

STRATIGRAPHY OF BASAL SANDSTONES
IN THE GREEN RIVER FORMATION,
NORTHEAST PICEANCE BASIN,
RIO BLANCO COUNTY, COLORADO

by

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A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Geology).

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ABSTRACT

Stratigraphy and sedimentation of basal members (Douglas Creek and Anvil Points) of the Green River Formation and adjacent strata were investigated. The Anvil Points Member and upper Wasatch Formation were studied at outcrops on the northeast rim of Piceance basin; the subsurface Douglas Creek and Garden Gulch members and Wasatch Formation, in Piceance Creek and South Piceance Creek fields, were investigated by acquisition of mechanical and sample log data.

The exposed Wasatch Formation is characterized by floodplain mudstones and point bar channel sandstones. The Anvil Points Member is characterized by two facies: sandstone and siltstone. The sandstone facies is composed of intercalated fluvial and lacustrine shoreline deposits and represents a transitional environment at the shoreline of Lake Uinta. The siltstone facies contains thinly interbedded fine-grained clastics and was produced by prolonged off-shore sedimentation.

The Wasatch in the subsurface has a westward increase in paludal and lacustrine deposits, especially in the upper 900 feet of the formation. The Douglas Creek Member trends northwestward across the study area and thickens northeast-

ward from a feather edge in the western part of Piceance Creek field. The Douglas Creek was deposited at the shoreline during the initial transgression of Lake Uinta; its upper contact shows a northeastward time transgression, and a similar time relationship has been inferred for the lower contact.

The northeast thickening of the Douglas Creek conforms to the northward thickening of the sandstone facies of the Anvil Points and the two units are believed to be equivalent. Increased thickening of this facies reflects a stillstand which is recorded in the subsurface by the time equivalent Garden Gulch Member. Deposition of the Douglas Creek-Anvil Points-Garden Gulch sequence was superceded by deep-water oil shale deposition when the lake was extended past the boundaries of the present structural basin.

Both gas and oil occur throughout the Tertiary section. Hydrocarbons have accumulated locally in isolated fracture zones in the Green River shales and in lenticular sandstones in the Wasatch. Gas and some oil is trapped stratigraphically in the continuous reservoir of the Douglas Creek. The high pour-point oil contained in these rocks is characteristic of a fresh water genesis and is indigenous to the various members and zones which contain it.

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INTRODUCTION

Orientation and Purpose

Lake deposits of Tertiary basins in the Colorado-Utah-Wyoming area have long been noted for their vast deposits of hydrocarbons. In addition to the famous high-yield oil shales of the Green River Formation, there are extensive occurrences of hydrocarbons in other forms: gas, oil, oil-impregnated sandstones and solid hydrocarbons (gilsonite, werlitzerite, etc.). The highly productive 200-million barrel Redwash field in Uinta basin is an illustration of the petroleum potential of these basins.

Although several fields have been established in the northern part of Piceance Basin, much of this Tertiary basin remains relatively unexplored. Oil and gas fields in this basin show that the occurrence of petroleum is closely related to the stratigraphy of the Tertiary section. Stratigraphy of the basal sandstone members of the Green River is particularly pertinent to petroleum exploration because these members contain the reservoirs for Tertiary hydrocarbons.

The purpose of this investigation, therefore, is to study the stratigraphy by means of correlation and

environmental interpretation in order to interpret the depositional history of the basal members, the Anvil Points and Douglas Creek, of the Green River Formation. The study involved two phases of investigation: surface mapping and section measurement of the Anvil Points Member and upper Wasatch Formation at the northeast rim of the basin and subsurface stratigraphic analysis of the Douglas Creek Member and adjacent strata in Piceance Creek and South Piceance Creek fields. Synthesis of the two phases of study has resulted in establishing facies, depositional modes and trends, and time-stratigraphic relationships between the Douglas Creek and Anvil Points members and with adjacent Garden Gulch Member and Wasatch Formation. A knowledge of these depositional parameters may help direct attention to those regions of the basin which are more favorable for stratigraphic accumulation of petroleum.

Location, Terrain and Accessibility

Surface investigation was concentrated along a 35-mile north-south-trending strip at the northeast rim of Piceance basin extending from Piceance Creek in the south to the northern boundary of Rio Blanco County in the north (figure 2 and pl. 1). Mapping and section measurement were limited to the marginal escarpment, a topographic expression of



Figure 1. View of valley between Grand Hogback and marginal escarpment; looking south from Fourteen Mile Creek. (Kmv = Mesaverde Group, Tw = Wasatch Formation, Tgr = Green River Formation)

basinward-dipping Green River strata (fig. 1). The area contains moderate topographic relief, ranging from a few hundred feet in the south to about 1000 feet north of White River. Rock exposure is variable and is largely controlled by the angle of exposure to the sun: southern exposure generally produces cliffs barren of vegetation, whereas north-facing slopes normally support heavy vegetation and soils. Two main highways, Colorado route 13 and Strawberry Creek road, parallel the basin rim and excellent accessibility to the escarpment is afforded by numerous ranch roads leading off the main highways.

Previous Work

The Green River and Wasatch Formations were originally mapped by Hayden (1869). Sears and Bradley (1924) worked out the basic stratigraphy and established the fluvial origin for the Wasatch and a lacustrine genesis for the Green River Formation. Bradley (1925, 1926, 1929, 1931, 1948, 1964) has continued studies of the Green River Formation throughout the Tertiary basins.

Geologic investigations of Piceance basin Tertiary rocks have been directed almost exclusively towards the Green River oil shales. The U.S. Geological Survey and U.S. Bureau of Mines have published numerous reports on oil shale

resources of the basin. Donnell (1961a) has mapped and described the Tertiary strata of the northern half of the basin and has reported briefly on the stratigraphy of the Wasatch Formation (1961b, 1969). Merriam (1954) investigated the petroleum potential of the basin and Cline (1957) studied the stratigraphy of the Douglas Creek Member in the northern portion of the basin.

Several short reports describe the structure and stratigraphy of Piceance Creek dome. A map of the surface structure of the dome was published by Kramer (1939). Duncan and Belser (1950) described the stratigraphic relationship of members of the Green River Formation between Piceance Creek field and the outcrop. Brief resumes (Thurman, 1961; Anon., 1961; Ritzma, 1962) describe the geology and development history of both Piceance Creek and south Piceance Creek fields.

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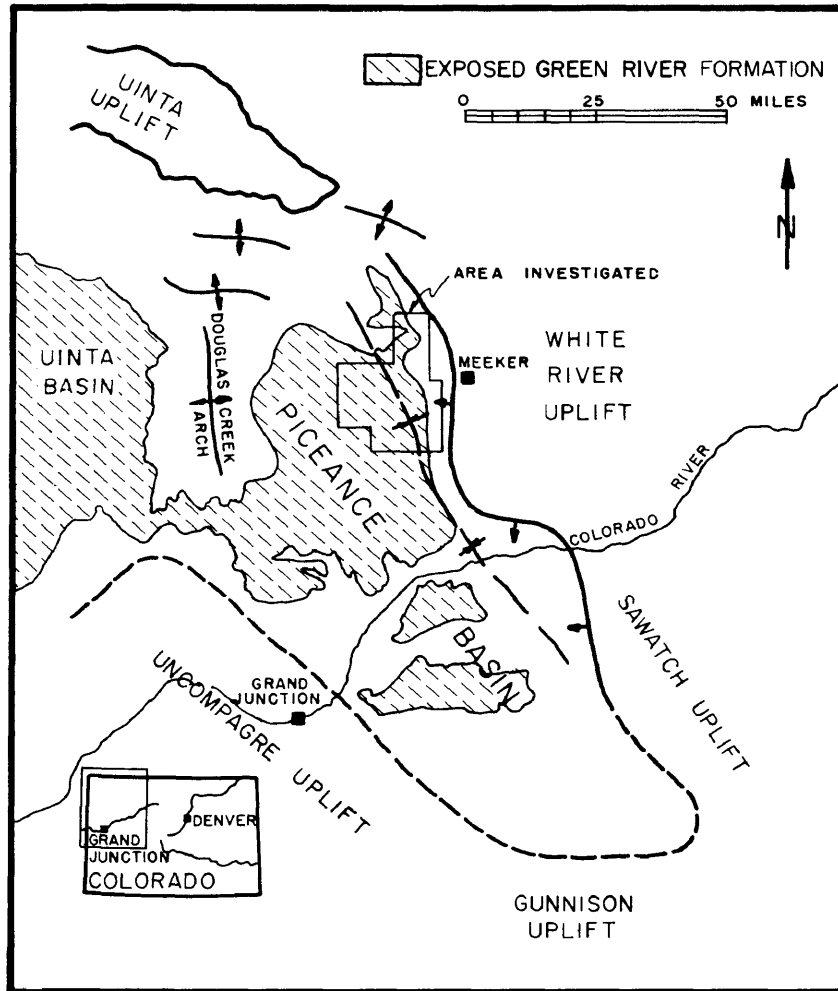


Figure 2. Index map and regional tectonic setting of Piceance basin.

REGIONAL GEOLOGIC SETTING

The Piceance basin is a broad, slightly elongate asymmetric structural basin. Tectonic events associated with the Laramide orogeny initiated subsidence in latest Cretaceous or early Tertiary time. The basin is defined by its surrounding positive tectonic elements (fig. 2): White River uplift on the east, Gunnison and Uncompagne uplifts on the south and southwest, and crustal upwarping associated with the Uinta uplift on the north. The Douglas Creek arch separated the Piceance basin from the Uinta basin during earlier phases of Piceance basin development. The arch was subsequently breached during middle Eocene to form one large basin comprising the two.

The basin is decidedly asymmetric due to the dominating effect of White River uplift relative to the other surrounding positive elements. Exceptionally high structural relief, in excess of 15,000 feet (Haun, 1966), occurs across the Grand Hogback monocline at the eastern edge of the basin. The structural axis, as developed at the base of the Tertiary strata, trends northwestward near the eastern margin.

Eighteen thousand feet of Paleozoic and Mesozoic rocks underlie the Tertiary sequence in the Piceance basin (Warner,

1959, figs. 17 and 18). The deepest drilling to date (19,702 feet) has penetrated the Permian Weber Sandstone. The only pre-Tertiary rocks exposed in the basin are the upper beds of the Cretaceous Mesaverde Formation which crop out at the basin margin.

The Tertiary system is represented by three formations: Ohio Creek Conglomerate, Wasatch Formation, and Green River Formation. The Ohio Creek Conglomerate is a thin conglomeratic sandstone which conformably overlies the Mesaverde and has been tentatively assigned to the Paleocene (Donnell, 1961, p. 844). The Wasatch Formation consists of a thick sequence of fluvial deposits which conformably overlie the Ohio Creek Conglomerate. The Wasatch has been dated as Paleocene at its base and Early Eocene near its top (Donnell, 1969). The Green River Formation is approximately 3,000 feet of lacustrine rocks which were deposited in the large and long-lived Lake Uinta during middle Eocene time. Bradley (1931) subdivided the formation into four members: Douglas Creek at the base, consisting of sandstones, shales and limestones; Garden Gulch, containing shales of low organic content; Parachute Creek, dominated by oil shales; and Evacuation Creek, the uppermost member consisting of sandstones and shales. Donnell (1961a) added a fifth member, the Anvil Points, which is confined to the eastern rim of

the basin and is stratigraphically equivalent to the Douglas Creek, Garden Gulch, and the lower portion of the Parachute Creek members.

STRUCTURAL GEOLOGY

The surface structure of the area is relatively uncomplicated and is dominated by the Grand Hogback monocline and Danforth Hills anticline which define the eastward limit of the basin (pl. 1). The north-trending Grand Hogback monocline is offset from the northwest-trending Danforth Hills anticline to form an intervening westward-plunging syncline.

Strata at the base of the Tertiary dip steeply westward and are locally vertical, but the dip decreases markedly toward the basin. Basal Green River beds dip at a maximum of 28° in the south and about 15° in the north.

The dominant structural element in the subsurface is Piceance Creek dome, the gas producing structure of Piceance Creek field. As contoured on the orange marker, a stratigraphic datum near the base of the Green River Formation, this structure is a symmetrical, unfaulted, northwest trending, doubly plunging anticline with 640 feet of structural closure. The uniform pattern and spacing exhibited by the contoured orange marker (pl. 1) obscures the complex change in geometry and axial position with depth caused by thinning of the Green River and Wasatch formations. As

mapped on the surface (Kramer, 1939), the structure has 200 feet of closure and a pronounced asymmetric steepening of the southwest limb. Moreover, the axial trend of the structure on the orange marker, 2,600 feet below the surface structure, migrates $1\frac{1}{2}$ miles to the southwest and its apex shifts $3\frac{1}{2}$ miles to the west. Maximum closure is developed at the orange marker; above this horizon, closure is diminished by the lowered dip of the northeast limb, and below, by the leveling of the southwest limb.

South Piceance Creek field is located on a east-west trending doubly plunging syncline on the south of Piceance Creek dome.

