesses of any given yield than actually exist because of erratic distribution of disseminated carbonate crystals, and the entire or partial removal of the same by the drilling fluid.

EDEN AREA

Well No. Locality	Oil shale bearing interval			Maximum continuous thickness averaging 25 gallons per ton		Maximum continuous thickness averaging 15 gallons per ton	
	Top	Base	Thick-ness	Interval	Thickness	Interval	Thickness
A McDermott #3	350	710	360	495 - 509	14	385 - 588	133
B McDermott #1	320	425	105 *	420 - 465	45	320 - 550	185 **
C McDermott #4	432	702½	270 *	565 - 593	28	432 - 672	212
D McDermott #5	520	810	290 *	605 - 626	21	513 - 775	262
E McDermott #2	340	525	185 *	435 - 450	15	370 - 522	184

* Incomplete penetration of Green River formation

** Measured and estimated

Problems inherent to the Eden area

The McDermott wells encountered no bedded trona deposits in the Eden area but encountered flows of carbonate brines. The flows of brine ~~were~~ encountered in the wells located at Localities A, B, and D, at depths ranging from 477 feet to 515 feet were remarkably uniform in composition, containing approximately 47,500 parts per million total dissolved solids, and having a temperature of 57° F. The flowing yields of these wells were reported to be from 3,500 to 5,000 barrels per day. Associated with the carbonate brines both dissolved and suspended organic matter related to the humic acid group. was reported. Potable water from a depth of 765 to 1,065 feet was encountered in the Wasatch formation at Locality A, with a reported flowing yield of the well of 17,000 barrels per day.

The recovery of oil shale in this area by underground mining methods would be complicated by the large volumes of water encountered in the three wells. The water flows lie both within and below the oil shale zones, and would constitute a hazard to underground mining. The brines do not appear to come from sandstone aquifers, but rather from fractures in the oil shale sequence.

b. Westvaco

Location.- The ~~area~~ district ~~[to be]~~ discussed ~~[under the name of]~~ as the Westvaco ~~district~~ area lies along the Union Pacific Railroad near the Westvaco siding and includes roughly Tps. 18 and 19 N., Rs. 109 and 112 W., entirely within Sweetwater County, Wyoming. The townsite of Granger lies within the area.

Geological background.- The area is situated near the center of the Green River Basin and the rock units are essentially flat-lying. The surface strata are part of the Bridger formation, underlain by the Green River and Wasatch formations.

At the nearest outcrops (east of the Westvaco area) the Wasatch, Tipton, Laney and Morrow Creek units are recognized.

Well data.- In the Westvaco area, trona, $(NaCO_3\ NaHCO_3\ 2H_2O)$ a mineral widely used as a flux in the glass and ceramic industry, was discovered in 1938 in the Mountain Fuel Supply #1 Hay, Sec. 2, T. 18 N., R. 110 W., drilled as an exploration test for oil.

Subsequent to the discovery the Union Pacific Railroad drilled four exploratory test holes and the Potash Company of America drilled two exploratory test holes. The Westvaco Chlorine Products Company has drilled one test and sunk a shaft for recovery of this bedded trona on a commercial scale. Two additional wells, one for water, and one an oil and gas test have been drilled in the area.

The U. S. Bureau of Mines Oil Shale Experiment Station at Laramie, has assayed samples of oil shale from four of the above-mentioned tests. The assay data reveal the presence of oil shale in varying amounts throughout an interval of approximately 1,265 feet. The assay data are summarized in graphic for Exhibit ___. Locality numbers correspond to those on the geologic map Fig. ___ and the tabulation sheet Exhibit ___.

Oil shale is present in the Westvaco ~~district~~ area between ~~the~~ depths of 500 feet and 2,000 feet, but due to insufficient sample and assay data no one locality presents a continuous section. The oil shale is associated with bedded trona, and disseminated crystals occur in the oil shale. The assay data indicate yields as high as 41.3 gallons per ton for thin zones (1' - 3') thick, but low yielding shales occur immediately above and below the rich zones. No intervals of 25 feet yielding an average of 25 gallons per ton were reported; the greatest thickness of rocks having this yield was 9 feet. In general the shales yield 15 gallons per ton or less.

