Case History of Red Wash Field, Uintah County, Utah[1]

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Abstract Discovery of Red Wash field was the result of a long and persistent effort on the part of many geologists and geophysicists. Surface expression of an anticlinal nose was first detected on aerial photographs and modifications were made by field mapping. Detailed stratigraphic studies along the outcrop at Raven Ridge indicated that potential stratigraphic traps existed in northern source sandstones of the Eocene Green River Formation. Gravity studies in the area, although not conclusive, furnished supporting evidence that the structural nose existed at depth. A detailed seismic program confirmed the existence of the Red Wash nose and furnished data to map its structural configuration at several horizons within the lower Green River Formation. Information now available from over 350 wells in the area indicates that prediscovery geologic concepts were remarkably accurate. The Douglas Creek and Garden Gulch Members of the Green River Formation form a lacustrine delta at Red Wash and yield hydrocarbons from a complex network of discrete sandstones. The individual sandstone bodies form separate stratigraphic traps. Cumulative production at the end of 1967 was more than 57 million bbl of oil, and ultimate recovery is expected to exceed 150 million bbl.

Introduction

The Red Wash field lies in the northeast corner of the Uinta basin in Uintah County, Utah (Fig. 1). The California Company completed the discovery well (Sec. 26, T7S, R23E) in February 1951 at an initial production rate of 339 bbl of oil a day from lenticular sandstones of the Douglas Creek Member of the Eocene lower Green River Formation. Subsequent drilling has extended production until there are now more than 320 oil and/or gas wells in the Red Wash area. Oil production averaged 17,554 bbl a day in 1967; cumulative oil production at the end of 1967 was 57,447,105 bbl. Gas produced in the Red Wash area averaged 57,131 Mcf per day in 1967. The Red Wash complex ranks as the second largest oil-producing field and the largest gas-producing field in Utah. According to Picard (1957, p. 927), Red Wash is the largest oil field in the world producing from lacustrine rocks.[2]

Prediscovery Exploration in Uinta Basin

Prior to the discovery of Red Wash field in 1951, Tertiary well control in the Uinta basin was limited. The first oil test in the basin, a 1,000-ft (305 m) Green River test, was drilled and abandoned in 1900 with no favorable indications of oil or gas (Hansen, 1957, p. 165). In 1925, commercial quantities of gas were discovered in Frontier (Cretaceous) and Morrison (Jurassic) sandstones at Ashley Valley field (Burchell, 1964, p. 181). This field was abandoned in 1941. In 1948, however, deeper drilling on the Ashley Valley anticline resulted in the discovery of oil in the Weber Sandstone (Pennsylvanian and Permian)—which already was productive at Rangely field, discovered in 1902—and the Phosphoria Formation (Permian; Fig. 1). This Paleozoic production is recognized as the first commercial oil field in Utah (Peterson, 1959).

Success at Ashley Valley triggered a brief surge of drilling activity in the Uinta basin, aimed primarily at the Weber sandstones and confined generally to areas of Cretaceous outcrop north of the limits of the Green River Formation. By 1948, development drilling was at its peak in Rangely field (Fig. 1), prolifically productive from the Weber and the largest oil field in Colorado. With Weber production established in the only two fields in the general area, interest in the hydrocarbon potential of the Green River Formation understandably was

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[2] Recent studies have shown that examples of large oil and gas fields productive from lacustrine sediments are more numerous and widespread on a worldwide basis than had been realized by most geologists (Halbouty *et al.*, 1970, Table 1). The reserves of several fields in intermontane basins of China exceed those of Red Wash, which is the largest North American field productive from lacustrine source rocks (Meyerhoff, 1970). Several Chinese fields in lacustrine strata have recoverable reserves of 500 million to 1.2 billion bbl. *Editor*

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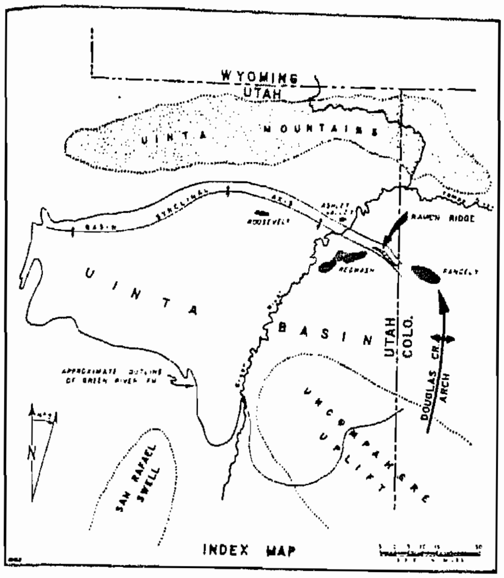

FIG. 1—Index map of Uinta basin showing major surrounding highlands, approximate limits of Green River Formation, Red Wash field, Raven Ridge, and oil fields discovered in area prior to 1951.

overshadowed by industry's attention to older objectives.

In the spring of 1949, however, oil was discovered in the Green River Formation at the Roosevelt field (Fig. 1) when the Carter Oil Company No. 1 Ute Tribal well was completed for an initial production rate of 1,633 bbl of oil per day. The Roosevelt field production, which established the first commercial Green River oil field in the Uinta basin, is from fractured shales and siltstones of the Douglas Creek Member at approximately 9,300 ft (2,835 m). The high initial production rates of the Roosevelt wells, although not truly indicative of the fractured reservoir's sustained capacity (cumulative production through 1967 was 2,531,747 bbl of oil), aroused interest in the Tertiary rocks of the Uinta basin. The Roosevelt field probably also influenced drilling of subsequent wildcat wells prior to the Red Wash discovery 18 months later.

Standard Oil Company of California's interest in the oil potential of the Uinta basin dates at least as far back as the early 1920s, when the first company geologic reports on the regional stratigraphy, structural history, and hydrocarbon potential of the basin were made. During fall of 1920 and summer of 1921, a Standard Oil Company of California field party studied the Tertiary rocks of the Uinta and Piceance basins. This reconnaissance work indicated favorable potential but failed to generate sufficient interest to start an immediate exploratory program. During these and other early investigations, Standard of California geologists were aided by Earl Douglass, a vertebrate paleontologist with the Carnegie Museum who, in 1909, had discovered the rich deposit of Jurassic dinosaur bones which is part of the Dinosaur National Monument.