SURFACE STRATIGRAPHY

Wasatch Formation

The non-resistant mudstones of the Wasatch form a prominent valley extending continuously along the margin of Piceance basin, bounded on the west by the Green River escarpment and on the east by the upturned sandstones of the Mesaverde Formation (the Grand Hogback) (Pl. 1). The Wasatch maintains a rather uniform thickness throughout the study area; a thickness of 3,400 feet was measured by Gale (1910) at the extreme southern end near the head of Piceance Creek, and Bradley (1931) reports a thickness of 3,500 feet at Price Creek, a few miles north of the northern boundary of the study area.

The most conspicuous aspects of the Wasatch Formation is its bright coloration of mudstones. The terrain underlain by this lithology is typically imparted with shades of red. Although reds dominate the soils, fresh surfaces of mudstones show that the red coloration is in fact a minor constituent of the variegated mudstones which are mottled and streaked with a wide range of colors: dull and moderate reds, purple, ochre, greys, and browns. The mudstones represent a very poorly sorted lithology, displaying a wide

range of grain sizes, dominated by clay but containing an admixture of silts and minor amounts of fine sand.

Good exposures of the Wasatch in many localities display a banded appearance produced by beds and elongate lenses of non-resistant siltstones and fine-grained sandstones. These siltstones and sandstones range from several inches to a few feet in thickness and are distinct from the thicker more prominent irregularly bedded sandstone lenses. Their mode of weathering causes them to blend with the mudstone, giving little or no topographic expression. These massive and unstructured quartz siltstones and sandstones range from clean and well sorted to poorly sorted, with a high percentage of interstitial clay. In general, the finer grained siltstones show a poorer degree of sorting.

Lenses of irregularly bedded and cross-bedded sandstones crop out sporadically through the entire thickness of the Wasatch. These sandstones comprise a variable percentage of the total Wasatch section. Of the upper one-third of the Wasatch observed during this study, the largest number of sandstones is present in the Powell Park region where they occupy as much as 39 percent of the section (MS 12, pl. 2). North and south of this locality, they are relatively sparse and make up only a minor part of the section.

The lenticular sandstones range from a few feet to a few tens of feet in thickness and from a few hundred feet to several thousand feet in lateral extent. They are typically irregularly bedded, and bedding structure is produced both by cross-stratification and by differential compaction between the sandstones and interbedded and surrounding relatively compressible mudstones.

A general description of these lithologically variable sandstones is as follows: limonite stained, friable, fine-grained, sub-rounded to sub-angular, poorly sorted, silty, commonly conglomeratic, slightly porous, slightly calcareous, quartz sandstone. Mineralogically, the sand fraction is almost entirely composed of varying amounts of quartz and chert, about 70 to 85 percent quartz and 10 to 25 percent chert. A major part of the chert is white, but small amounts of black chert give the rocks a speckled appearance; this is characteristic of many sandstones, both in the Wasatch and in the Green River formations. Feldspars form a minor component (less than five percent) and include orthoclase, microcline and, in some samples, plagioclase. Clay is a ubiquitous constituent, present in various quantities and destroying much of the initial porosity. The clays probably are derived secondarily, subsequent to burial, from adjacent mudstones and interbeds of clay

within the sandstone units. The presence of some grain support by the clay, however, indicates that at least some of the clay was deposited with the sand. It is also conceivable that the interstitial clay was emplaced penecontemporaneously with sand deposition. Interstitial water percolating through the sands would have contained clay which would have been filtered out and trapped in the sand interstices. Limonite is present in the vast majority of these sandstones and accounts for their rust brown color. In a few cases the limonite is present in sufficient quantity to act as a binding agent, reducing the friability of the grains. Calcite is rather uncommon in these sandstones; some units contain a small amount of calcite, but not normally enough to indurate the rock.

Grain size distribution is extremely variable. Beds and laminae normally display poor sorting and in most samples grain sizes range from silt through medium and coarse sand. Cobbles and pebbles of well-rounded red and black chert are common in most sandstones and are present as isolated interclasts or as conglomeratic concentrations in zones or beds. In some outcrops a crude sense of grading can be observed in the vertical size distribution. In such cases, a poorly sorted sequence may grade upward from a coarse conglomeratic sandstone into a fine, poorly sorted

sandstone over an interval of a few feet. This sequence may be truncated and superimposed by another similar sequence. Siltstones, claystones, and mudstones are abundant within the dominantly sandstone units. The finer lithologies occur variously as interbeds, lenses or tongues extending from the surrounding lithologies.

The geometry of, and the sedimentary structures within the sandstones suggest that they represent point bar channel deposits. The above mentioned graded bedding is typical of the lateral accretion of point bar deposits. Scour and fill is a common feature and scour channels are present within the sandstone units and in places at the base of the units. Cross-bedding occurs both as tangential-wedge sets and as trough types. Ripple marks are not as common as in Green River sandstones, but are present in some outcrops as symmetrical ripples, climbing ripples, and sets of ripple cross-beds. Clay galls are plentiful. Carbonaceous material is incorporated in the form of small granules of coally matter and is most commonly preserved in the coarser sandstones.

Green River Formation

The Green River Formation crops out at the eastern rim of the basin as a series of prominent sandstones and shales.

Only the lower portion of the basal member, the Anvil Points Member of Donnell (1961), is represented on the basin's marginal escarpment. Anvil Points is extended northward in this study and includes those rocks north of White River on the east side of the Grey Hills escarpment (pl. 1).

The Anvil Points is characterized by a high sand and silt content. Unlike its equivalent members, Douglas Creek and Garden Gulch, sandstones and siltstones are ubiquitously present, not only as discrete units, but as units interbedded and interlaminated with the shales and limestones. This member, which is present exclusively on the eastern edge of the basin adjacent to the west flank of the White River uplift, is the result of coarse clastic deposition produced by the continued tectonic activity of the uplift.

The contact of the Wasatch Formation with the overlying Green River Formation is traditionally placed where the red and varicolored mudstones below meet the relatively thick and regularly bedded sandstones and somber colored shales above. The boundary is conformable, representing a change in sedimentation from fluvatile to dominantly lacustrine. Owing to the transitional environment which produced the Anvil Points, its lower boundary is correspondingly gradational and indistinct. In the northern part of the area, interfingering and migration of its stratigraphic

position is demonstrated by its relationship to a mapped datum horizon (pl. 2). At Powell Park the lower contact loses identity due to the numerous channel sandstones contained in the Wasatch and in the Anvil Points. The contact has been tentatively placed at the top of the uppermost variegated mudstone. South of Powell Park, the contact is more distinct and is placed at an abrupt lithologic break between the variegated mudstones and regularly bedded sandstones.

A total thickness of the Anvil Points was not established in this study. Previous workers have shown that this member is 1600 feet thick at Piceance Creek, 1350 feet at the White River (Donnell, 1961a, pl. 53), and in excess of 1175 feet a few miles north of Deep Channel Creek (Bradley, 1931, pl. 8).

The present study indicates that the Anvil Points contains two facies: sandstone and siltstone. As will be demonstrated below, the sandstone and the siltstone facies are believed to represent the Douglas Creek and Garden Gulch members respectively. The distribution of these facies is depicted in plates 1 and 2. The sandstone facies is the more common of the two, extending throughout the study area, and in most of the area accounting for the entire measured thickness of Anvil Points. The siltstone facies is present only in the southern ten miles of the area where it overlies and interfingers northward with the thinner portion of

the sandstone facies. The sandstone facies is thinnest at the southern boundary of the study area and thickens northward at the expense of the siltstone facies.

Oil staining and impregnation is present in several sandstones south of the White River and is not limited to a particular facies or horizon. Oil staining is present in both facies, and ranges in stratigraphic position from the lowermost Green River sandstones to approximately 800 feet stratigraphically above the formation contact (pl. 2). Oil-impregnated sandstones are present sporadically from about three miles south of the White River to Piceance Creek, but apparently are most common in the area a few miles north of Thirteen Mile Creek (pl. 1). The sandstones that host the oil vary from thin stringers to units ten or more feet thick, and vary in saturation from slightly stained to completely saturated with dark brown viscous asphalt.

Sandstone Facies

The sandstone facies is composed of sandstones, silty shales and mudstones, and minor limestones. These rocks are exposed as relatively prominent discontinuous sandstone ledges with intervening shale slopes. The sandstones crop out as massive and irregularly weathered beds and lenses, locally developing a flaggy and blocky texture. The light gray and tan sandstones are typically discolored with

streaks and patches of heavy limonite stain. The shales and mudstones, generally shades of brown and gray, weather to light drab soils. Only locally do the sandstones dominate the lithologies, ranging from 72 percent at the White River to about 40 percent on the south and north.

Sedimentation in this facies has been influenced by both fluvial and lacustrine processes. In this study the sandstone units have been subdivided into two categories: channel sandstones and shoreline sandstones.

Channel sandstones are best developed in the Powell Park area where they are the dominant type of sandstone body and produce thick, widespread units. Outside this area they become less abundant and are distributed among the shoreline sandstones. The channel sandstones of the Green River show a differing sequence from those in the Wasatch. Whereas the coarser bed-load zone seems to dominate sandstones in the Wasatch, the upper fine-grained zones of the point bar model (Visher, 1965) prevail in Green River deposits.

The channel sandstones are generally fine-grained, ranging from silt to medium-grained sand. Conglomeratic zones are present, but not abundant. These conglomerates are present at the base of some sandstone units, but are not recorded in many of the sequences. These sandstones

show a mineralogy similar to those of the Wasatch: they are composed principally of quartz and chert with minor amounts of feldspars. Sorting is generally moderate to good; locally sorting is poor due to interstitial silts and clays. Packing is extremely tight; even the well-sorted sandstones have grains closely juxtaposed, giving a maximum number of grains for a given volume. Owing to this closed texture, porosities are very low. Calcite content is variable within and among individual units, with concentration ranging from a trace to heavy induration. Calcite in these sandstones is of secondary origin, and it is presumably controlled, at least in part, by permeability and available pore space. Limonite is common in most of the deposits; it too is secondary and is concentrated mostly on the weathered surfaces.

The well-developed channel sandstones are roughly tabular in shape. Many of the basal contacts are quite flat, maintaining stratigraphic position for considerable distances. Where a basal conglomerate is present the lower boundary is abrupt, otherwise the lower contact may grade up from siltstones to fine-grained sandstones. The upper contact is irregular and transitionally interbedded with the overlying fine-grained deposits. These deposits generally lack a characteristic vertical lithologic trend.

Variation from silt to medium-grained sand is present throughout the deposits as zones and beds. Shales and mudstones are also incorporated throughout the sequence in irregularly shaped lenses, tongues, and stringers.

Sedimentary structures preserved in these sandstones include most of those noted in the Wasatch sandstones. Bedding is massive, flat bedded, laminated or cross-bedded. Cross-bedding is of trough, tangential-wedge and cross-ripple types. Whereas trough cross-beds seem to dominate in the Wasatch sandstones, tangential-wedge is more common in Green River deposits. Clay galls, limonite nodules, and carbon granules and fibers are common. Burrow structures are infrequently represented.

Fine-grained lithologies associated with these sandstones are chiefly sandy and silty mudstones containing small lenses and stringers of sandstones and siltstones. Most mudstones are presumably flood plain sediments, however, restricted fine-grained channel-fill sequences are also associated with the point bar channels. These sequences are interbedded mudstones and siltstones, similar in appearance to the flood plain sequence. Good exposures of channel-fill reveal their small lateral extent and their bedding draped to conform to the shape of the confining channel.

The channel deposits are a westward interfingering of

continued Wasatch-type sedimentation contemporaneous with Green River deposition. In the Powell Park area a wedge of these rocks extends into the transitional lacustrine sequence and has been preserved. Throughout most of the region, however, the fluviatile sequence has been lost by post-Eocene erosion and only remnants of this facies remain.

The shoreline sandstones form relatively thin tabular bodies, normally less than ten feet thick, and typically only a few feet thick. These sandstones are light gray, tan and orange, fine grained, moderately to well sorted, and consist of quartz and chert. Good initial porosity is developed by their characteristic loose packing, but the porosity is commonly destroyed by variable amounts of calcite cementation. Calcite contained in most of the sandstones is secondary, but thin sections of some reveal that primary calcite is developed as druse and micrite. Limonite is also primary in a few samples. Limonite is commonly concentrated in blebs and laminae as encrustations on oolites, ostracods and sand grains.

The shoreline sandstones are variously massive, thin-bedded, laminated, cross-bedded, and ripple-marked. Cross-bedding is generally low-angle and tangential-wedge. Shale is commonly interbedded and interlaminated with the sandstones. These shales are generally more evenly bedded, in

contrast to the irregular lenses and tongues of the channel sandstones. Many of the sandstones contain ostracods. The ostracods are most commonly fragmented and generally in low concentrations in the sandstones, but are highly concentrated in limestones associated with the sandstones. Oolites are also associated with the sandstones in some localities. Presumably both the oolites and ostracods are detrital and are from some nearby source. In some localities burrow structures are preserved in the sandstone.

The fine-grained lithologies associated with these shoreline sandstones form sequences of interbedded gray shales, and gray and orange siltstones and fine-grained sandstones, similar in appearance to the off-shore siltstone of the siltstone facies. The shales are commonly quite sandy and silty, and have a flaky, and occasionally papery, fissility. The siltstones and sandstones are generally thinly flat-bedded or laminated. Low-angle cross-beds and ripple marks are present in some localities. The contacts between the interbedded lithologies are variously gradational or quite sharp, and are generally flat and continuous. Thin limestone stringers are a part of these sequences in some sections. Ostracods are commonly preserved in the siltstones and sandstones. Fragments, nodules and heads of Chorellopsis coloniata, a shallow,

clear-water calcareous algae (Bradley, 1928), are present sparsely in the shales and siltstones.