The reserves for the Westvaco area are all in the secondary category as set forth by the requirements of this survey.

Problems inherent to the Westvaco area

The best oil shale zone in the Westvaco area lies at an approximate depth of 1,200 feet below the surface, with richer zones in the Westvaco Chlorine Products Company shaft lying at a depth of 1,400 feet. Underground mining would be necessary to recover the raw material in this area therefore, the presence of water in certain sands in the area becomes of importance. Two fairly persistent water bearing sands have been encountered in this area, one at a depth of about 850 feet ~~-foot depth~~, and one near the 1,100-foot depth. The sands carry small flows of saline brines rich in sodium carbonate and bicarbonate. Adequate provision ~~should~~ would have to be made in any mining plans for handling these waters.

The estimation of the reserves in the Westvaco area is complicated by the high percentage of trona occuring in association with the oil shale both as thin layers and as disseminated crystals. Brown (Ref. 8) believes that at the time of formation and deposition of the rich oil shale beds, the lake was supersaturated with sodium salts which were in turn precipitated by any small change in environment. This assumption is borne out by the cores recovered from trona tests drilled by the Union Pacific Railway. A core from Core test #3, sec. 31, T. 19 N., R. 109 W., between 1,400 and 1,410 feet, on the basis of visual estimates contained 26.61% disseminated trona crystals. The amount of trona in individual thin beds ranges from 5% to 50%. The presence of this disseminated trona must be considered both in terms of calculating yields, and in the problem of removing it from the shale with which it is associated ~~after~~ should the shale ~~is~~ be mined.

c. Church Buttes area

Location.- The area encompassing the wells drilled in the Church Buttes gas field is discussed as a district under that name. The gas field lies in Tps. 16 and 17 N., Rs. 112 and 113 W., Sweetwater and Uinta Counties, Wyoming, and can be considered to include an area in excess of fifteen square miles on the basis of present development. The district lies south of the Union Pacific Railroad siding of Church Buttes, and east of Blacks Fork.

Geologic background.- The district is situated in the southern portion of the Green River Basin, with the Bridger formation outcropping at the surface. The area is remote from any surface exposures of the oil shale-bearing portion of the Green River formation. The rocks are essentially flat-lying, and no surface structure is visible.

Well data.- Knowledge of this area is based on a series of deep gas wells drilled by the Mountain Fuel Supply Company. The wells produce gas from the Cretaceous Cloverly formation at depths ranging from 12,500 to 13,000 feet. Ten wells have been completed and two are currently drilling. The U.S. Bureau of Mines Oil Shale Experiment Station at Laramie, has assayed samples of the oil shale zone from five of these wells for oil yield. The thickness assayed in these wells varied from 1,735 to 2,070 feet between depths of 1,200 and 3,500 feet.

A comparison of the yield of the shales can be summarized in terms of thickness of shale of varying yields. Two wells, Mountain Fuel Supply #5 Unit and Mountain Fuel Supply #6 Unit penetrated shale 22 feet and 12 feet thick respectively which assayed 25 gallons per ton. Four wells at Localities O, P, Q, and R penetrated sections of oil shale which yielded 15 gallons per ton on assay. The thickest section yielding 15 gallons per ton is 189 feet at Locality O, and the thinnest section yielding 15 gallons per ton is 85 feet at Locality R. A test at Locality S had no shale which yielded 15 gallons per ton on assay. The best 25-foot section in this latter test yielded an average of 6.5 gallons per ton. The oil shale zone occurs in all wells and can be readily correlated on the basis of Schlumberger electrical resistivity logs. The individual shale zones within the major unit can be correlated with reasonable assurance. It has not been possible to make a close and accurate direct correlation with the nearby Westvaco area due to the fact that no electric logs are available for the latter area.

North of the Church Buttes area, the Union Oil Company of California #1 Moxa test, SE NE NE sec. 30, T. 19 N., R. 112 W., encountered a low-grade oil shale section, which on the basis of electric logs can be correlated readily with the wells in the Church Buttes district. No assayed yields of shale samples from the Moxa well reached 15 gallons per ton. The best 25-foot section assayed in this well was 1,570-1,595 which yielded 10.1 gallons per ton.