Interest in the Uinta basin continued at a low key for many years. Several regional reports on stratigraphy and the remarkable Green River oil shales were prepared during the late 1920s and 1930s, but no active exploratory program was undertaken. It was during these years, however, that W. H. Bradley (1929, 1931) published some of his classic work on the Green River Formation that contributed immeasurably to knowledge of the Tertiary section of the Uinta basin.

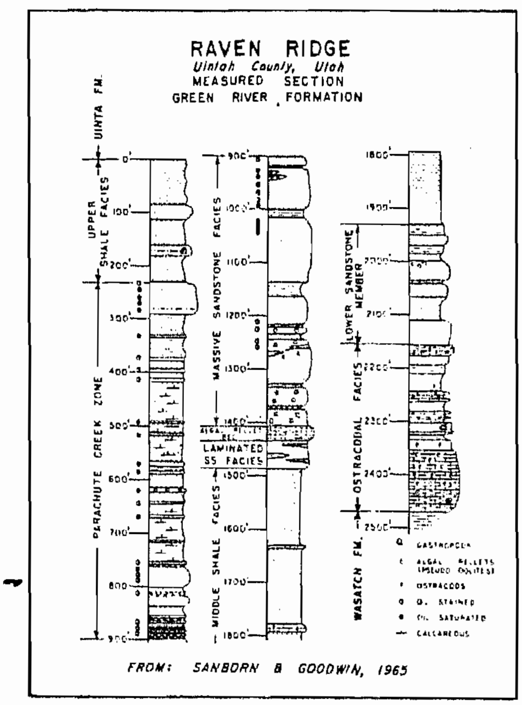

FIG. 2—Measured section of Green River Formation at Raven Ridge showing oil-stained and oil-saturated intervals. Designated intervals within Green River Formation are informal lithologic units recognized only along Raven Ridge outcrop. See Figure 3 for location.

In 1945, Standard Oil Company of California began the exploratory program that was eventually to result in the discovery of Red Wash field. This program called for a compilation and synthesis of all available geologic knowledge, field work along the outcrops rimming the basin, a reconnaissance gravity survey, a basinwide study of aerial photographs, and detailed surface mapping of indicated anomalies. If warranted, this work was to be followed by seismic programs in the most promising areas.

Geologic Program

Geologic studies of four-lens photographs from aerial surveys flown in 1936–1937, integrated with limited surface control, proved to be useful during the early stages of evaluating the Uinta basin. Numerous surface anomalies were outlined and scheduled for detailed mapping by two- and three-man field parties. One of these features was a broad, subtle anticlinal nose detected in T7S, R22–23E, Uintah County, Utah. Subsequent field mapping of the varicolored siltstones, shales, and sandstones of the predominantly fluvial Uinta Formation confirmed the surface existence of the Red Wash nose and contributed additional knowledge of its structural configuration.

Detailed stratigraphic mapping of the Raven Ridge outcrop, 12 mi (20 km) east of the Red Wash surface anomaly, followed almost immediately. Rocks at Raven Ridge are of Late Cretaceous and early Tertiary age and generally are exposed in a series of northwest-trending hogbacks. Field mapping of the Eocene Wasatch and Green River beds provided the model of facies changes that were predicted to exist at Red Wash field. The lithofacies distribution patterns indicated a northwest to southeast succession of paleoenvironments—from fluvial-floodplain through nearshore lacustrine to an open lacustrine environment characterized by fine-grained clastic and chemical deposits. The Green River Formation (Fig. 2) is a sequence of interbedded sandstone, shale, and thin limestone units. In the northern part of Raven Ridge, more than half the section consists of

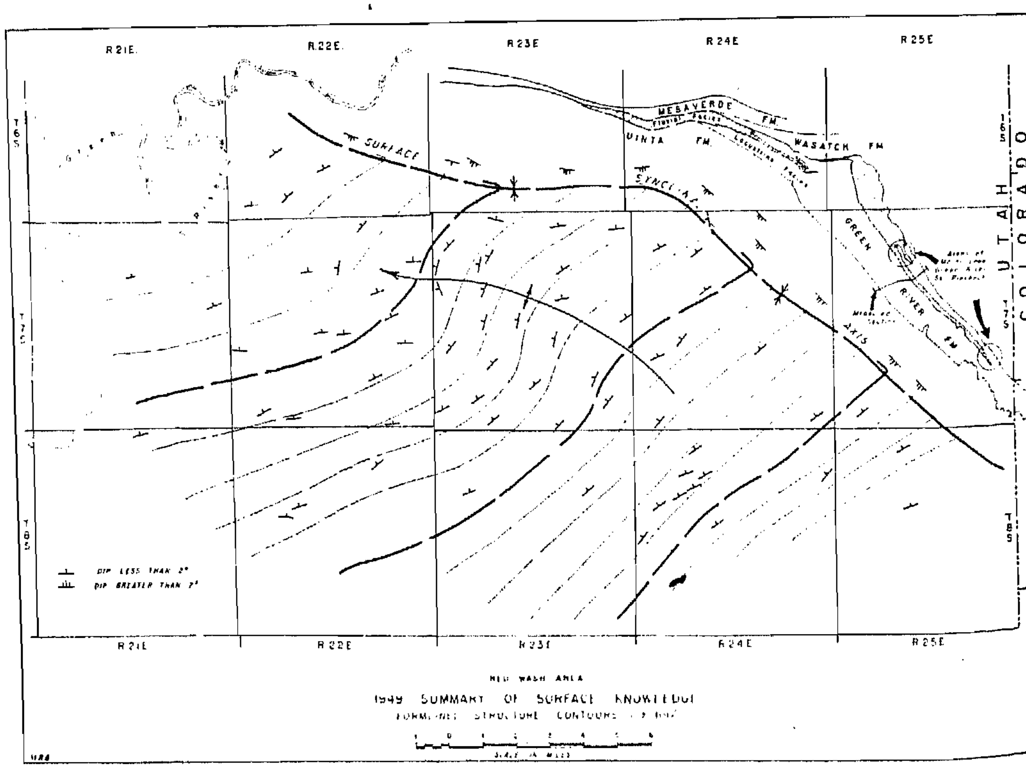

Fig. 3—Surface structure map (1949) showing areas of major pinchout of lower Green River sandstone along Raven Ridge.