Limestones form a minor constituent of the sandstone facies. Carbonates have been observed throughout the area, but are best developed and most common north of Powell Park; south of the White River they are relatively scarce. All of the limestones are quite sandy. Sand and coarse silt are variously associated both as interlamination or within the limey matrix. The limestones generally are present as thin stringers, however, several beds in excess of ten feet thick are developed in the northern part of the area. Most of the clastic constituents have grain-to-grain contacts. Sand commonly is the dominant clastic component, but ostracods, oolites, and pisolites are common framework materials. The clasts are cemented by sparry, drusy, or micrite cement. Cementation normally causes strong induration of the limestones. Some limestones containing larger clasts, large oolites and pisolites, are moderately cemented, producing large interstices that yield exceptionally good porosity.

The ostracods were not identified in this study, but Cline (1957, fig. 7) reported Cypridea bisulcata, Candona pagei, Erpetocypris? sp. and Cyprois cf. C. marginata from the lower portion of the Anvil Points at the White River.

Many of the ostracods, which presumably thrive in relatively shallow, quiet water (Swain, 1949), have been transported and deposited outside of their indigenous environment. High concentrations of ostracods in many outcrops are accompanied by evidence of relatively high-energy deposition. In these deposits, well-sorted, flatly packed, clean ostracods are highly cross-bedded and ripple-marked, probably indicative of beach deposition. The ostracods are more typically covered with a durable layer of limonite, however, which was presumably encrusted on the shells in relatively quiet water.

Oolites are present as minor inconspicuous intraclasts in sandstones or as highly concentrated beds or lenses; organic or inorganic origin is not determinable. Inasmuch as the oolites may show good sorting, grain support, and contemporaneous splitting, a mechanical process may be inferred. In thin section, however, the oolites have concentric layers of micrite, druse, and limonite. This layering is the same as that of associated pisolites, which Bradley (1928) described as algal pebbles. Both the similar structure and the close association seem to suggest an organic origin. Organic or inorganic, however, these structures would require a shallow clear-water environment either to maintain constant wave agitation for a physio-chemical

origin or to permit penetration of light for an algal origin. Consequently the oolites indicate the same near-shore environment as do the algal structures.

Siltstone Facies

The siltstone facies overlies and interfingers northward with the sandstone facies. The full thickness of this facies is not represented in the study area, but the measured sections of Donnell (1961, pl. 53) indicate that the facies is 1450 feet thick at Piceance Creek and 1100 feet thick at Fourteen Mile Creek. The facies is exposed as a monotonous sequence of light gray and orange siltstones, containing only an occasional prominent sandstone unit. The siltstones make up the most representative lithologic constituent, but there is an increase in sand southward. Shales dominate much of the silt facies at MS3, but there is more sandstone in MS1 (pl. 2).

The siltstones are thinly flat-bedded and laminated, and highly intercalated with sandstones and shales (fig. 3). Alternation of beds ranges from a few feet down to inter-laminations. The sandstones are generally fine- to very-fine-grained, silty and moderately to poorly sorted, flat-bedded and in some places ripple-marked. Ostracods are present in some of the sandstones and siltstones. The shales are silty and sandy. Fissility of the shales is

typically flaky, although some are papery. Some of the shales have pulverized carbonaceous matter preserved on bedding planes.

It is believed that this facies was deposited in an off-shore environment analagous to the neritic environment of the marine model. Its considerable thickness and lack of significant shoreline or fluvatile deposits suggests that deposition took place under conditions which maintained a higher degree of stability than shoreward equivalents. That the distance from the shoreline was not great is indicated by fine sand that was deposited in the area. Fluctuations in lake level probably had some effect on sedimentation, and presumably influenced the relative coarseness of clastics, but throughout most of its history the area remained submerged.



Figure 3. Interbedded shales and siltstones of siltstone facies.

SUBSURFACE STRATIGRAPHY

Stratigraphic Markers

Stratigraphic markers have been used in reconstruction of the Eocene depositional history. The orange, blue and black markers, which have common usage in the existing literature, have been used. These electric-log markers are distinctive and persistent beds of low resistivity. It has been shown by Dyni (1969, fig. 1) that the resistivity of lacustrine shale of the Green River Formation is principally a function of relative oil content; the resistivity of strata increases in almost direct proportion to potential oil yield. Inasmuch as preservation of the organic constituent of the shales reflects the chemistry of the lake's bottom water during a given interval of time, each marker may be considered a time surface recording a concurrent basinwide event. Numerous other, less distinctive but never-the-less correlatable, markers are present throughout these shales, and are equally useful in demonstrating detailed time relations.

Stratigraphic markers also have been utilized in Wasatch Formation correlations. These horizons, however, lack the precision of those in the lacustrine shales, and consequently are termed "correlation lines" in order to

denote a lower degree of accuracy than the "time lines" which are drawn through the Green River Formation. The correlation lines are established by the various correlations of beds, zones and phantom horizons and give time relationships only in a gross sense.

Wasatch Formation

The variegated siltstones and mudstones which typify the Wasatch Formation on the surface predominate in the eastern portion of the subsurface section, but become less dominant on the west.

The siltstones and poorly sorted sandy mudstones are gray and brown, but in many samples are highly mottled with red, purple, green, and ochre. Beds of light gray, commonly calcareous, siltstones are scattered among the variegated mudstones. Lenticular sandstones are very common throughout the Wasatch, ranging in thickness from thin stringers up to a few tens of feet. Most of these sandstones persist laterally only a short distance; only a small minority may be correlated between more than two wells. The sandstones are light gray, fine- to medium-grained, moderately sorted, subangular, slightly porous, and primarily composed of quartz.

In the western part of Piceance Creek field the upper portion of the Wasatch Formation contains both fluvial

and lacustrine deposits. The variegated siltstones and mudstones, while not absent, are less common. The lacustrine sandstones have a similar fine- to medium-grained, moderately sorted, subangular lithology as those of the fluvial sequence, however, many sandstones and shales are ostracodal and in places are associated with the limestones. The sandstones are generally thin and rarely persist laterally. Sparse data will not permit delineation of these Wasatch lacustrine deposits, but they apparently are restricted to the western portion of Piceance Creek field, and are present in the upper 900 feet of the formation. Sample and core description from wells in sections 15 and 27, T. 2 S., R. 96 W. indicate that the upper Wasatch is dominated by the variegated lithologies and is essentially devoid of ostracods at these localities. Therefore, the fluvial Wasatch interfingers with lacustrine deposits in the upper 900 feet of the formation in the vicinity of the western half of T. 2 S., R. 96 W. Below 900 feet, sporadic occurrences of ostracods have been reported in the westernmost wells of Piceance Creek field.

Lacustrine deposits presumably reflect the incipient development of Lake Uinta. Minor small lakes were apparently developed locally for short periods of time as drainage was deranged by the structural movements affecting the basin. These non-fluvial environments were present

locally and intermittently throughout the deposition of the Wasatch, but near the end of Wasatch deposition these conditions became more common, dominating the topographically lower portions of the basin.

Total thickness of the Wasatch Formation shows a marked increase from 3400 feet at the exposed eastern edge of the basin to an undetermined thickness, probably in excess of 6000 feet, at a basinal axis east of Piceance Creek field. Four wells that penetrate the entire Wasatch section show a northeastward thickening at the rate of about 200 feet per mile, achieving a maximum penetrated thickness of 5400 feet in section 15, T. 2 S., R. 96 W. The rate of change is relatively uniform across the basin as the formation thins to about 300 feet (Cashion, 1969) where it crops out on the western side of the basin, 22 miles west of the field. The rate of thickening is also apparently uniform vertically throughout the Wasatch section. Correlation among deep wells shown on plate 3 indicates that the interval between each pair of correlation lines tapers at about the same rate throughout the whole thickness, suggesting a relatively continuous and uniform subsidence throughout Wasatch deposition.

Green River Formation

Douglas Creek Member

The Douglas Creek Member is the lowermost member of the Green River Formation and the principle gas producer for both Piceance Creek and South Piceance Creek fields. The member consists of a series of sandstones, limestones, and shales which pinch out in the central part of Piceance Creek field and west of South Piceance Creek field. This member is characterized by the diverse lithologies which overlie the dominantly fluviatile Wasatch Formation and underlie the relatively homogeneous shales of the Garden Gulch Member.

In many localities the lower boundary of the Douglas Creek Member is indistinct owing to the common occurrence of sandstones at the top of the Wasatch. Sufficient control may be attained from sample and core descriptions in some wells to permit delineation of the boundary on the basis of lithology. In the western wells the lithologic criterion, even where available, is unsatisfactory for recognition of the base of the Douglas Creek owing to the similar nature of the lacustrine deposits above and below the contact. However, many of the electric logs display the Wasatch with a characteristic resistivity response -- a relatively low resistivity ($10 \text{ ohms. m}^2/\text{m}$), lacking sharp peaks, showing very little separation between the normal

and induction curves -- which permits a gross correlation of the upper Wasatch from control wells.

A distinct lithologic break between the Douglas Creek and Garden Gulch members exists throughout most of the area. Well-developed sandstones are directly overlain by a distinctive sequence of shales. Locally, however, a clear distinction between the two members is lost due to the occurrence of discontinuous sandstones and siltstones in the lower Garden Gulch. These beds, which are most common in South Piceance Creek field, have been excluded from the Douglas Creek because they are enclosed by homogeneous shales more characteristic of the Garden Gulch Member.

The sandstone units of the Douglas Creek Member are generally composed of light gray, speckled, subrounded to subangular, well sorted, moderately packed, generally calcareous, quartz sandstone. The sandstone beds are up to a few tens of feet in thickness. Cutting samples of these sandstones suggest a close similarity in sorting and packing to the lacustrine sandstones sampled at the outcrop. Many sandstones contain ostracods and are closely associated with ostracodal and oolitic limestones. Small coal granules are present in some sandstones. The good sorting and loose packing typically produce very good primary porosities, but secondary calcite cementation has destroyed much of this porosity in many of the sandstones. Oil staining and oil

accumulations are common in many of the sandstones, especially in south Piceance Creek field. Oil staining is also common in Piceance Creek field as both live and dead oil stain.

Siltstones are associated with both the sandstones and the shales. The siltstones are light to dark gray, generally calcareous, and commonly laminated. Most of the siltstones are carbonaceous, deriving their dark color from pulverized carbon dispersed throughout.

Most of the shales are dark, ranging from medium brown and gray to black. Fissility ranges from absent to papery. Both siltstones and shales are sparsely ostracodal and pyritic.

Thin stringers of light brown ostracodal limestone are abundant throughout the Douglas Creek Member. The ostracods are typically cemented either by lime mud or secondary calcite. Interstitial and vugular porosity is developed in some moderately cemented ostracodal limestones. These limestones commonly contain interlamination of carbonaceous black shale. Oolitic and dense microcrystalline limestone is present, in addition to the more prevalent ostracodal limestone. Turratella sp. is contained in a few of the microcrystalline limestones.

The porous zones of the Douglas Creek Member have an average porosity of 13.5 percent and an average permeability

of 19 md (Anon., 1961, p. 210). Porosity is developed interstitially in the sandstones and interstitial and vugular porosity is developed in the limestones. Fractures in the shales and calcareous lithologies are commonly recorded in cores and apparently account for a significant amount of transmissibility, and probably also provide porosity. Good pressure communication exists among the various productive sandstone units of the Douglas Creek in Piceance Creek field, demonstrated by a predictable pressure decline which affects all producing wells (Mobil Oil, personal communication, 1969). The lateral persistence and vertical isolation by shale of the individual sandstone units suggests that communication within the member should be best developed laterally. However, vertical communication among porous zones in upper and lower parts of the member may be implemented locally by vertical fractures developed in the siltstones and shales.