Problems inherent to the ~~district~~ Church Buttes area

The top of the oil shale portion of the Green River formation in the Church Buttes district lies at an average depth of 2,150 feet below the surface. The oil shale of highest yield lies near the major trona-bearing zone at depths of approximately 2,700 feet. These depths are the greatest of any sampled subsurface localities in the Green River Basin. The depth to this deposit would make mining an expensive problem.

In the Church Buttes district there is a persistent trona-bearing zone, and apparently a correlatable bedded trona deposit. The major trona bed occurs at a depth of about 2,700 feet (~~Brown 6~~ Ref. 8) but was not encountered in all wells drilled. Wells on the west side of the field show no signs of trona in drill samples, and apparently delimit the western margin of the trona deposit. Trona is reported both as bedded deposits and as ~~a~~ disseminated crystals of the various sodium carbonate salts. Since the trona is very soluble, and since the trona zone was not cored, it is impossible to accurately predict the effect of dissolved trona on the assays of the shale taken from samples. The effect in general is to make the shale appear to make up a larger volume of the rock than actually exists.

The only data concerning water-bearing horizons in the Church Buttes field are derived from a test drilled by the Mountain Fuel Supply Company, sec. 7, T. 16 N., R. 112 W., in a search for water for drilling operations, and which encountered minor shows of water at 1,208-1,245 feet and 1,325-1,334 feet. The hole was carried to 1,410 feet and abandoned for lack of sufficient water for sustained drilling use. The oil and gas tests drilled do not indicate any water sands. It is assumed that water is not a serious problem in the Church Buttes district.

The reserves for the Church Buttes district are set forth on Figure ___ and Tabulation ___.

A P P E N D I X

DESCRIPTION OF ELIMINATED AREAS

The following areas are eliminated as sources of primary and secondary reserves of oil shale, as defined in this survey, on the basis of lack of sufficient data to evaluate them, and on general geologic considerations as to the extent and distribution of the oil shales of the Green River formation.

WASHAKIE BASIN

General.- The Washakie Basin is a prominent topographic feature located in south-central Wyoming and occupies portions of Sweetwater and Carbon Counties, Wyoming, and extends south into Moffat County, Colorado. The Sand Wash Basin, Colorado, is the southward extension of Washakie Basin and with it forms a single unit. Because of the close similarity of geologic conditions in the two areas, and their topographic continu~~ation~~ity, the Sand Wash Basin of Colorado has been included with the discussion of Wyoming oil shales. In the Washakie Basin approximately 2,900 square miles, and in the adjacent Sand Wash Basin approximately 600 square miles, are underlain by the Green River formation. The rocks dip gently toward the center of the basins, in such fashion that the basins are roughly circular in character. Dips average 2° ~~degrees~~ to 4° ~~degrees~~ along the margins and flatten toward the central portions.

Rocks present.- The rocks in the Washakie Basin and the Sand Wash Basin ~~(Colorado)~~ are divided into three main units (from bottom to top); ~~(1)~~ the Wasatch, ~~(2)~~ the Green River and ~~(3)~~ the Bridger formation, all of Eocene age.

Basis for elimination

The area has been eliminated as a source of primary or secondary reserves for two reasons:

(a) There is insufficient assay data on oil shales occurring in the area.

(b) Geologic factors indicate a near-shore phase of the Green River formation not conducive to the deposition of rich oil shales.

(a) Assay data on this region are limited to 7 assays ~~(15, 20)~~ (Refs 18, 23) covering a total thickness of ~~58.5~~ 58.25 feet of shale. One sample of a 5-foot bed yielded 30 gallons per ton. Four thin beds yielded 7.5, 10, 11 and 15 gallons per ton; two thicker beds yielded 4 and 9.5 gallons per ton. The samples were apparently taken in the field to represent the richer shales in measured stratigraphic sections. The thinness of the single rich bed indicates the fact that rich shales are not extensive. Visual estimates by observers consistently stress low-grade oil shale with occasional beds of moderately rich material. Low-grade oil shale by visual estimate is considered to be that capable of yielding less than 10 gallons per ton. The inadequate data do not allow an estimate of reserves, though the evidence suggests that the shales are of low grade.