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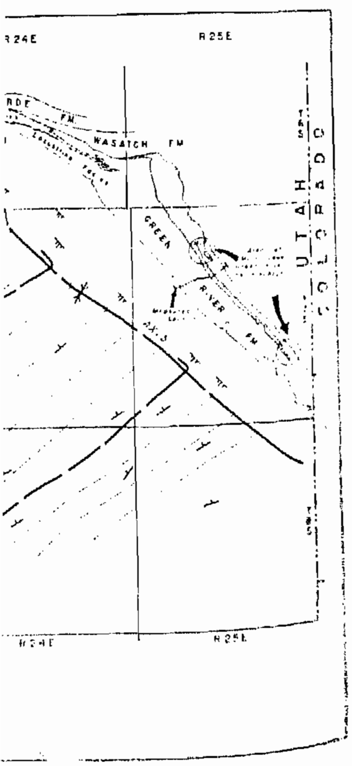

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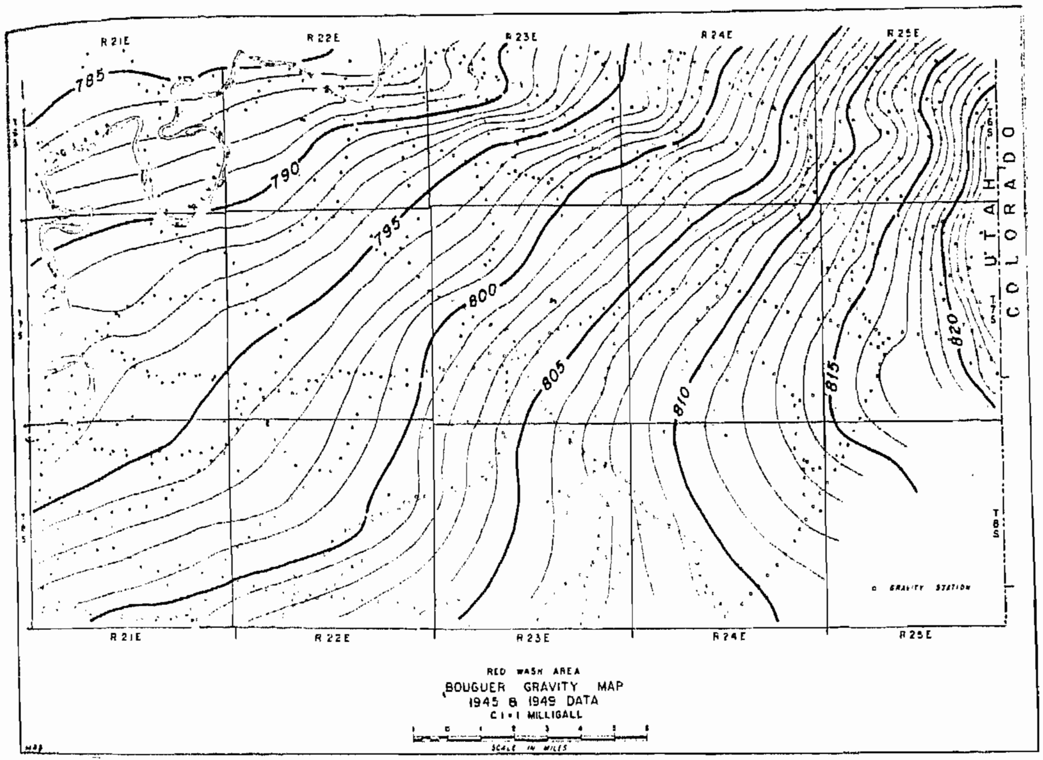


FIG. 4—Bouguer gravity map of Red Wash area (1949).

sandstone units, most of which wedge out into shales and marlstones of the open lacustrine environment on the south. The lenticular sandstones and enclosing strata were considered to be part of an ancient lacustrine delta which derived clastic sediments from the Uinta Mountains on the north. A more detailed paper by Sanborn and Goodwin (1965) on the Tertiary lithofacies exposed at Raven Ridge and a more regional study of the Green River facies distribution in the Uinta basin by Porter (1963) are available.

As important as the mapping of facies changes at Raven Ridge was recognition of the oil-stained and oil-saturated Green River sandstones. The entrapped hydrocarbons are primarily in the southern (basinward) extremities of the sandstone bodies or within more porous lenses of the generally low-permeability sandstones. Most of the oil saturation is in the middle and upper Green River beds (Fig. 2), although evidence of hydrocarbons can be recognized also in older units of the Green River at Raven Ridge.

By 1949, as a result of regional photogeologic studies and detailed surface mapping, an anticlinal nose had been detected and a stratigraphic framework favorable to the entrapment of hydrocarbons had been established in the Red Wash area. A summary of the results of this work is shown in Figure 3. Although only the major areas of lower Green River sandstone pinchout have been shown at Raven Ridge, similar positions for middle and upper Green River sandstones also exist along the outcrop. Projection of the potential Green River reservoir beds into the subsurface suggested that these sandstones could wedge out at a position near the axis of the surface anticlinal nose. However, no well control existed in the area to support this hypothesis.

Geophysical Program

Exploration in the late 1940s was still directed—at least in the Uinta basin—toward structural traps, the preferred target being closed anticlines. The earliest subsurface indication of a structural anomaly in the Red Wash area was furnished by a basinwide reconnaissance gravity survey in 1945. This survey also resulted in several promising leads that were evaluated before the Red Wash anomaly was