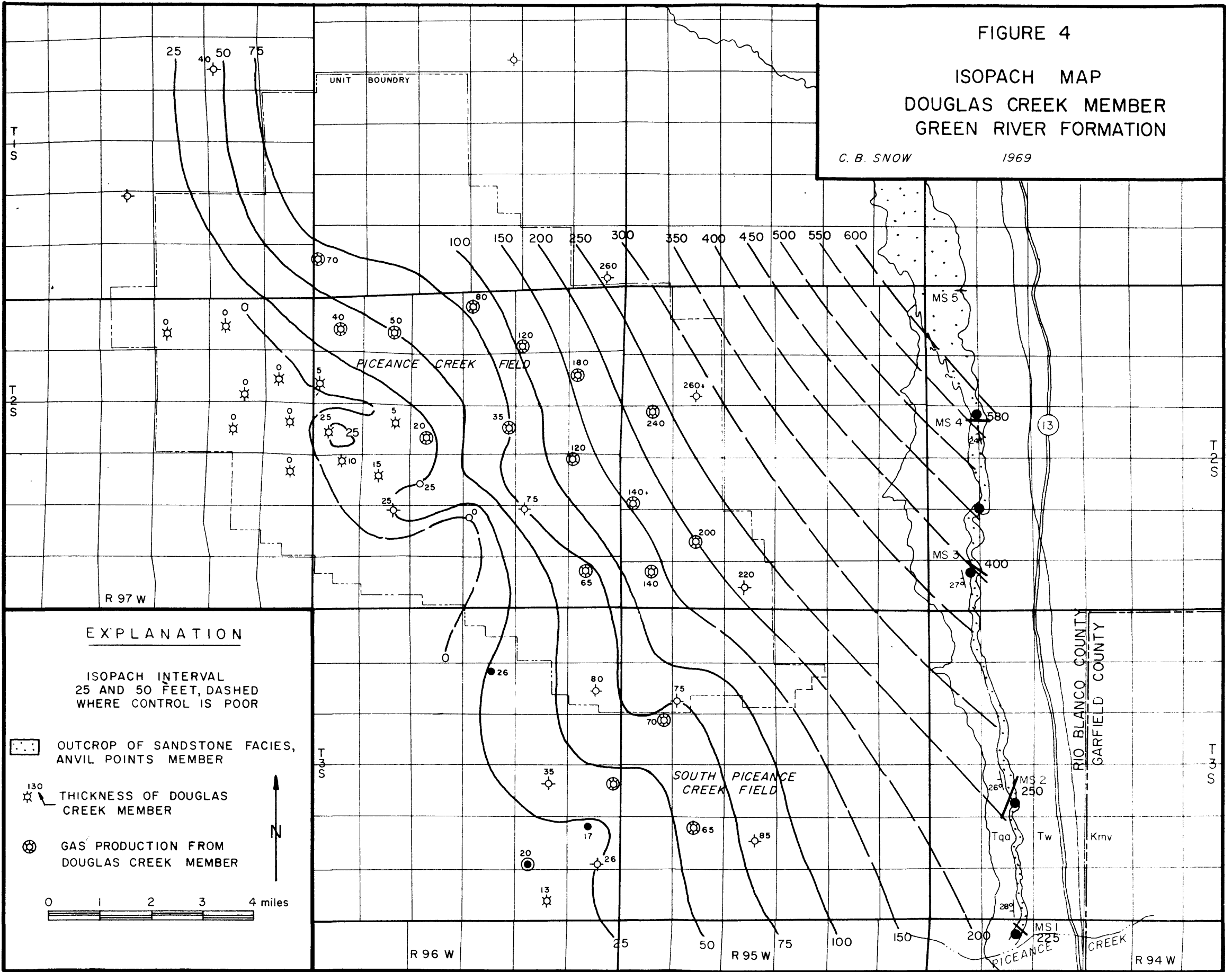
The Douglas Creek Member thickens to the northeast from the zero isopach to greater than 260 feet in the northeasternmost well of Piceance Creek field. The thickening of the member is accomplished by the combined effects of an increasing number of sandstone units and a thicker development of the individual sandstone bodies. Both the isopach (fig. 4) and the sandstone isolith (fig. 5) maps show a similar northwest trend across both gas fields. This

FIGURE 4

ISOPACH MAP
DOUGLAS CREEK MEMBER
GREEN RIVER FORMATION

C. B. SNOW

1969



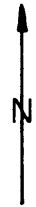
EXPLANATION

ISOPACH INTERVAL
25 AND 50 FEET, DASHED
WHERE CONTROL IS POOR

OUTCROP OF SANDSTONE FACIES,
ANVIL POINTS MEMBER

THICKNESS OF DOUGLAS
CREEK MEMBER

GAS PRODUCTION FROM
DOUGLAS CREEK MEMBER



0 1 2 3 4 miles

R 96 W

R 95 W

R 94 W

T 33 S

T 25 S

T 25 S

T 33 S

T 25 S

T 25 S

RIO BLANCO COUNTY
GARFIELD COUNTY

MS 5

MS 4

MS 3

MS 2

MS 1

T 26

T 27

T 28

T 29

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trend is best developed in the northeast where the member is thickest. The contour pattern becomes increasingly erratic as the member thins. The geometry of the edge of the member, where it consists of only one or two sandstone units, more closely reflects the lenticular and irregular nature of the units which comprise the Douglas Creek, than does the more uniform trend elsewhere in the area. The same lenticular and unpredictable nature is also characteristic of most of the sandstone units on the east, however, the increased number of these units reduces the disruptive effect on the isopach and isolith trends.

As illustrated in figure 4, the isopach trend established by the eastern portion of the Douglas Creek Member has been tentatively extended to the outcrop of the sandstone facies of the Anvil Points Member. This extension is speculative owing to the tenuous control established in the subsurface and relatively long distance to the outcrop. However, a general geometric continuity is maintained, suggesting that the Douglas Creek of the subsurface and the sandstone facies at the northeastern margin of the basin are stratigraphically equivalent and continuous.

The upper portion of the Douglas Creek Member inter-fingers with the lowermost part of Garden Gulch Member and demonstrates a time transgression in the direction of thickening. The time relationship between the two members

is shown by the time lines drawn below the orange marker in plate 3. These time lines, present throughout the area, are truncated by the Douglas Creek Member successively farther to the northeast with higher stratigraphic position, demonstrating that the top of this member becomes progressively younger.

Whether or not a similar interfingering relationship exists at the base of the Douglas Creek Member cannot be firmly established with existing well control. Adequate penetration of the Wasatch Formation is restricted to the western part of Piceance Creek field; throughout the rest of the area data are sparse or unavailable. On the west, the Green River Formation apparently conformably overlies the Wasatch without significant interfingering. As shown in plate 3, the base of the Douglas Creek Member parallels the correlation line drawn a short distance below the top of the Wasatch Formation. A slight drop in stratigraphic position on the west, indicated between wells T52-19-G and 43-24, may suggest minor interfingering at the base of the Green River Formation. The upper Wasatch in this region has been influenced by lacustrine sedimentation, and therefore, the nature of its upper contact cannot be considered representative of that to the east. The lacustrine Wasatch has been interpreted as indicative of a flat bottomland in the topographically lower region of the basin, and as such the

initial development of Lake Uinta would naturally affect most of this area simultaneously, producing an abrupt contact.

While the use of the orange marker as a level datum is useful in portraying the chronologic and stratigraphic relationships at the top of the Douglas Creek Member, it distorts these relationships at the base of the member. The basal contact relationship depicted on plate 3 suggests a time transgression to the east whereas the reverse situation is more probable; one which maintains a parallel time relationship at both the top and base of the member. This discrepancy is produced both by topography inherent to the orange marker and by increased rates of sedimentation of the Douglas Creek Member to the northeast. The shale which contains the orange marker was deposited on a surface which sloped basinward. This basinal gradient was produced in part by tectonic downwarping, and was apparently enhanced by the geometry of the wedge-shaped Douglas Creek Member on which the lake floor was developed. An accurate restoration of this marker, therefore, would require it to slope gradually basinward.

The time relationship of the Douglas Creek Member is even more profoundly affected by increasing rates of sedimentation on the northeast. The increasing rate of deposition results in a corresponding increase of spatial

separation of time surfaces. The dramatic effect of this phenomenon is suggested by the marked thickening of the upper Douglas Creek between the two closely spaced wells at the eastern end of plate 3. The prominent shale units, present in both wells, are stratigraphically equivalent and presumably time equivalent. An additional 50 feet of sediment was deposited in the upper part of the member as recorded in the eastern well, presumably due to the more rapid rate of deposition in that direction. Extending the effect of this rate of thickening below the shale unit, it becomes apparent that a time surface near the base of the Douglas Creek Member or in the Wasatch Formation should be shifted significantly with respect to time surfaces in the Garden Gulch Member, and in effect, this reverses the sense of stratal continuity.

The transgression of the initially developing lake probably occurred as cycles of fluctuation in strand line position with the net result of a northeastward migration. The rate of net migration was apparently highest during the initial inundation of the basin lowlands and diminished to the east as the strandline transgressed. The sandstone facies of the Anvil Points Member represents a continuation of this same process; its thickest development reflects the slowest rate of transgression and a prolonged stillstand of the lake's strand line.

Garden Gulch Member

The Garden Gulch Member overlies the Douglas Creek Member in the subsurface and presumably is the stratigraphic equivalent of the siltstone facies and a portion of the sandstone facies of the Anvil Points Member on the east. Within the limits of this study area the member thickens markedly to the east, from 200 to 1180 feet. The Garden Gulch is distinguished from the overlying Parachute Creek Member on the basis of the lower kerogen saturation of its shales. Owing to the sensitivity of resistivity logs to the kerogen content of the Green River shales, delineation between the two members on this basis is readily practicable in subsurface studies.

The lithology of the Garden Gulch Member is characterized by a uniform sequence of shales. These shales are brown and gray, generally finely laminated, and in places calcareous. Siltstones and silty shales are present locally at the base of the member where the off-shore siltstones of the Douglas Creek interfinger with the deeper water shales. Ostracods are sparsely present in the lowermost shales and in some localities are concentrated as stringers of grain-supported ostracodal limestone. These shales, although considerably less organic than those of the Parachute Creek Member, may yield as much as 55 gallons of oil per ton (Smith, Trudell and Dana, 1968, p. 26). Many cores of the

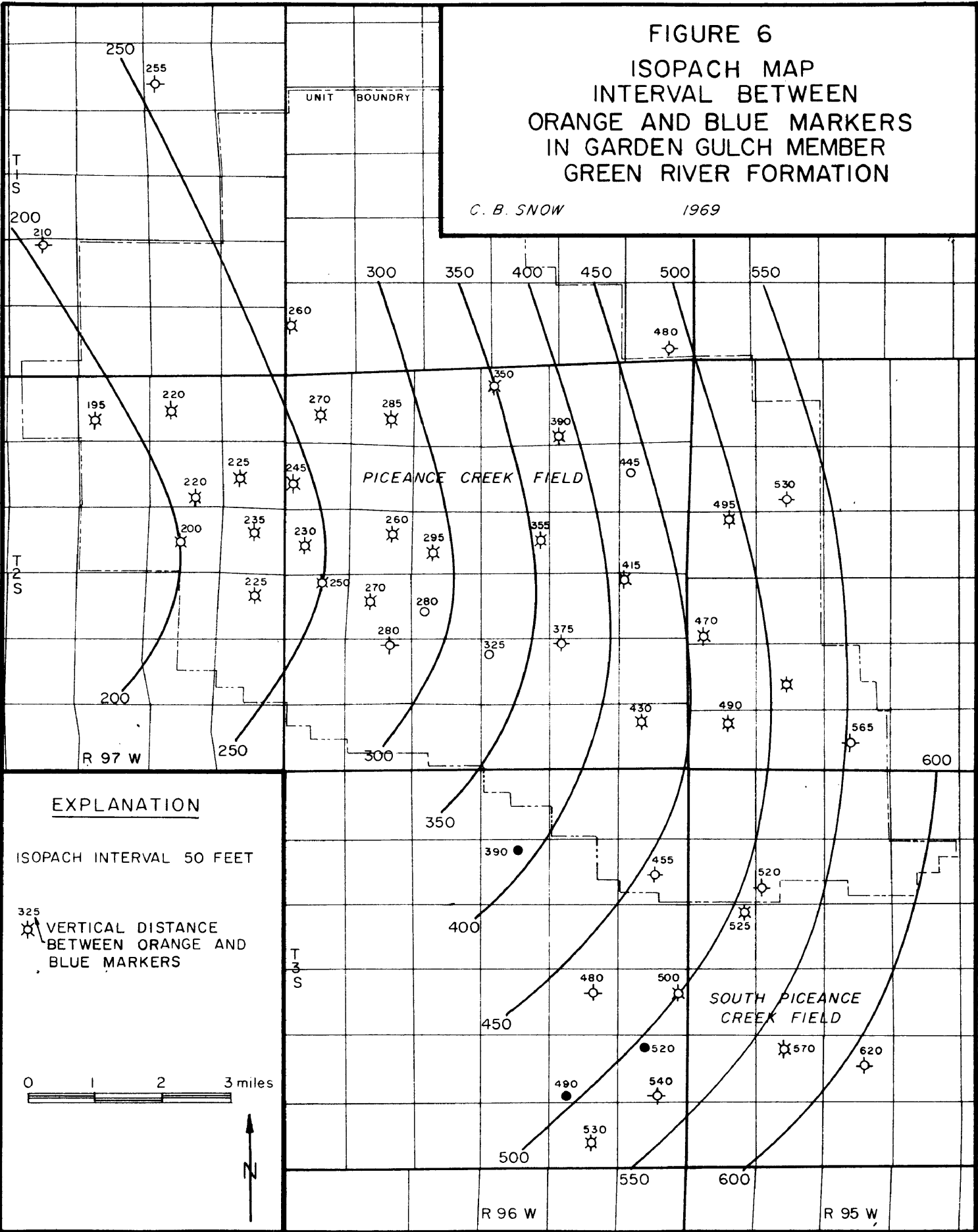
Garden Gulch contain free oil in fractures and vugs of the shales and within porous siltstones and limestones.

Interfingering between the Garden Gulch and the siltstone facies of the Anvil Points Member is recorded in the easternmost wells of south Piceance Creek field. Tongues of the siltstone facies are present as isolated beds of siltstone and sandstone in the lower 200 feet of the member (pl. 4 in no. 1 Miller and 17X-8 wells). The Anvil Points is not recognized as a separate unit in the eastern wells of Piceance Creek field, but the lower part of the Garden Gulch Member (secs. 10 and 36, T. 1 S., R. 95 W.) may represent the siltstone facies. The trend of isopach contours in figure 6 suggests that the siltstone facies should be present a short distance east of the present limit of Piceance Creek field.