(b) The Green River formation was deposited in a lake, with the thicker portions of the formation in the central part of the lake. The Washakie Basin and Sand Wash Basin ~~(Colorado)~~ appear to have lain to the east of the pricipal sites of Green River oil shale deposition. This is evidenced by the intertonguing of oil shale with the river type of deposits. The Tipton tongue of the Green River formation thins out and finally becomes nonexistent along both the northeast and the southwest margins of the basin. The Tipton tongue consists of soft shales, low-grade oil shale interbedded with barren shale, thin beds of limestone and sandstone.

The sandstone content of the unit increases to the south across the basin at the expense of the shales, and thereby eliminates oil-bearing rock. Such sandy units are not known to contain oil shales of high yield anywhere in the region.

The Laney ~~tongue~~ member of the Green River formation in the Washakie-Sand Wash Basin consists of 400 to 500 feet of buff-brown, chalky, marlstone and light ash-gray shale. There is considerable low-grade oil shale and an occasional thin bed of moderately rich oil shale. The lower portion of the Laney ~~tongue~~ contains abundant algal limestone beds, and considerable sandstone. The presence of algal limestones, and abundant limy marlstone suggests a marginal phase of the lake and an environment which did not permit preservation of the materials that now constitute the organic content of oil shale.

Both the Laney and the Tipton tongue~~s~~ have the characteristics of near-shore deposition, with a large percentage of sandstone and limestone. These rock-types are not associated with high-grade oil shales.

A number of wells drilled for oil and gas in the southern ~~portion~~ part of the Washakie Basin have passed through or into the oil shale portion of the section. ~~The~~ Most of these wells have yielded no detailed information on the extent and nature of the oil shales. Three deep wells have been drilled that penetrated through the oil shale section. Samples have not been assayed. The geologic location of the wells suggests that they lie in the low-grade oil shale area.

Great Divide Basin and north end of Rock Springs Uplift

General.- North of the Union Pacific Railroad between Rawlins and Black Buttes Station and extending northward to the south end of the Wind River Range, is the Great Divide Basin. The area of the Great Divide Basin and the contiguous territory around the north end of the Rock Springs uplift is approximately 3,500 square miles. Within this broad basin only about 1,400 square miles are underlain by or occupied by beds of the Green River formation. The exact outline of the area of Green River rocks is poorly understood due to lack of detailed geologic mapping within the region.

The area of Green River formation specifically included in this area lies in:

T. 27 N.; Rs. 96-102 W.
T. 26 N.; Rs. 94-102 W.
T. 25 N.; Rs. 94-103 W.
T. 24 N., Rs. 96-104 W.

The eastern boundary is near Lost Creek, and the western boundary extends almost to Pacific Creek.

Rocks present.- The Green River strata at the north end of the Rock Springs uplift in Tps. 23, 24, 25, and 26 N., Rs. 100, 101, 102, 103 and 104 W., are best known and have been described by Bradley (Ref. 1). An additional portion of the area has been described by Nace (Ref. 10). In this area the formations present are, from the base upward: Wasatch, Tipton tongue of the Green River, Cathedral Bluffs tongue of the Wasatch, Morrow Creek member of the Green River and the overlying Bridger formation. All units above the main body of the Wasatch and Green River are thin, totalling approximately 650 feet of rock as compared to 1,700 to 1,800 feet of rock for the same units in ~~the~~ Green River Valley.

The area has been eliminated from consideration as a source of primary and secondary reserves as defined by this survey for two reasons:

(a) There are insufficient assay data on the oil shale.

(b) Geologic factors ~~that~~ indicate a near-shore, low-grade oil shale phase of the Green River formation.

(a) Assay data on this area are limited to two assays of thin beds in widely separated localities, one indicating low-grade oil shale, and the other a single thin (less than one foot) rich shale zone. An assay of samples from the interval 45-55 feet in the California-Wyoming Development Company #1 Lost Creek well, sec. 7, T. 25 N., R. 94 W., yielded 4.2 gallons per ton.

Bradley (Ref. 1) ~~(1925)~~ reports an assay of 35.5 gallons per ton for a thin (less than one foot) shale bed in sec. 2, T. 24 N., R. 104 W. (Locality 18). ~~Wyoming~~. There are no other assays of samples taken within the Red Desert area.