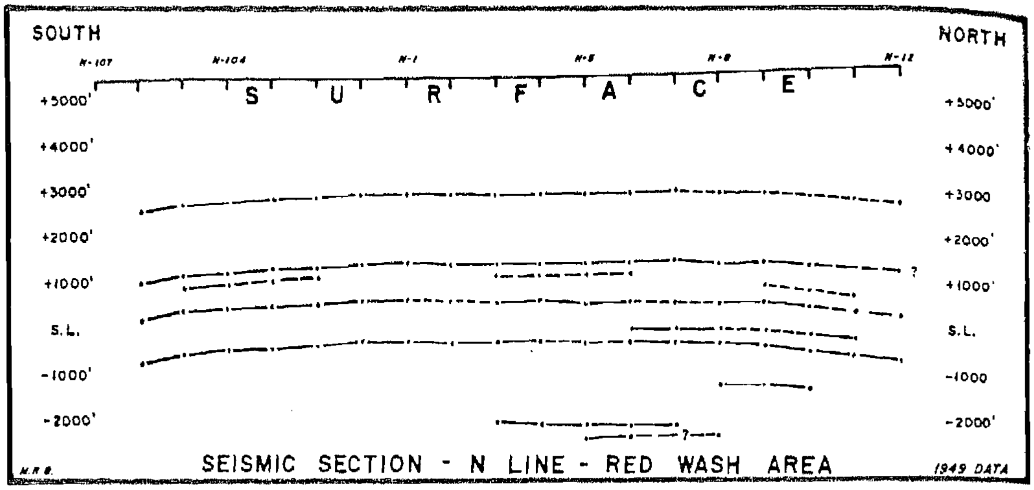


FIG. 5—Seismic depth section across most pronounced part of Red Wash structural nose. See Figure 7 for location.

tested. In 1949, however, additional gravity readings were recorded to complete the previously loose control grid. Interpretation of these data (Fig. 4) did not suggest a closed anticline but did indicate a broad, west-plunging structural nose similar to, but slightly south of, the feature mapped from surface and photogeologic work. Some geophysicists tended to discount the validity of this interpretation, attributing many inaccuracies to effects of the badlands topography of most of the Red Wash area. However, the existence of a subsurface structural anomaly was accepted eventually as a realistic possibility, and a seismic program designed to validate the existence of the Red Wash anomaly at depth and to determine the details of its configuration was begun.

Seismic work on the Red Wash prospect was done between August 26 and December 8, 1949. Rugged badlands topography slowed production and necessitated the extensive use of bulldozers. Continuous split profiles (2,800- and 3,120-ft or 855- and 950-m spreads) with two seismometers per group were shot throughout the area. Considerable experimentation was conducted with various filter responses and mixed records during the first days of the program. Eventually, however, the data were recorded straight with frequencies attenuated below 35 Hz and above 55 Hz. These parameters,

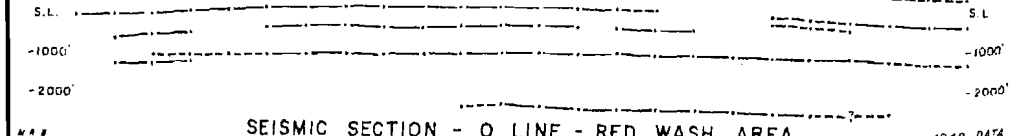


FIG. 6—Seismic depth section across Red Wash nose showing generally subtle nature of reversal. See Figure 7 for location.

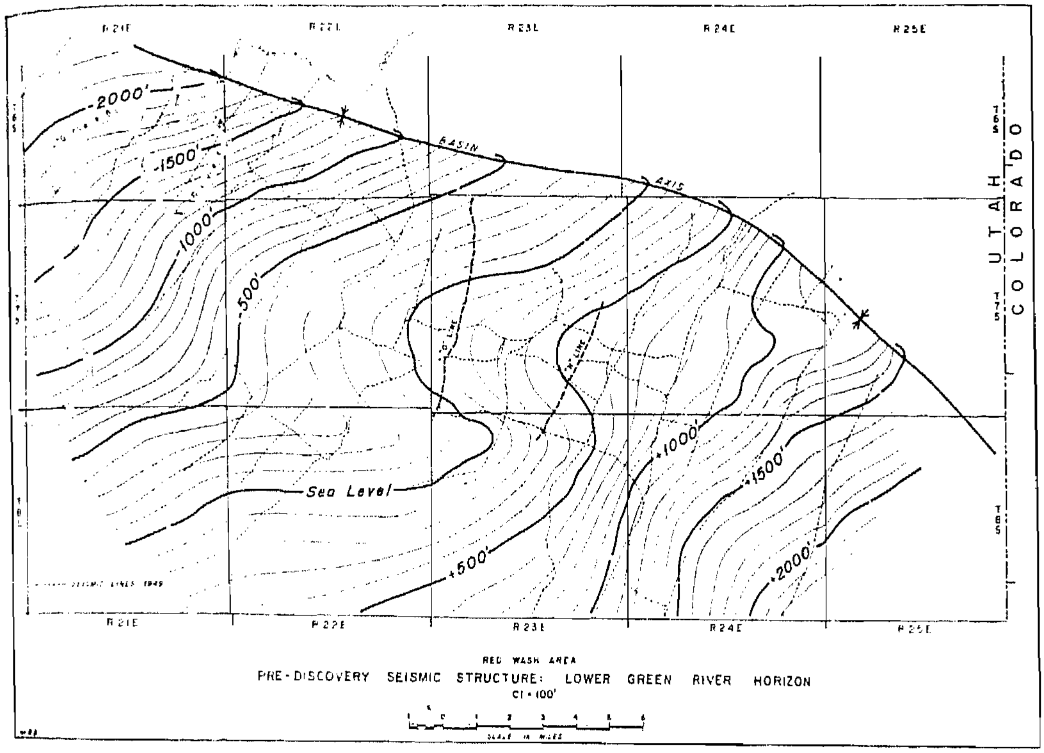


FIG. 7—Seismic structure map at a horizon within lower Green River Formation (1950).

although not permitting significant seismic character, generally resulted in usable data. Hole noise provided another problem during the early days of shooting. This effect was minimized by first cleaning the hole with a 10–15 lb charge, then loading 50–70 lb of powder and completely filling the 80-ft (25 m) holes with dry earth. Generally, clean usable records were obtained.