A slight but significant modification in depositional conditions in the Garden Gulch Member is reflected by lithologic and geometric changes just below the orange marker. Shales of the lower Garden Gulch have a low organic content and time lines within them are essentially parallel (pl. 3), whereas the upper Garden Gulch contains moderate- and high-yield oil shale and shows a marked westward thinning. Both the upper and lower shales were presumably deposited in relatively deep water, but the lower Garden Gulch, which is time equivalent to the Douglas Creek Member in the subsurface, was deposited relatively

FIGURE 6 ISOPACH MAP INTERVAL BETWEEN ORANGE AND BLUE MARKERS IN GARDEN GULCH MEMBER GREEN RIVER FORMATION

C. B. SNOW 1969



EXPLANATION

ISOPACH INTERVAL 50 FEET

325
 VERTICAL DISTANCE
 BETWEEN ORANGE AND
 BLUE MARKERS

0 1 2 3 miles



close to the strand line. The upper shales, laterally equivalent to the more distant Anvil Points Member, were deposited much farther basinward. The oil shale, which is thought to originate in stratified bottom water (Bradley, 1948), is indicative of the basinward deep-water deposition. Westward thinning of the upper shales is shown by the isopach map of the interval between the orange and blue markers (fig. 6). The thinning presumably reflects the decreasing rate of sedimentation with distance from sediment source. Apparently the position of the strand line remained relatively constant during deposition of this interval. This is suggested by the remarkably uniform vertical distribution of thinning throughout the sequence (fig. 7).

The upper contact of the Garden Gulch Member exhibits a time transgression to the east. The time relationship between Garden Gulch and Parachute Creek members is demonstrated by their change in stratigraphic position with respect to the essentially parallel blue and black markers (pl. 3).

Parachute Creek Member

The Parachute Creek Member, which contains the potential resource of high-yield oil shale and deposits of soda and alumina salts, is composed primarily of organic shales and dolomitic marlstones. The member ranges in thickness from

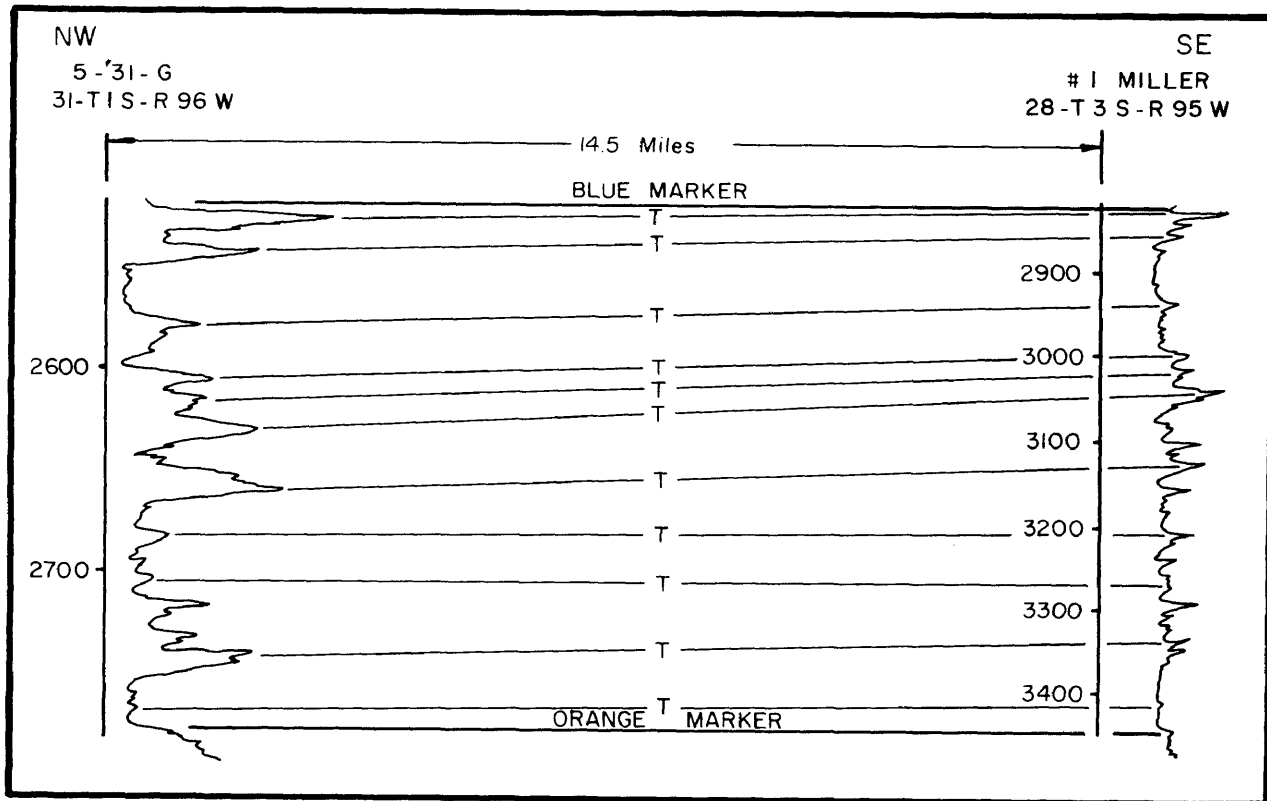


Figure 7. Uniform distribution of thinning of shales between orange and blue markers, Garden Gulch Member. Vertical scales of short normal electrical logs are adjusted to restore time parallelism to markers.

about 1,000 to 2,000 feet in the subsurface area of this report. Variations in thickness result generally from interfingering with the underlying Garden Gulch Member; the upper contact is stratigraphically flat, approximately 600 feet above the black marker. The thickness diminishes to the east and is approximately 700 feet where it crops out above the Anvil Points Member (Donnell, 1961a, pl. 53).

Evacuation Creek Member

The Evacuation Creek, the uppermost member of the Green River Formation, contains the youngest Tertiary sedimentary rocks in the basin. The member is composed of a lithologically variable sequence of sandstones, siltstones, shales, and marlstones. In the subsurface, the basal contact of the member is placed at a point above which the shales abruptly lose their organic content as inferred by a drop in resistivity on electric logs. The lower 350 feet of the member contains approximately equal proportions of sandstone and marlstone (Donnell, 1961a, p. 858) and the upper part, which was originally assigned to the Bridger Formation (Bradley, 1931), is dominated by lenticular sandstones.

GEOLOGIC HISTORY

The differential tectonic movement between the actively rising White River uplift and continued subsidence along the eastern edge of the basin exerted the principle control over sedimentation of the Wasatch Formation. Deposition of the Green River Formation was largely influenced by the relative depth and strand line position of Lake Uinta (fig. 8). During Wasatch deposition, streams heavily charged with sediments, removed from the newly formed highlands, underwent aggradation upon encountering the basin's abruptly lower gradient. Sedimentation was greatest along the basin axis where the continual downwarping accommodated thicker deposits than elsewhere in the region. The rate of sedimentation diminished to the east partly because the streams became increasingly depleted of sediments, but primarily because the structural downwarping was not sufficient to permit a thick deposit to accumulate there. The structural low was at the eastern margin, but the topographic low was more nearly in the center of the basin, displaced to the west of the downwarp by thick sediments that were deposited there. Throughout most of Wasatch deposition the topographically low basin interior was the site of occasional swamps and ponds which were subsequently covered by the more dominant fluvial sedimentation.

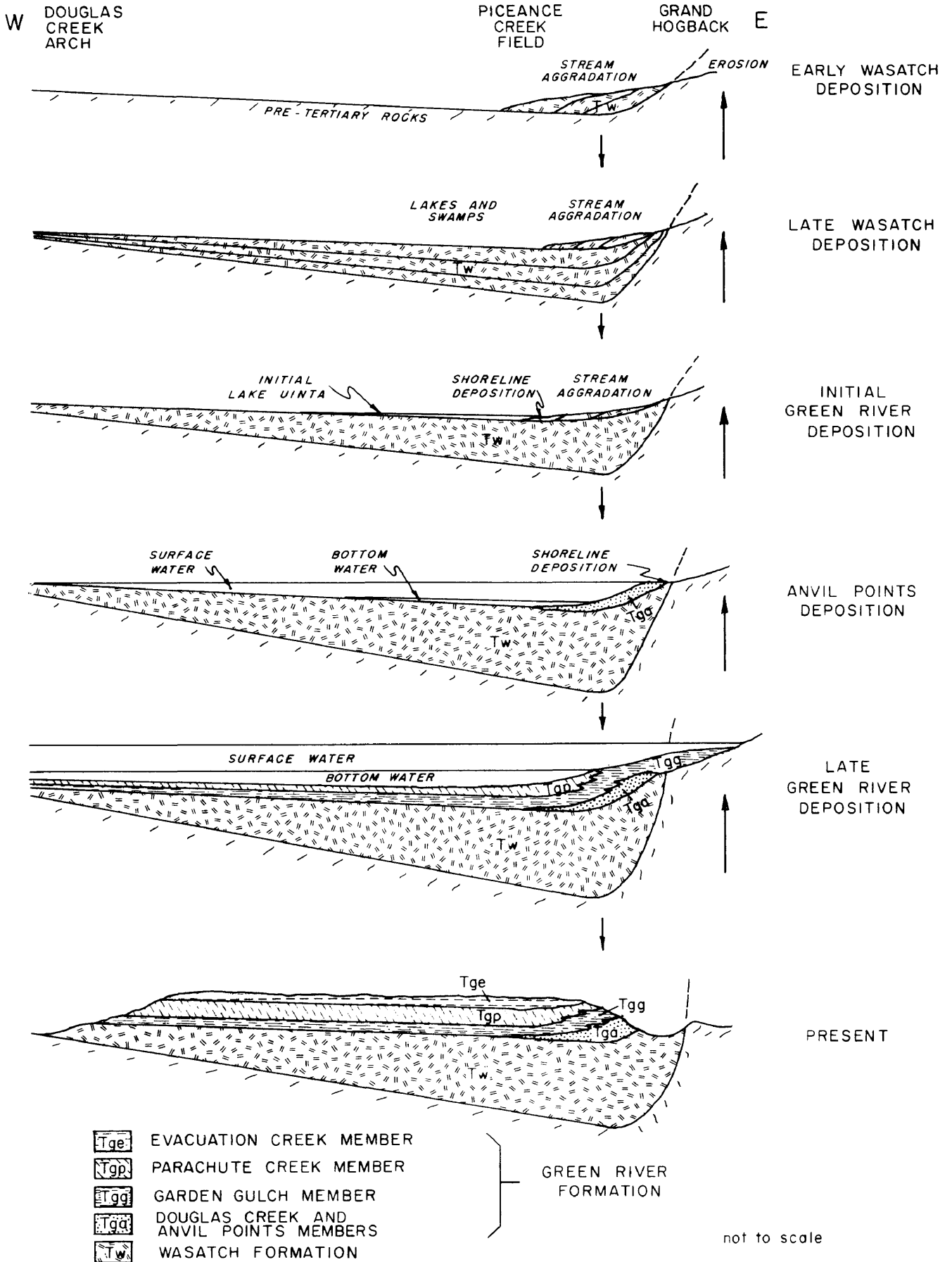


FIGURE 8 STRUCTURAL AND DEPOSITIONAL HISTORY OF PICEANCE BASIN

Nearing the close of Wasatch deposition, however, these intermittent swamp and ponds became increasingly prevalent and may have dominated much of the lowlands.

The close of Wasatch sedimentation was marked by the inundation of the basin. Basinal flooding probably resulted from a gradual tectonic uplift across the basin's outlet. The flat lowlands of the basin interior was quickly inundated, but enlargement of the lake proceeded more slowly where its strand line encountered the increased topographic gradient rising toward the highlands on the northeast. Streams entering the basin continued to discharge large amounts of clastics which were distributed along the shoreline. The lake's transgression was marked by minor fluctuations which resulted in several superimposed strand line deposits constituting the thickening wedge of the Douglas Creek Member. As a consequence of the basinward gradient, off-shore deposition of coarse clastics extended only a short distance from shore, and clay deposition prevailed beyond. The rate of transgression diminished as the lake extended farther eastward, and the shoreline deposits became successively thicker to the east due to both higher rates of sedimentation that occurred nearer the highlands and to the greater number of fluctuations which affected the area.

The shoreline became stabilized at the edge of the present structural basin. During this time of relative stability, a thick sequence of coarse clastics (sandstone

facies of Anvil Points Member) was deposited along the zone of minor strand line oscillation by both fluvial and lacustrine agencies. Thick sedimentation produced shoaling out from the shore and resulted in extensive deposits of off-shore silts (siltstone facies of Anvil Points Member). In the deeper water, basinward from the marginal shoals, slow clay deposition persisted, while in the deepest water, still farther basinward, organic-rich clay was deposited, as interpreted by Bradley (1948).