Visual estimates by Bradley (Ref. 1) indicate that all oil shales of the Tipton tongue that he measured and described were low-grade (less than 10 gallons per ton yield). Ten stratigraphic sections were measured and described in this area, none of which is described as containing any high-grade oil shale.

(b) The Tipton tongue of the Green River in the Great Divide Basin consists of finely laminated shales, fossil-bearing limestone, oolites, and algal reef limestones. Northwestward across the area, sandstone becomes more and more abundant indicating that the shore of the lake was nearby. The near-shore environment which allowed the deposition of limestone and sandstone did not allow the preservation of organic matter necessary for the formation of rich oil shale. For this reason, the Great Divide Basin and the north end of the Rock Springs uplift are eliminated from consideration, since rich oil shales apparently were never deposited there.

The Laney shale ~~tongue~~ member of the Green River consists ~~entirely~~ largely of fine-grained sediments which contain varying amounts of organic matter to form ~~the~~ oil shales. Near the north end of the Rock Springs uplift the oil shale makes up a ~~larger~~ minor part of the total ~~rock~~ section, and Bradley (Ref. 1) reported a thin shale bed which assayed 35.5 gallons per ton from a locality 18, ~~in sec. 8, T. 24 N., R. 104 W.,~~ ~~and~~ The thin bed is presumed to be less than a foot ~~or less~~ thick. Northward from this locality the organic content rapidly decreases until the limestone and shale are entirely barren of organic material.

Since this area has good surface exposures of the Green River formation and has been covered by detailed geological mapping, the low organic content of the sediments is considered to be adequately established, indicating that no oil shale meeting the requirements of this survey exist.

Fossil area

An area in western Wyoming lying north and south of Fossil Station on the Union Pacific Railroad has been designated the Fossil area. The name is derived from the wonderfully preserved fossil fish found in the Green River formation near this station. The Green River formation occurs in an area roughly outlined by Tps. 17 to 24 N., and Rs. 117 W. to 119 W., inclusive, comprising some 450 square miles.

Rocks present.- Immediately east of this area the Eocene rocks are divided into the Wasatch, the Tipton tongue of the Green River formation, the Cathedral Bluffs tongue of the Wasatch, the Morrow Creek and Laney undivided, and the overlying Bridger formation. The oil shale near Fossil Station is separated from the main body of the sediments in the Green River Basin by a distance of 12 miles, and exists as a group of isolated exposures capping a series of flat topped topographic eminences.

The zone carrying oil shale in this area is about 75 feet thick, is overlain by 95 feet of barren sandy shale and is underlain by sandy shale and coarse sandstone. The richest oil shale bed is two feet thick, is located near the top of the oil shale zone and yielded 37 to 50 gallons per ton. Two measured sections with assays appear as Localities No. #27 and No. #30 on the map and appear in Tabulation ___. The thin oil shale zones are apparently the same in both sections. The strata which contain the oil shale ~~are tentatively~~ may correlated with the Laney shale ~~tongue~~ member of the Green River formation, and on the basis of thickness and character ~~are believed to~~ may represent a thin western equivalent of the main body of that shale as known to the east in the Green

River Basin proper, but since the Green River formation of the fossil area is believed to have been deposited in a separate lake (Ref. 7, p. 640), precise correlation is impossible.

The area has been removed from consideration for three reasons:

(a) There are insufficient assay data on the oil shales.

(b) Geologic evidence indicates that the area is marginal to the principal locus of oil shale deposition and, therefore, the sediments were deposited in an environment unfavorable for the necessary preservation of organic material.

(c) Known oil shale beds are thin.

Thin beds assaying over 15 gallons per ton exist, but the thicker oil shales in the middle of the section average less than five gallons per ton. The area must be eliminated because of (1) thinness of beds and (2) low yield of oil shales.

Sublette County area

The Green River formation outcrops in a broad band across the northern margin of the Green River Basin and extends from the north end of the Rock Springs uplift northwestward to Big Piney and LaBarge in southern Sublette County. The main outcrop belt lies in Tps. 26, 27 and 28 N., through Rs. 104 to 108 W., with scattered isolated exposures as far north as T. 33 N., in the same ranges. West of R. 106 W., the outcrop belt broadens and swings southward along the Green River drainage to the southern boundary of Sublette County.