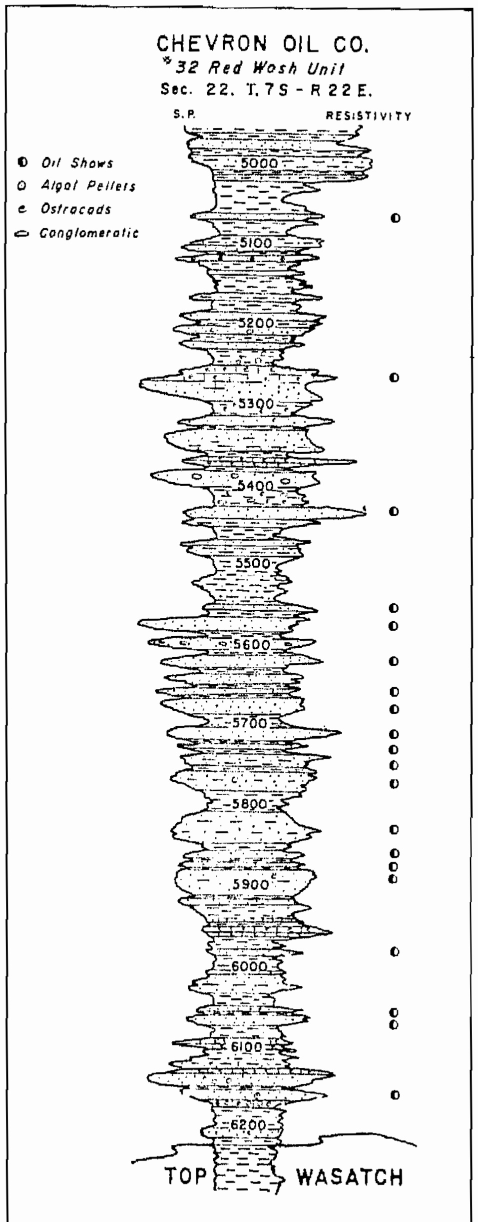
All data were computed to a flat 5,300-ft (1,615 m) datum plane for interpretational purposes. In addition, isolated parts of lines in exceptionally rough terrain were computed to a sloping plane and to the depth of shot in order to determine the effect of topography on the subsurface data. Corrected reflection times were converted to depth using the velocity function (instantaneous velocity = 11,312 ft/sec plus 0.383 Z at 5,150-ft datum), determined from well shooting at California Company No. 1 Gusher Unit, Sec. 35, T5S, R19E, Uintah County, Utah.[3]

[3] The so-called "shales" are in fact high in carbonate content, so the high velocity is due to composition, not induration.

Interpretation of the seismic data confirmed the existence of a west-plunging anticlinal nose within the lower Green River in the Red Wash area. Figures 5 and 6 show the broad, gentle nature of this feature as seen on 1949 seismic depth sections. The control permitted structural mapping of several Green River horizons and partial mapping of at least one deeper unit. Isochron studies based on the seismic data failed to show any positive thinning of beds suggestive of early structural growth along the anomaly. However, the data showed conclusively that the Red Wash anticlinal nose was a pronounced subsurface feature of considerably more magnitude than previously realized. The seismic structural configuration of the Red Wash area at a horizon within the lower Green River Formation is shown in Figure 7.

PREDISCOVERY CONCEPTS

Very limited Tertiary well control, all for an area considerably northwest of the Red Wash area, was available. Nevertheless, this information was integrated as effectively as possible into the total interpretation. Some land had been leased as early as the summer of 1949, and lease operating agreements were acquired on significantly larger acreage blocks. During July, August, and September of 1950 these agreements, which involve the majority of the Red Wash acreage, were executed.



TYPICAL LOG: *Red Wash Producing Section*

FIG. 8—Typical electric log and lithology of producing section at Red Wash field.

The prospect was visualized as a potential stratigraphic trap in deltaic Green River sandstone derived from the Uinta Mountains. These sandstones were known to pinch out southward into shales, marlstones, and carbonate rocks of the open lacustrine facies along Raven Ridge. Projection of these pinchout positions into the subsurface suggested that the facies change crossed the axis of the broad, west-plunging anticlinal nose mapped by seismograph. No evidence was seen to indicate Green River structural growth along this feature which might have affected distribution of detritus entering Eocene Lake Uinta. Therefore, the initial well was located along the structural crest and near the projected position of maximum sandstone pinchout in Sec. 26, T7S, R23E. There was no way of knowing if this projection was reasonable or even if the Green River sandstones extended for any distance into the subsurface. An additional incentive to locate the Red Wash wildcat test along the crest of the structural nose was the production established earlier at Roosevelt field in fractured Green River strata. The possibility that hydrocarbon-bearing shales along the structural crest would be more severely fractured due to tensile stresses seemed a valid assumption, and potentially fractured Green River oil shales constituted an intriguing additional objective.

PRESENT FIELD STATUS

The California Company No. 1 Red Wash Unit was spudded November 13, 1950, in Sec. 26, T7S, R23E, Uintah County, Utah, and completed February 2, 1951, at an initial production rate of 339 bbl of oil per day. Field development followed quickly and established hydrocarbon production in a complex network of lenticular Green River sandstones extending over parts of five townships. Chevron Oil Company (the present Red Wash Unit operator), Humble Oil & Refining Company, Belco Petroleum Corporation, Gulf Oil Corporation, and Pan American Petroleum Corporation control parts of the Red Wash field. During 1967 development drilling slowed considerably, and the limits of the accumulation may have been very nearly defined. Ultimate recoverable reserves are expected eventually to exceed 150 million bbl of oil.

Red Wash crude oil is a dark brown, paraffin-base crude ranging from 22 to 30° API gravity. Pour points grade from 85 to 105°F, the lower values being more common in older reservoir beds. Red Wash gas is over 95 per-