At least two major transgressions affected the lake after its initial expansion. A second transgression occurred at the time recorded by the blue marker, in which the deep-water region of Parachute Creek deposition migrated to the area occupied by Piceance Creek field. The lake remained stable for a relatively long time and then was again extended. During this third transgression the shoreline was apparently far removed from the boundaries of the present structural basin, and deep water organic shales were deposited throughout the area of present Green River exposure.

The final phase of Green River deposition was a gradual withdrawal of Lake Uinta. The waning stage of the lake was marked by a series of rapid regressions and transgressions which is recorded by the shales and sandstones of the Evacuation Creek Member.

ECONOMIC GEOLOGY

History of Field Development

Piceance Creek field has had a relatively long exploration and development history. Piceance Creek Dome was first recognized from its surface structure near the beginning of the century, but the initial drilling which led to the discovery of the field was not undertaken until 1929. White Eagle Refining Company completed the discovery gas well (Fordham No. 1) in the Douglas Creek Member in 1930, and two additional wells were drilled in the early 1930's. The field remained dormant until 1945 when General Petroleum drilled 84-15-G, a deep test which penetrated the upper sandstones of the Mesaverde Formation. Although there were three significant gas shows in the Wasatch, the well was plugged back and completed in the Douglas Creek for an initial flow of 4,350,000 cu ft per day. In 1950 development activity was stepped up with the drilling of six wells. Although four of these holes were dry, they not only established a gas-water contact on the eastern and northern flanks of the structure, but they also indicated a more complex stratigraphy and structure than had been assumed previously. The field was first produced in 1956 when ten wells were connected to the El Paso Pacific Northwest pipe-

line. Mobil Oil Company initiated exploration for deeper accumulation of gas in 1961 and this has proved reserves in the upper and lower Wasatch Formation in the western portion of the field.

At present, Piceance Creek field consists of a 15,600-acre unit which is operated by Mobil Oil. A total of 39 wells have been drilled to January 1, 1969; 29 have been completed as gas wells and ten have been abandoned. Original reserves have been estimated as 241,382 million cubic feet; 148,489 MMCF from the Douglas Creek and upper Wasatch and 92,893 MMCF from the lower Wasatch ("Wasatch G") (unpublished files of Federal Power Commission, 1967). Total production through 1968 was 67,573 million cubic feet of gas and 70,088 barrels of condensate (files of Colorado Oil and Gas Commission).

South Piceance Creek field is a combined oil and gas field. It was discovered by Equity Oil Company, the present operator of the field, in 1955. Nineteen wells have been drilled to January 1, 1969; six were completed as gas wells, five as oil wells, one as an oil-gas well, and seven have been suspended or abandoned as dry holes. Most of the wells are completed in the Douglas Creek Member or upper Wasatch Formation; minor reserves are present in the Parachute Creek, Garden Gulch, and possibly in the lower Wasatch. Gas production was initiated in 1961 and is marketed through the Pacific Northwest pipeline. Gas production

through 1968 has totaled 1,534 million cubic feet (files of Colorado Oil and Gas Commission); the oil wells have produced only during tests and have remained shut-in since completion.

Petroleum Occurrence

Present production of both Piceance Creek and south Piceance Creek fields comes from three principal gas zones: the Douglas Creek Member and two zones in the Wasatch Formation which have been designated informally by the field operators as the "Wasatch A" (upper 900 feet of the formation, consisting of the lacustrine facies) and the "Wasatch G" (in the lower Wasatch and includes the thick sandstone unit below 4920 feet in well 43-24 in plate 3). Although production is primarily limited to these three zones, shows and reserves of both gas and oil have been reported locally throughout the Tertiary sequence below the Evacuation Creek Member. Fractured zones in the shales of both the Parachute Creek and the Garden Gulch members have yielded gas and high pour-point oil in south Piceance Creek field, as have the siltstones and sandstones of the lower Garden Gulch.

Although the Douglas Creek is primarily gas productive, significant amounts of high pour-point oil are common in the member. Several wells in south Piceance Creek field have been completed for oil in the Douglas Creek. No oil

completions have been made in the Douglas Creek of Piceance Creek field, but occurrences of high pour-point oil are common. The Douglas Creek oil exists in part as a discrete oil column at the base of the gas column; curtailed gas production of the down-structure gas wells is associated with increased production of oil (Mobil Oil, personal communication, 1969) which presumably has migrated with the encroaching gas-water interface.

In addition to the two principal gas zones in the Wasatch, minor production comes from the middle Wasatch (Wasatch D). Gas shows have been reported from many of the sandstones throughout the Wasatch and locally in the Fort Union. Oil shows have been reported locally throughout the Wasatch sandstones, normally as dead oil stain on cutting samples, but oil-bleeding cores have been recovered from the "Wasatch A" and significant amounts of condensate are being produced with gas from "Wasatch G."

Entrapment of gas in the Douglas Creek of Piceance Creek field is largely the result of the stratigraphic pinch-out of the member with a favorable up-dip structural gradient. The member acts as a single reservoir throughout the field, exhibiting a single gas-water contact and a uniform gas expansion-water drive pressure system. In south Piceance Creek field, however, the Douglas Creek production is irregular and apparently discontinuous. Gas

and oil exist in isolated accumulations which are trapped in stratigraphic irregularities at the top of the member, where the sandstones pinch out laterally up-dip to the west. A lower productivity of the member, compared with Piceance Creek field, should be expected as a result of the generally unfavorably low structural position.

The accumulations of hydrocarbons above and below the Douglas Creek Member occur in isolated stratigraphic traps. Production in the Garden Gulch and Parachute Creek is from local fractured zones and in the Wasatch it is from discontinuous sandstone lenses.

Oil that occurs throughout the Green River and Wasatch Formations is characterized by its high pour-point (85° to 120°F) and high paraffin content. Analysis of crude oil recovered from Piceance Creek field has shown considerable similarity with oils produced from Red Wash and Duchesne fields in the Uinta basin. Table 1 lists the properties and analysis of a sample of oil recovered from the Wasatch at White River dome, about ten miles north of Piceance Creek field.

The lenticular nature of sandstones which contain oil in the Wasatch suggests that the oil is indigenous to that formation, but the similarity of properties of oils produced in the Wasatch and Green River might suggest a common source despite the large vertical distance between occurrences. Hedberg (1968), however, has related numerous

API Gravity	39.8°
Pour Point	70°F
Sulphur Content	.03%
Color	Brownish green
Analysis -	
light gasoline	5.3%
total gasoline and naptha	18.1
kerosene	26.9
gas oil	21.5
non-viscous lubricating distilate	20.4
medium lubricating distilate	4.1
viscous lubricating distilate	----
residuum	9.0

Table 1. Analysis of crude oils from the Wasatch Formation at White River Dome (Mobil Oil, personal communication).

high wax, low sulfur oils to various non-marine, below-normal salinity sources in a diverse variety of occurrences. The similar properties of crude oils in the Piceance basin may reflect the fact that they were formed in fresh water environments, regardless of whether the environment was deep water lacustrine or paludal. Thus the hydrocarbons are probably indigenous to the members and zones in which they occur and are derived from the organic paludal deposits associated with marginal lacustrine deposits of the Douglas Creek and Anvil Points Members and transitional lacustrine deposits of the upper Wasatch. The Wasatch, therefore, should be more favorable for hydrocarbon accumulations near the central part of the basin where deposition occurred as both fluvial and paludal-lacustrine rather than to the east where fluvial deposition dominated.

SUMMARY AND CONCLUSIONS

1. Deposition of the Wasatch Formation was influenced most profoundly by the differential tectonic movement which occurred at the extreme eastern margin of the basin. Greatest rates of deposition were along the locus of maximum subsidence where deposition was characterized by stream aggradation. The central part of the basin received smaller volumes of sediment and is characterized by both fluvial and paludal-lacustrine deposition. The upper Wasatch of the central basin contains a lacustrine facies produced by intermittent flooding.

2. The Douglas Creek Member trends southwesterly across Piceance Creek and south Piceance Creek fields, and it pinches out in the western part of Piceance Creek field and on the southwest of south Piceance Creek field. The member thickens to the northeast and was deposited at the strandline during the initial transgression of Lake Uinta. The upper contact of the member exhibits a time transgression to the northeast.

3. The Anvil Points Member of the northeast rim of the basin contains two facies: sandstone and siltstone. The sandstone facies is stratigraphically equivalent to and contiguous with the Douglas Creek Member of the subsurface.

The increased thickness of this facies resulted from a stillstand of the lake's strand line. The siltstone facies is equivalent to the Garden Gulch Member and represents prolonged high rates of off-shore deposition.

4. The Douglas Creek-Garden Gulch-Anvil Points sequence was deposited during an early phase of Lake Uinta and was superceded by deep-water oil shale deposition when the lake extended a considerable distance past the present structural basin.

5. Both gas and oil occur throughout the Tertiary sequence. Reserves or shows of gas and oil have been reported from all the members of the Green River Formation (except the Evacuation Creek) and from the Wasatch and older formations. The oil and gas are indigenous to Douglas Creek and Anvil Points members and to the Wasatch Formation and are probably derived from associated organic paludal and lacustrine deposits. Facies analysis indicates that the Wasatch should be most promising for petroleum accumulation in the central part of the basin.

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APPENDIX

Measured Section 1, Upper Piceance Creek
NE $\frac{1}{4}$, Sec. 5, T. 3 S., R. 94 W.

Top of Measured Section	Feet
-Siltstone facies (part), Anvil Points Member, Green River Formation-	
Interbedded sandstone, siltstone and shale. Carbonaceous and gypsiferous.	
Sandstone: Pale orange, very-fine-grained, silty, locally calcareous and limonitic, laminated, ripple-marked, limonite concretions.	
Siltstone: Tan and pale orange, laminated, few ripple-marks, interlaminated with shale.	
Shale: Gray and light green, locally flaky fissility, interlaminated with siltstone	137
Shale: gray, flaky.	13
Sandstone: rust brown, fine-grained, moderately to well sorted, flaggy, ripple-marked, slight oil-stain.	3
Shale: gray, flaky.	16
Sandstone: rust orange, fine-grained, moderately sorted, moderate porosity, sparse ostracods, calcareous limonitic, locally carbonaceous, minor interbeds of siltstone and shale, ripple-marked	2
Covered: inferred gray flaky shale.	22
Sandstone: rust orange, fine-grained, ripple-marked .	1
Covered: inferred interbedded siltstone and shale . .	60
Shale: gray, flaky.	9
Sandstone: rust orange and light gray, fine-grained, calcareous	2

	Feet
Shale: gray, flaky.	33
-Top of sandstone facies, Anvil Points Member-	
Sandstone: light gray, fine-grained, well sorted, rounded, porous, slightly calcareous, massive, few ripple-marks and cross-bedding, minor limonite mottling and concretions	15
Shale: gray, flaky, and mudstone: light brown, sandy	8
Sandstone: tan and light gray, fine-grained, calcareous, heavily ripple-marked	5
Covered: inferred gray flaky shale.	29
Sandstone: light brown and light gray, fine- grained, friable, ripple-cross-bedded	10
Covered: inferred shale	11
Sandstone: pale orange, medium-grained, locally calcareous, base and top of unit gradational with shales, trough-cross-beds, ripple- marked.	5
Shale: gray, flaky.	5
Sandstone: light gray and rust brown, fine- grained, well sorted, porous, slightly calcareous, slabby, minor ostracod fragments. . .	3
Covered: inferred shale; contains ½-foot stringer of limestone; gray, weathers orange, sandy (fine grained), minor ostracods	17
Sandstone: light gray, fine-grained, moderate porosity, sparry calcite in hairline frac- tures, asymmetric ripple-marks, ostracod fragments	3
Covered: inferred gray flaky shale.	20
Sandstone: rust brown, at base gray above, medium-grained, calcareous, trough cross- beds, very ostracodal	4

	Feet
Mudstone: drab, sandy and siltstone: sandy, friable .	10
Sandstone: light brown and light gray, fine-grained, well sorted, low porosity, moderately to highly calcareous, locally ostracodal, few ripple marks.	15
Mudstone: drab, shaly	2
Sandstone: light gray, fine-grained, moderately sorted, calcareous, minor ostracods	1
Covered:	33
Sandstone: light gray, fine- to medium-grained, friable, irregularly bedded, locally oil-stained	<u>13</u>
Total thickness - sandstone facies	209
-Top of Wasatch Formation-	
Mudstone: light gray and drab, sandy, occasional sandstone lamination.	10
Mudstone: variegated red, purple, orange, brown and gray.	90
Base of Measured Section	

Measured Section 2, Halandras Ranch
Road Cut, Sec. 20, T. 3 S., R. 94 W.