Within this area one oil and gas test was drilled from which samples were assayed for oil yield. The [assays of samples from] ~~yield of~~ this well, the General Petroleum Company #78- 4- Govt., sec. 5, T.27 N., R. 113 W. [showed no oil shale in the] ~~was zero gallons per ton for the Green River~~ interval assayed.

A geologic map of southwestern Wyoming recently has been released by the U. S. Geological Survey (Ref. 11) ~~(Love and Weitz, 1950)~~. This map indicates the presence of the Tipton tongue of the Green River formation, the Cathedral Bluffs tongue of the Wasatch, and the Laney-Morrow Creek (undivided) members of the Green River formation in Sublette County. Additional information on the area near the junction of the New Fork and Green River in the western part of the outcrop area is given by Donovan (Ref. ~~8~~ 10) and confirms the data presented on the geologic map.

The Sublette County area has been eliminated as a source of primary or secondary reserves as defined by this survey [because:] ~~due to~~:

(a) insufficient assay data.

(b) Geologic evidence shows that the Tipton tongue does not exist as an oil shale-bearing unit in the northern part of the area.

(c) The Laney shale is predominantly a shale and algal limestone unit barren of oil shale.

The ~~isolated areas of the~~ Green River formation in northern Sublette County occurs as isolated areas of flat-lying rocks capping numerous large mesa-like topographic features. No detailed mapping of these areas has been done, nor are there any measured stratigraphic sections with assay data. It is believed that these areas may contain minor amounts of oil shale, and that such shales occur in the Laney shale member of the Green River formation.

Area south from the Sublette County line to the Utah boundary.
(western margin of the Green River Basin)

General.– The outcrop area of the Green River formation along the southwestern margin of the Green River Basin extends in a north-south band from near LaBarge, Wyoming (T. 26 N.) to the Utah-Wyoming boundary, and lies in Tps. 12- 26 N., and trends diagonally through Rs. 113 W. to 118 W. The outcrops occur in central Uinta County, eastern and northeastern Lincoln County, and in the extreme northwestern corner of Sweetwater County.

The rock units in this area are the Wasatch, Tipton tongue of the Green River formation, the Cathedral Bluffs tongue of the Wasatch, and the undivided Laney and Morrow Creek shales, all overlain by the Bridger formation. The outcrop pattern of these units are shown on the geologic map Exhibit #___ accompanying this report. Within the area 6 scattered wells have been drilled in the course of exploration for ~~crude~~ petroleum and natural gas. Samples from three of these wells have been assayed for oil yield by the Bureau of Mines Oil Shale Experiment Station at Laramie. Only one test, the M. R. Homer #1 Herschler, NW¼ sec. 3, T. 24 N., R. 114 W., on Fontenelle Creek, showed any oil shale on assay. The highest yield from this well was obtained in the interval 13-155 feet and yielded 0.3 gallons per ton.

Basis for elimination.–

The area has been eliminated from consideration as a source of raw material as defined by this survey ~~for two reasons:~~ because there are insufficient assay and geological data.

~~(a)~~

~~(b) insufficient geologic data.~~

Areas buried beneath the Bridger formation.

The Bridger formation outcrops over wide areas in the central and deeper portions of the basin areas in southwestern Wyoming. The Bridger ~~formation~~ overlies the rocks of the Green River formation and buries them to a depth of at least 2,000 feet in certain areas. The only existing knowledge of the nature and extent of the oil shale-bearing rocks beneath this thick sedimentary cover was obtained from wells drilled through the Bridger formation into the underlying shale section. A total of 42 wells have been drilled under these circumstances, and samples from 20 have been assayed for oil yield.

Data sufficient to evaluate reserves are available in three local areas, namely, Eden, Westvaco, and Church Buttes. The remainder of the Green River Basin which is covered by the Bridger formation has been eliminated as a source for raw materials under the requirements of this survey because of a lack of geologic data and a lack of assay data for the Green River formation.

APPENDIX

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