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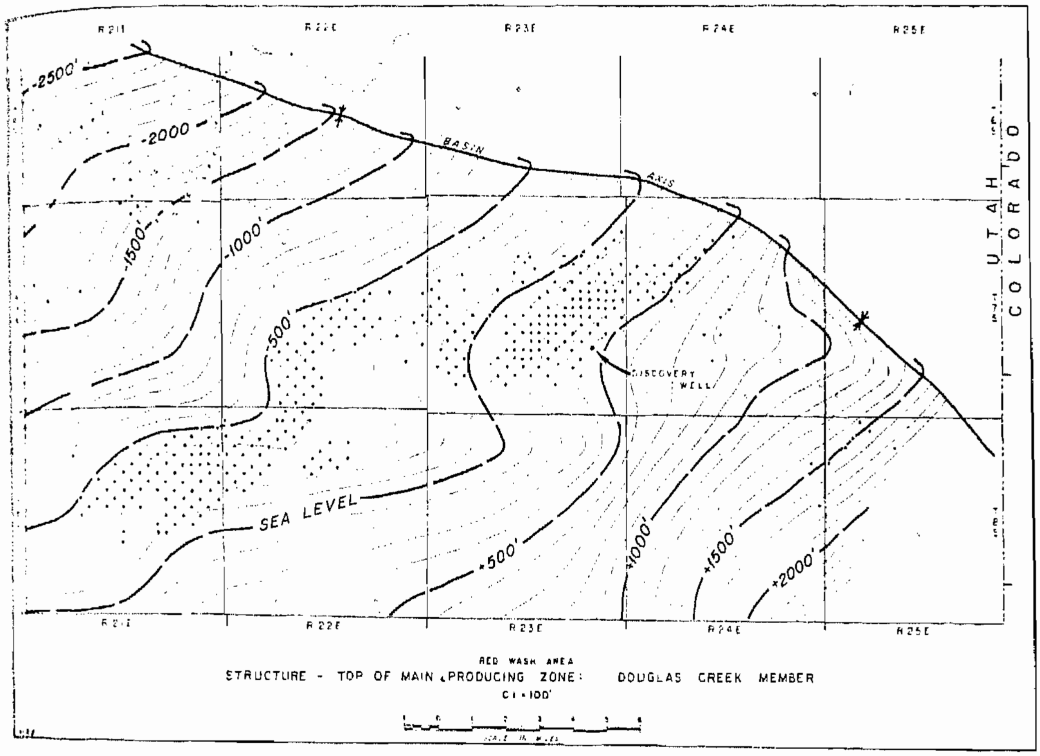

FIG. 9—Structure map of top of main producing zone of Douglas Creek Member, Red Wash area.

cent methane and has a specific gravity of approximately 0.595. Formation-water salinities vary widely, both vertically and areally, across the field. In general, the waters become more saline toward the southwest (basinward) and at greater depths. Measured resistivities range from 0.11 to 3.3 ohm-m at 68°F.

Most of the Red Wash sandstones produce by a gas-expansion mechanism, particularly the lenses which are most discontinuous. Some of the thicker, more persistent sandstone bodies seem to have at least a minor water drive. Gas-injection and waterflood programs have been instigated in recent years with encouraging results.

Red Wash crude oil is transported to Salt Lake City via a 10-in. pipeline originating at Rangely field. The high-pour point Green River oil is mixed with Weber-Mancos crude on a ratio determined by temperature and refinery requirements.

RESERVOIR ROCKS

Except for minor amounts of gas from the Uinta Formation, all of the production in the Red Wash area is from the Douglas Creek and overlying Garden Gulch Members of the lower Green River Formation present at Red Wash; they are conformable with the underlying Eocene Wasatch Formation in the field area. The aggregate thickness of these two members varies from approximately 850 ft (260 m) near the eastern limits of the field to almost 1,450 ft (440 m) near the southwest margin of production. Essentially, the Douglas Creek and Garden Gulch Members are composed of alternate beds of light gray, very fine- to fine-grained, calcareous sandstone and dark gray to dark brown, brittle shale (Fig. 8). Minor amounts of limestone, dolomite, siltstone, conglomerate, and ostracodal coquina are also present.

Individual producing sandstones vary in thickness from 3 to more than 30 ft (1–9 m). Generally, sandstone bodies toward the western margin of the field are thicker, more continuous, and more easily mapped. Toward the east the sandstones are thinner, more lenticular, and much more difficult to map as separate units. The total effective oil-producing section in some of the better wells approaches 150 ft (45 m).

In parts of the field the sandstones contain much silt- and clay-sized detritus. It is not uncommon to find fine-grained sandstones with silt-sized particles and lenses (⅛–¼ in. or 0.3–0.6 cm thick) of medium to coarse-grained quartz sandstone. The coarser elements in places appear in bands a few grains thick or as floating quartz grains in a fine-grained matrix. Sorting of the reservoir sandstones varies from poor to excellent and roundness from angular to subrounded. Calcite is the most common cementing agent, although dolomite, silica, and argillaceous material also may serve as bonds between grains. More than one cementing agent may be present in a single sample. Chert is the most common accessory mineral. Oolites, ostracod fragments, and algal(?) remnants are common constituents of many sandstone bodies.

Cored sandstones commonly show massive bedding, but thin intervals of low-angle cross-bedding have been found in every part of the field. A few internal dips up to 13° have been reported. Scour-and-fill features and very small-scale flow casts (sandstone lenses up to ½ in. or 1.3 cm thick completely encased in crenulated shale) are visible in many cores. "Pinch-and-swell" features are common in sequences of laminated sandstone and shale.

Porosity and permeability values may have a wide range in a single well, although averages for the entire field are remarkably consistent. From west to east across Red Wash field, the average porosity of the sandstone ranges from 13 to 15 percent and average permeability ranges from 75 to 125 md. Such figures, however, are misleading. An individual sandstone body may have several "tight" streaks in an otherwise porous reservoir, or it may have good porosity but insufficient permeability to produce hydrocarbons. Fractures do not seem to be significant to reservoir capacity of the sandstones, and there is no production from fractured Green River shales.

Geologic Structure

The dominant structural feature at Red Wash field is the broad, west-plunging anticlinal nose trending through T7S, R22–23E (Fig. 9). Comparison of this map, based on data from dense well control, with the 1949 seismic structure map (Fig. 7) indicates that the pre-discovery interpretation was remarkably accu-