Top of Measured Section	Feet
-Siltstone facies (part), Anvil Points Member, Green River Formation -	
Interbedded sandstone and siltstone.	
Sandstone: light brown, fine-grained, moderately sorted, calcareous, ostracodal.	15
Shale: gray, contains stringers of dense cryptocrystalline limestone	16
Interbedded sandstone, siltstone and shale. Sandstone: light brown, fine-grained, moderately sorted, calcareous, lamin- ated, ostracodal.	14
Covered: inferred shale	9
Sandstone: light brown, medium-grained, poorly sorted, calcareous, possibly ostracodal	8
Shale: gray	7
Siltstone and very fine-grained sandstone.	12
Interbedded sandstone, siltstone and shale. Sandstone: light gray, fine-grained, calcareous, interbeds and inter- laminations of siltstone and shale. Shale: gray, flaky, some papery, inter- laminations of siltstone.	219
Covered: inferred interbedded sandstone, silt- stone and shale	70
-Top of Sandstone facies, Anvil Points Member-	
Siltstone: sandy, resistant	13
Sandstone: light brown, very-fine-grained, silty, laminated, interlaminations of siltstone, resistant	4
Shale: gray, flaky, locally pale orange, locally papery, relatively free of silt	20

	Feet
Siltstone: locally sandy	13
Sandstone: light brown, fine-grained, poorly sorted, silty, slightly calcareous, friable, locally laminated	14
Siltstone: clayey	9
Shale: gray, flaky, silty, carbonaceous, silt- stone stringers	4
Sandstone: light brown, fine-grained, poorly sorted, silty, slightly calcareous, minor ostracods, laminated, interbedded and interlaminated with siltstone and shale, few low-angle cross-beds.	36
Interbedded sandstone, siltstone and shale. Sandstone: light brown, fine-grained, thinly flat-bedded, few low-angle cross-beds.	33
Shale: gray, flaky, contains 3-inch stringer of oolitic limestone and 6-inch stringer of oil-impregnated fine-grained sandstone.	12
Siltstone: brownish gray and rust orange, medium- to coarse-grained, laminated, locally calcareous, possibly contains ostracod fragments.	20
Covered.	57
Interbedded sandstone and siltstone. Sandstone: rust orange, very-fine- to fine-grained, calcareous, limonitic, locally very ostracodal	19
Sandstone: light brown, very-fine-grained, interlaminations of siltstone and shale, few low-angle cross-beds.	10
Sandstone: light gray, fine- to medium-grained, poorly sorted, silty, isolated conglomeratic siltstone interclases, calcareous	<u>3</u>
Total Thickness - Sandstone facies	267

Feet

-Top of Wasatch Formation-

Interbedded sandstone, siltstone and shale. Sandstone: rust orange, fine-grained, moderately to poorly sorted, calcareous, laminated, locally ripple-marks and low- angle cross-beds. Siltstone: pale orange and gray, laminated interbeds of shale. Shale: gray, massive to flaky, carbonaceous.	22
Shale: gray, silty, locally carbonaceous, locally interbeds of fine-grained sand- stone and siltstone	118
Interbedded siltstone and shale. Siltstone: pale orange and drab, thinly- bedded and laminated, carbonaceous, locally fine-grained, ripple-marked, sandstone. Shale: gray and drab, flaky and papery, silty, carbonaceous	23
Interbedded sandstone, siltstone and shale, carbonaceous and gypsiferous. Sandstone: light brown, fine-grained, moderately sorted, silty, laminated, flat-bedded	32
Covered.	23
Interbedded gray carbonaceous shale and siltstone.	8
Sandstone: light gray, medium-grained, well sorted, calcareous, massive, locally flat-bedded and tangential-wedge cross- beds, locally ostracodal, minor interbeds of shale and siltstone.	7
Mudstone: variegated, mottled, dominantly gray and gray green, locally red and orange.	99
Base of Measured Section	

Measured Section 3, Cox Ranch
Road Cut, Sec. 31, T. 2 S., R. 94 W.

Top of Measured Section	Feet
-Siltstone facies (part), Anvil Points Member, Green River Formation-	
Interbedded shale and siltstone. Siltstone: gray and rust orange, locally calcareous, shaley. Shale: dark gray, silty, carbonaceous, massive and flaky	47
Sandstone: rust orange, fine- to medium-grained, silty, laminated, partly oil-stained.	5
Interbedded shale and siltstone, dominantly shale, minor sandstone. Siltstone: gray and rust orange, laminated, shaley. Shale: dark gray, massive and flaky, carbonaceous. Sandstone: rust orange, fine-grained, moderately to poorly sorted, silty, locally calcareous, thin-bedded, few ripple marks.	211
Shale cut by minor sandstone stringers. Shale: dark gray, flaky, carbonaceous. Sandstone: rust brown, fine- to very-fine- grained, locally calcareous, ripple- marked, interbedded with siltstone, oil- stained and oil-impregnated, locally where porosity is good.	101
Interbedded shale, siltstone and sandstone, as above, locally oil-stained and oil- impregnated	25
Shale: gray and drab, flaky, gypsiferous.	25
Sandstone: rust brown, very-fine-grained, limonitic, flat-bedded.	2
Shale: gray and drab, flaky	20

	Feet
Slumped and cross-bedded sandstone, siltstone and shale (filled channel scour) Sandstone: rust orange, fine-grained, silty, trough cross-bedded, clay galls. Siltstone: gray and rust orange, sandy and shaley, carbonaceous. Shale: gray, flaky, carbonaceous, silty.	32
Sandstone: gray, fine-grained, cut by siltstone and mudstone stringers.	9
Covered: inferred drab mudstone	13
Sandstone: rust brown, very-fine-grained, moderately sorted, limonitic, calcareous, tangential-wedge cross-beds	1
Mudstone: greenish gray, limonite concretions	8
Sandstone: gray, very-fine-grained, well sorted, calcareous, massive	2
-Top of Wasatch Formation-	
Mudstone: mottled gray, green, orange, and purple, locally gypsiferous	13
Gray siltstone, lenses and stringers of sandy mudstone, locally conglomeratic	80
Variegated mudstone and gray siltstone	40
Sandstone: rust brown, fine- to medium-grained, very poorly sorted, silty, clayey, locally calcareous, becomes silty upward.	10
Gray siltstone and variegated mudstone	175
Base of Measured Section	

Measured Section 4, Sanderson Ranch
Road Cut, Sec. 18, T. 2 S., R. 94 W.

Top of Measured Section	Feet
-Siltstone facies (part), Anvil Points Member, Green River Formation-	
Interbedded sandstone, siltstone and shale.	
Sandstone: light gray and orange, fine- grained, locally calcareous and limonitic, laminated cross-laminated.	
Siltstone: light gray, laminated, shaley, and sandy.	
Shale: gray and rust brown, silty and sandy. . .	206
-Top of Sandstone facies, Anvil Points Member-	
Sandstone: gray and rust brown, fine-grained, laminated, ripple-marked.	4
Gray shale	6
Sandstone: gray and rust brown, fine-grained, laminated, ripple-cross-laminated	5
Shale: gray and rust brown, minor siltstone stringers	20
Covered.	60
Sandstone: gray speckled, fine-grained, thin- bedded, few cross-beds.	3
Gray and rust brown shale.	5
Sandstone: rust brown, fine-grained, well sorted, moderate porosity, laminated and thin- bedded, flat-bedded, cut by shale stringers, oil-stained at base	20
Interbedded gray shale and fine-grained sandstone. . .	11
Shale: gray and drab, contains thin stringers of cryptocrystalline limestone	20
Sandstone: rust brown, fine-grained, laminated, oil-stained	3

	Feet
Light green siltstone and shaley mudstone.	14
Sandstone: rust brown, fine-grained moderate porosity, laminated, oil-stained.	4
Shale, gray and drab, silty, locally papery, contains siltstone stringers.	23
Sandstone: fine-grained, well sorted, porous, oil-impregnated	½
Shale with stringers and beds of siltstone and sandstone. Shale: gray and drab, locally papery and carbonaceous. Sandstone: rust brown, fine- to medium-grained, moderate sorting, locally carbonaceous, laminated	43
Sandstone: rust brown, fine- to medium-grained, moderately sorted, locally silty, laminated, flat-bedded	6
Covered.	53
Green mudstone, siltstone and fine-grained sandstone .	52
Sandstone: gray and rust orange, fine-grained, moderately sorted, silty, massive, contains small (5 mm) vugs.	5
Gray and drab shale with sandstone stringers	20
Sandstone: pale orange and gray, fine- to medium-grained, moderately sorted, locally carbonaceous and silty, thin-bedded, cross-bedded, clay disks.	6
Gray and drab mudstone and shale	20
Sandstone: light gray, very-fine-grained, very calcareous	2
Siltstone: light gray, sandy, clayey, massive	6
Shale: gray, massive, locally silty	15

	Feet
Sandstone: rust orange, fine-grained, very calcareous, locally carbonaceous, massive	13
Covered: inferred shale with stringers of sandstone	30
Interbedded sandstone and shale. Sandstone: rust orange, fine-grained, moderately sorted, calcareous, massive, units about 5 feet thick. Shale: not exposed, units about 5 feet thick	30
Sandstone: rust brown, fine-grained, well sorted, laminated, symmetrical ripples, ripple cross-beds, becomes massive upward.	50
Sandstone: light gray, fine-grained, well sorted, laminated, ripple-marked, cross-laminated	<u>8</u>
Total thickness - Sandstone facies	558
-Top of Wasatch Formation-	
Covered: inferred sandstone	14
Mudstone: gray, drab and orange	115
Sandstone: light gray, fine- to medium-grained, moderately sorted, calcareous, siltstone and mudstone lenses, trough cross-bedding	9
Base of Measured Section	

Measured Section 5
NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 6, T. 1 S., R. 94 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: light gray and rust orange, fine- grained, moderately sorted, massive, few ripple marks, migrating ripples, locally ostracodal, fish bone fragment.	9
Siltstone: pale green, clean, massive, locally very calcareous	5
Sandstone: bright orange, fine-grained, moderately sorted, very calcareous, limonitic, grades upward into siltstone, lower part contains abundant ostracods and few oolites	5
Sandstone: light brown, fine-grained, moderately sorted, lenses of siltstone, massive, some low-angle cross-beds, few ostracod fragments, locally very calcareous	14
Covered.	70
Sandstone: light gray and rust orange, fine- to medium-grained, very calcareous, locally ostracodal, thinly flat-bedded.	5
Sandstone: light brown, fine-grained, moderately sorted, silty, friable, shale stringers, limonite concretions.	14
Shale: dark gray, flaky and papery, carbonaceous, gypsiferous	13
Sandstone: light brown, fine- to medium-grained, moderately sorted, friable, calcareous, channel scour at base	9
Interbedded siltstone and gray flaky shale, gypsiferous	12
Shale: dark purplish gray, flaky to papery, gypsiferous	19

	Feet
Siltstone: pale orange, interbeds of dark gray papery shale, laminated, few ripple marks	5
Sandstone: light gray, fine- to medium-grained, moderately sorted, friable, locally very calcareous, low-angle cross-beds, ripple- marked.	6
-Top of Wasatch Formation-	
Mudstone: gray and orange, sandy.	20
Covered: inferred purple variegated mudstone.	80
Base of Measured Section	

Measured Section 6
 NE $\frac{1}{2}$, SE $\frac{1}{4}$, Sec. 11, T. 1 S., R. 95 W.
 and NE $\frac{1}{2}$, NW $\frac{1}{4}$, Sec. 14, T. 1 S., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: brown, fine- to medium-grained, moderately sorted, silty, top 4 feet very calcareous, carbon granules, locally slight oil stained, flat-bedded	13
Covered: inferred shale, contains 1-foot bed of sandstone; light brown, fine-grained, carbon granules and fibers, slight oil-stain. . .	19
Sandstone: rust brown, fine- to very-fine- grained, well sorted, porous, carbon granules and fibers, oil-stained and oil-impregnated, flat-bedded and cross-bedded.	18
Covered: inferred slabby claystone.	32
Sandstone: fine-grained, well sorted, porous, heavily oil-impregnated, massive.	3
Gray shale with stringers and beds of fine- grained flat-bedded sandstone	56
Sandstone: light gray and light brown, fine- to medium-grained, well sorted, calcareous, shale stringers, flat-bedded, few low-angle cross-beds.	10
Covered: inferred shale with sandstone stringers. . .	27
Sandstone: light brown, fine-grained, calcareous, locally ostracodal, stringers of siltstone, flat-bedded, low-angle cross-beds	32
Sandstone: light gray, fine-grained, well sorted, very calcareous, ostracodal, flat-bedded, low-angle cross-bedded.	2 $\frac{1}{2}$
Covered: inferred siltstone and shale	34

	Feet
Sandstone: light brown, fine- to medium-grained, moderately sorted, locally ostracodal, carbon granules, siltstone, and shale stringers, flat-bedded, tangential-wedge and trough cross-beds	10
Covered: inferred shale with siltstone stringers. . .	11
Sandstone: light brown, fine-grained, flat-bedded . .	9
Gray shale with thin fine-grained sandstone stringers	6
Sandstone: light brown, fine- to medium-grained, well sorted, calcareous, thin shale stringers, flat-bedded, thin-bedded.	16
Covered: inferred shale with siltstone stringers. . .	25
Sandstone: rust brown, fine-grained, well sorted, very calcareous, flat-bedded, persistent.	2
Covered: inferred shale	28
Sandstone: light brown, fine-grained, well-sorted, calcareous, flat-bedded, very-thinly-bedded, shale stringers	25
Covered: inferred shale with siltstone and sandstone stringers and beds.	35
Sandstone: light gray, fine- to medium-grained, moderately sorted, carbon fibers, thin-bedded, flat-bedded, tangential-wedge, cross-beds.	12
Covered: inferred shale with siltstone.	15
Sandstone: light brown, fine-grained, well sorted, locally coarse-grained, carbonaceous, thin-bedded, flat-bedded, cross-bedded.	8
Covered: inferred shale	6
Sandstone: light brown, fine- to medium-grained, moderately sorted, thin-bedded, flat-bedded, ripple-cross-bedded, base of unit flat.	4½