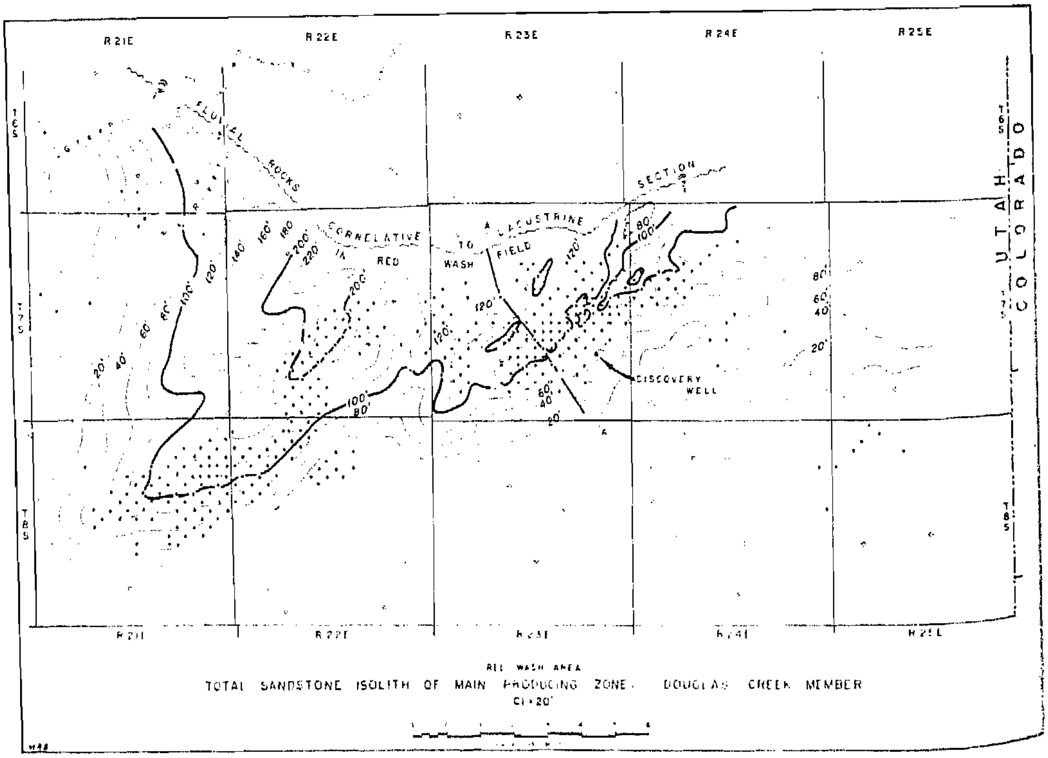

Fig. 10—Total-sandstone isolith of main producing zone of Douglas Creek Member, Red Wash area.

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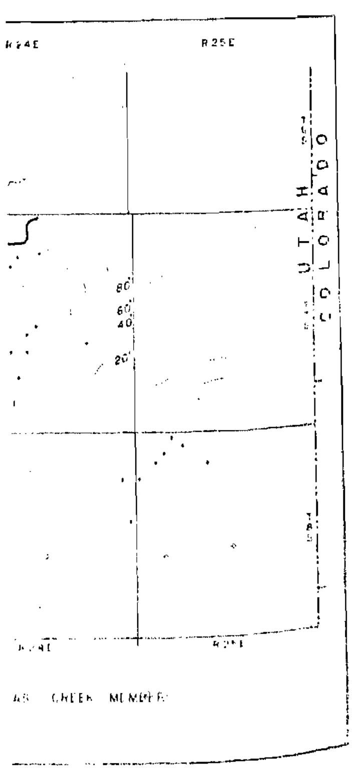

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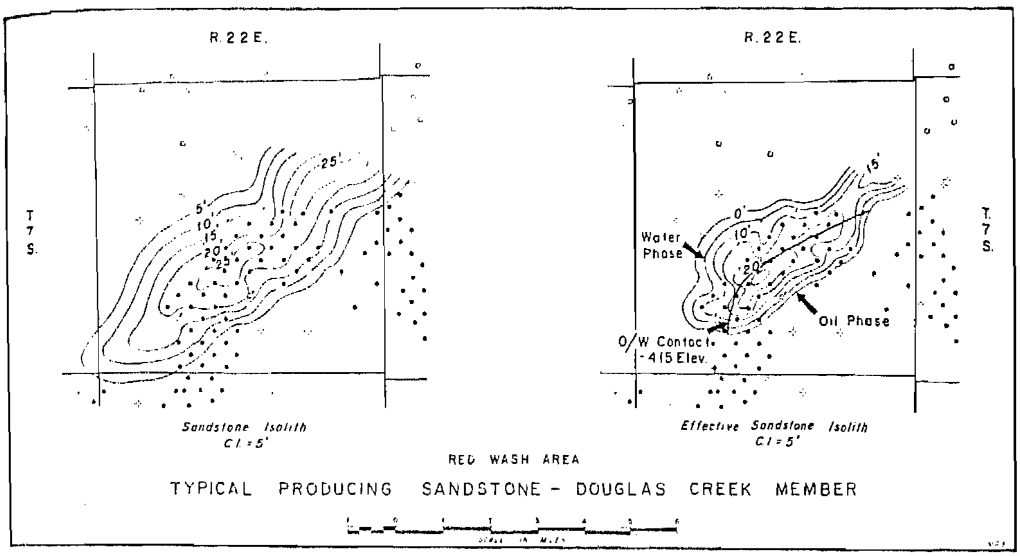

FIG. 11—Sandstone isolith and effective-sandstone isolith maps showing geometry, reservoir distribution, and fluid content of a single Douglas Creek sandstone in Red Wash field.

rate. Early development drilling was confined to positions along the axis of the structural nose or along the north flank of this feature. The subparallel Red Wash syncline on the south discouraged drilling in that direction. Eventually, however, successful development of the western part of Red Wash, where the reservoirs are more continuous and more easily mapped, led to a southwesterly expansion of the field and extended production across the syncline.

Surface mapping of beds of the Uinta Formation, based on high-quality, low-altitude photographs not available during the 1940s, indicates a structural picture which conforms closely to the configuration now recognized at lower Green River depths. Regional structural studies suggest that the Eocene Duchesne River Formation also has structural aspects very similar to those of the underlying Uinta and Green River Formations. Isopach and sandstone-distribution maps do not suggest the existence of any significant structural features at Red Wash during deposition of the Douglas Creek and Garden Gulch Members. From this evidence, plus seismic evidence indicating the absence of thinning, a post-Duchesne River age (late Eocene–early Oligocene?) is postulated for the formation of the Red Wash anticlinal nose and the associated syncline.

Trap Geometry

Certain shale beds and units which have a characteristic resistivity curve on electric logs are remarkably persistent throughout Red Wash field, and it seems reasonable to interpret them as time markers. Reservoir mapping involves the tracing of individual sandstone units or very small intervals of sandstone within the framework of these electric-log markers. Mapping of thicker intervals is useful to understanding gross reservoir distribution (Fig. 10) and geologic history. However, such maps do not always clearly delineate the hydrocarbon traps.

Production histories, production tests, drill-stem tests, core analyses, electrical and acoustical logs, sample descriptions, core examinations, and mud logs are used to define effective criteria (ability of the rock to produce oil, gas, or water) in different parts of the field and to determine the fluid content of each individual reservoir. Figure 11 shows the geometry, effective reservoir distribution, and fluid content of a single Douglas Creek sandstone. It is apparent that structure controls the distribution of hydrocarbons within the limits of the reservoir sandstone. The producing section at Red Wash field is composed of many similar, discrete sandstone bodies, each forming an individual stratigraphic trap but all interwoven into a vast, complicated network of separate reservoirs.

Geologic History of Lower Green River

The lower Green River Formation in the Red Wash area was deposited in very shallow water along the northern margin of Eocene

Lake Uinta. Detritus was derived from the Uinta Mountains, on the north, which were probably breached, at least locally, to Precambrian quartzites. The sediment was carried to the shore by slow-moving streams meandering across a broad floodplain. Much of the coarser grained detritus probably was deposited in these streams as point bars along the bends of meanders, leaving a predominantly very fine- to fine-grained stream load. Most of the Green River floodplain has been destroyed by erosion, but a few wells north of Red Wash field have penetrated fluvial facies equivalent in age to the producing section (Fig. 12). Fluvial rocks which contain terrestrial fossil remains (Kay, 1957, p. 110) and are believed to be lower Green River equivalents have been described in outcrops north of the present basin axis.

Where the detritus-loaded streams entered Lake Uinta, a delta was formed. This lacustrine delta apparently continued to build for several million years, the estimated time it took the lower Green River section at Red Wash to form. Deposition was interrupted by intermittent subsidence; with each period of subsidence, the lake encroached farther upon the land. Individual sandstones were built outward into the shallow water predominantly as topset beds. The distribution of these sandstones was controlled by many factors. Depositional slope, variations in available sediment, offshore currents, wave action, and sandstone flowage on unconsolidated clay-sized sediments probably all contributed, in varying degrees, to the geometric shapes of the individual sandstone bodies. The changing lake level caused the sands to be deposited in a disordered manner over the zone of fluctuation. The end result was an extremely complex network of deltaic sandstones.

The effects of accumulating younger sediments forced hydrocarbons from the enclosing and basinward equivalent shales into the sandstone reservoirs. I favor an early migration (pre-Uinta) for the hydrocarbons. Thus, the northerly trapping mechanism, before the formation of the present structural configuration of the basin, was a decrease in reservoir capacity of individual sandstones caused by the facies change from lacustrine to floodplain deposits.

The last event in formation of the present subsurface configuration at Red Wash field was structural. After deposition of the Duchesne River Formation, the Red Wash anticlinal nose and the adjoining syncline on the south were formed, probably in conjunction with basinwide tilting and formation of the present Uinta basin syncline. This movement reoriented the lower Green River sandstones into their present structural positions and marked the final step in formation of the Red Wash stratigraphic trap.

Conclusions

Discovery of Red Wash field was the direct result of a well-integrated geological and geophysical exploration program in the Uinta basin. A subtle structural nose in the surface rocks of the Eocene Uinta Formation was detected by photogeologic methods. Subsequent

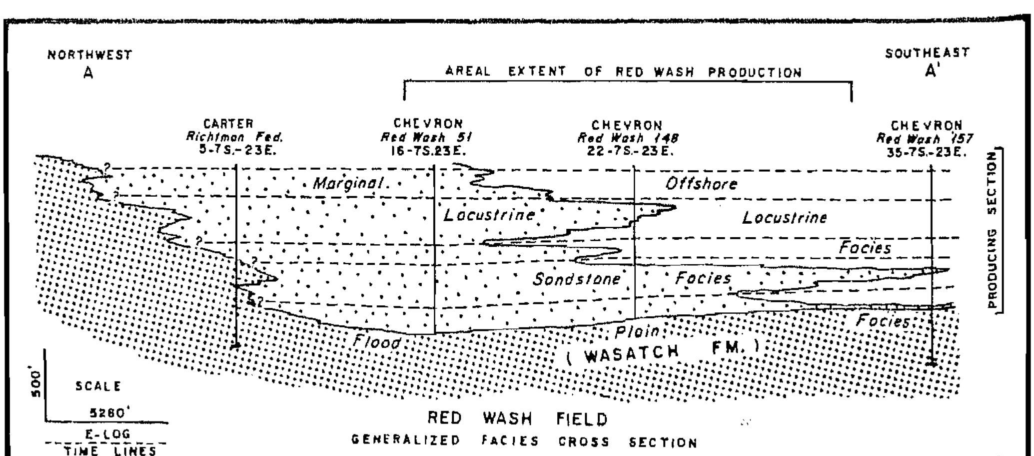

FIG. 12—Generalized stratigraphic section across Red Wash area showing distribution of facies changes. See Figure 10 for location.

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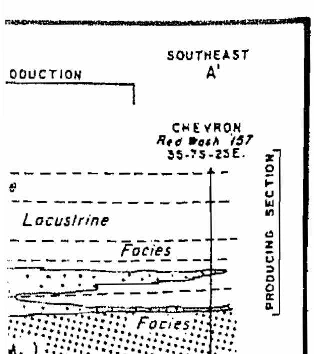

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field mapping confirmed the existence of this feature and clarified its structural configuration. Detailed stratigraphic studies along the Raven Ridge outcrop indicated favorable potential for stratigraphic oil entrapment in sandstone lenses of the Green River Formation. Gravity studies supported the existence of the structural nose at depth, and a detailed seismic program confirmed the presence of the anomaly and outlined its extent and configuration. The very limited well control in the basin was integrated into the interpretation.

Time has proved the original concepts in the area to be remarkably accurate. Red Wash field now is recognized as a lucustrine delta formed in the Douglas Creek and Garden Gulch Members of the Green River Formation. Detritus, which was deposited and modified into an intricate pattern of individual sandstone bodies, was derived from the Uinta Mountains on the north. Structural features in the area were formed at a considerably later time and served to localize oil and gas in the updip parts of individual sandstones.

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