	Feet
Sandstone: light brown, fine- to medium-grained, moderately sorted, friable, massive and flat-bedded	24
Sandstone: light green and gray, fine-grained, porous, massive, thick-bedded, lenses and zones of siltstone and shale.	56
Sandstone: light brown, fine-grained, moderately sorted, silty, friable, massive, carbon granules.	20
Gray gypsiferous shale, few stringers of siltstone and beds of flat-bedded, fine-grained sandstone .	22
Conglomerate: granules of chert and siltstone in coarse-grained sandstone matrix, very calcareous, carbon granules, unit tabular.	1
Gray shale	15
Sandstone: light brown, fine-grained, moderately sorted, silty, flat-bedded, low-angle cross-beds, limonite concretions.	12
Shale: gray, gypsiferous, massive siltstone at base .	15
Sandstone: light gray, fine- to medium-grained, local pebble and cobble conglomerate, locally silty, carbon granules, massive, flat bedded, tangential-wedge and trough cross-beds.	27
Lenticular sandstones and shale.	31
Covered: inferred shale with siltstone stringers. . .	20
Sandstone: light gray, fine-grained, well sorted, well rounded, porous, friable, thin-bedded, trough cross-beds	5
Mudstone: gray, shaley, locally sandy and silty . . .	36
Sandstone: light gray, medium-grained at base, fine-grained above, porous, lenses of siltstone, thin-bedded.	18
Mudstone: gray, shaley.	2

	Feet
Sandstone: pale orange, very-fine-grained, poorly sorted, silty, very calcareous, massive, base of unit flat	3
-Top of Wasatch Formation-	
Mudstone: variegated gray, drab, orange and purple, lenticular sandstones and siltstones.	100
Base of Measured Section	

Measured Section 7
S $\frac{1}{2}$, SE $\frac{1}{4}$, Sec. 34, T. 1 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: light brown, fine- to medium-grained, moderately sorted, porous, silty, thin- bedded, flat-bedded, cross-bedded	17
Covered: inferred shale and siltstone with sandstone stringers	25
Sandstone: light brown, fine-grained, poorly sorted, silty, calcareous, flat-bedded, thin- to thick-bedded, continuous	2
Irregular lenticular sandstones in siltstone and shale. Sandstone: light gray, medium-grained, well sorted, porous, friable.	45
Sandstone: rust brown and gray, fine-grained, poorly sorted, silty, calcareous, massive and thick-bedded, locally thin-bedded and cross-bedded, stringers and lenses of shale, siltstone and granule and pebble conglomerate . .	30
Covered.	47
Sandstone: light brown, fine- to medium-grained, poorly sorted, silty, calcareous, massive, flat-bedded, asymmetric ripple marks, low- angle cross-beds, stringers of gray flaky shale, unit irregular lens.	17
Mudstone: gray and brown.	50
Sandstone: rust brown, fine-grained, poorly sorted, silty, very calcareous, unit lenticular.	11
Sandstone: light gray, fine-grained, moderately sorted, silty, flat-bedded, thin-bedded	3
Gray mudstone.	12

	Feet
Sandstone: rust brown, fine- to medium-grained, massive to laminated, flat-bedded, trough cross-bedded, limonite concretions, silt- stone stringers	12
Gray mudstone with stringers of fine-grained sandstone	20
Sandstone: rust orange, fine-grained, very cal- careous, limonitic, unit continuous	4
-Top of Wasatch Formation-	
Variegated mudstone, containing structureless siltstones and irregular fine- to medium- grained sandstones.	289
Base of Measured Section	

Measured Section 8
N $\frac{1}{2}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 34, T. 1 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: light brown, fine- to medium-grained, well sorted, porous, friable, thin-bedded, flat-bedded, cross-bedded at base	8
Covered: inferred shale	4
Sandstone: light brown, medium-grained, moderately sorted, porous, very calcareous at base, local siltstone conglomerate at base, cross- bedded.	5
Covered: inferred shale	11
Sandstone: light brown, fine- to medium-grained, ripple marked, trough cross beds.	6
Covered: inferred shale	14
Sandstone: light gray, very-fine- to fine-grained, cross bedded.	7
Sandstone: rust brown, medium-grained, poorly sorted, porous, calcareous, carbon granules and molds of small logs, lenses of siltstone and shale - granule conglomerate, cross bedded. .	10
Not sampled.	115
Sandstone: light gray, coarse-grained, poorly sorted, porous, zones of shale- and chert- pebble conglomerate, low-angle cross-beds, channel scour at base of unit	11
Sandstone: rust brown, very-fine- to fine-grained, calcareous, massive, siltstones and shale beds. .	46
Covered: inferred siltstone	7
Siltstone: gray, laminated, clayey, calcareous. . . .	7
Sandstone: pale orange, very-fine- to fine-grained, calcareous, flat-bedded, thin-bedded, laminated, shale stringers.	13

	Feet
Covered: inferred siltstone with shale stringers. . .	43
Sandstone: light gray and rust orange, very-fine-grained, moderately sorted, flat-bedded, low-angle cross-beds, stringers of ostracodal limestone	18
Sandstone: light brown, fine- to medium-grained, poorly sorted, flat-bedded.	13
Gray silty shale	16
Interbedded gray shale and massive siltstone, beds about 3 feet thick	18
Sandstone: gray and light brown, fine-grained, calcareous, thin-bedded, flat-bedded, low-angle cross-beds, base of unit gradational with siltstone and shale.	4
Covered.	70
Sandstone: light gray, fine-grained, flat-bedded. . .	6
Covered.	13
Sandstone: brown, very-fine-grained, flat-bedded. . .	4
Covered: inferred interbedded shale and siltstone, stringers of oolitic limestone.	13
Sandstone: gray, fine-grained, very calcareous, massive	4
Siltstone: gray, calcareous, massive.	3
Sandstone: light brown, fine-grained, poorly sorted, silty, interlaminated with siltstone, flat-bedded	10
Sandstone: light brown, fine-grained, well sorted, very calcareous, sparse ostracods, massive. . . .	4
Siltstone: light gray, massive, flat-laminated. . . .	5
Sandstone: light brown, coarse-grained, moderately to poorly sorted, locally conglomeratic, trough cross-beds, unit continuous	10

	Feet
-Top of Wasatch Formation-	
Covered: inferred variegated mudstone	65
Sandstone: light gray, medium- to coarse-grained, moderately sorted, porous, loosely packed, carbon granules, cross-bedded	5
Shale: black, massive	6
Sandstone: light brown, fine- to medium-grained, massive	1
Base of Measured Section	

Measured Section 9
 From SW $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, to
 NW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 28, T. 1 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: gray and light brown, fine-grained, limonitic, interbeds and interlamina- tions of siltstone and shale, flat-bedded, cross- bedded, ripple-marked	33
Shale: gray, silty, contains stringers of ripple- marked, sandy siltstone	20
Sandstone: light brown, fine-grained, locally heavily laminated	3
Interbedded shale and siltstone, carbonaceous.	3
Sandstone: light gray, fine-grained, poorly sorted, possibly ostracodal, cross-bedded, ripple- marked, limonite concretions.	2
Covered: inferred siltstone and shale	9
Sandstone: light brown, very-fine- to medium- grained, moderately to poorly sorted, silty, porous, friable, flat-bedded, ripple-marked, burrow tubes locally abundant, cross-bedded, becomes massive upward, limonite concretions, siltstone zones more numerous upward.	40
Covered: inferred shale with interbedded siltstone. .	12
Interbedded sandstone, siltstone, and shale, sand- stone dominant. Sandstone: light gray, fine-grained, flat- bedded, ripple-marked, interlaminated with siltstone and shale.	7
Covered: inferred pale green siltstone.	6

	Feet
Sandstone: white, fine-grained, well sorted, calcareous, flat-bedded, thin-bedded to laminated, burrow tubes, cut by ½-foot stringers of ostracodal limestone	7
Covered: inferred gray shale	15
Sandstone: light brown, fine- to medium-grained, moderately to poorly sorted, shale-granule conglomerate at base, heavily cross-bedded - tabular and tangential-wedge, carbonaceous at base, becomes fine-grained and flat-bedded upward.	5
Shale: gray, flaky and papery, upper part contains thin lenses of massive siltstone.	13
Interbedded gray shale and fine-grained silty sandstone	3
Sandstone: light brown, fine-grained, poorly sorted, lightly interlaminated with siltstone, flat-bedded, ripple-marked	4
Covered: inferred siltstone	5
Siltstone: sandy, clayey, interlaminae of shale, carbonaceous	4
Conglomerate: subrounded, siltstone interclasts, 0.5 to 5 cm. in diameter, fine-grained sandstone matrix.	1
Covered.	3
Sandstone: rust brown, fine-grained, friable, massive	3
Covered.	8
Siltstone: coarse, locally sandy, flat-bedded, few low-angle cross-beds.	9
Interbedded gray papery shale and gray clayey siltstone, beds from 1 to 6 inches.	3
Siltstone: light gray, coarse, flat-bedded, few low-angle cross-beds.	2½

	Feet
Sandstone: light brown, fine- to medium-grained, interbeds of siltstone, lenses of shale, thin-bedded, flat-bedded, low-angle cross-beds, ripple-marked	18
Covered: inferred interbedded sandy siltstone and shale	9
Sandstone: light brown, fine- to medium-grained, moderately sorted, thin-bedded, flat-bedded, low-angle cross-beds, becomes massive upward. . .	7
Covered: inferred shale	4
Siltstone: rust orange, laminated, ripple-marked, carbonaceous.	8
Sandstone: light brown, fine-grained, calcareous, friable, laminated, tabular cross-beds, plant fragments	3
Sandstone: light brown, fine-grained, poorly sorted, silty, carbonaceous, flat-bedded, trough cross bedded, contorted bedding, slumped, <u>in situ</u> brecciation.	3
Limestone: light brown, weather: orange, very sandy and silty, dense, grains loosely packed, oolitic (Sample PRC-63-4)	1½
Sandstone: light brown, fine-grained, flat-bedded, few low-angle cross-beds, stringers of gray shale	3
Sandstone: rust orange, fine-grained, ostracodal, carbon granules, massive.	6
Sandstone: rust orange, medium-grained, calcareous, ostracodal.	5
Siltstone: rust orange, flat-bedded, locally calcareous.	21
Interbedded siltstone and shale.	2
Siltstone: rust orange, massive, gray papery shale stringer.	21

	Feet
Interbedded shale and limestone. Shale: pale green, massive, blebs of ostracods. Limestone: rust orange, sandy, ostracodal, massive	7
Shale: pale green, silty, massive.	10
Interbedded shale and fine-grained silty sandstone (Sample PRC-63-5)	20
Sandstone: rust orange, fine- to medium-grained, moderately sorted, silty, porous, shale stringers base of unit flat	58
Interbedded shale and sandstone.	10
Shale: gray, sandstone stringers.	6
Sandstone: rust orange, fine- to medium-grained, poorly sorted, silty, cross-bedded.	10
Gray shale	4
Sandstone: rust orange, fine- to medium-grained, well sorted, porous, flat-bedded, cross- bedded, base of unit scoured into underlying siltstone	20
Covered: inferred siltstone	30
Siltstone: rust orange, sandy	7
Sandstone: rust orange, fine- to medium-grained, well sorted, porous, friable, massive, limonite concretions.	6
Shale: gray, massive, flaky and papery.	8
-Top of Wasatch Formation-	
Mudstone: variegated gray, brown and red, beds of light gray, massive siltstone.	106
Base of Measured Section	

Measured Section 10
SE $\frac{1}{4}$, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 8, T. 1 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: light gray, fine-grained, well sorted, moderate porosity, chert-granule conglomerate at base, locally carbonaceous, heavily cross-bedded.	17
Covered: inferred siltstone with beds of shale	36
Sandstone: light brown, fine- to medium-grained, moderately to well sorted, locally calcareous, cross-bedded.	4
Covered: inferred siltstone	30
Sandstone: gray, very-fine- to fine-grained, moderately sorted, calcareous, very-fine- grained and thin-bedded at base, fine- grained and massive above, ripple-marked, sparse ostracods.	4
Sandstone: gray, fine-grained, moderately sorted, contains blebs of siltstone, locally extremely calcareous (sandy limestone), sparse ostracods (Sample PRC-63-3)	7
Covered: inferred siltstone and minor sandstone	26
Sandstone: pale orange, fine-grained, moderately sorted, calcareous, massive, local cross- bedding, trough-cross-bedded, ripple-marked	16
Covered: inferred shale, continuous stringers of extremely calcareous, fine-grained, ostracodal sandstone	25
-Top of Wasatch Formation-	
Sandstone: light brown, fine- to coarse-grained, grain size variable, local chert-granule conglomerate, large lenses and wedges of siltstone and silty shale, massive, flat- bedded, cross-bedded, bedding thinner and more regular upward, finer grained upward, few burrow tubes.	70

	Feet
Covered: inferred variegated mudstone	24
Sandstone: light brown, fine- to medium-grained, moderately sorted, poorly sorted at base, massive at base, cross-bedded above, burrow tubes, unit lenticular.	8
Base of Measured Section	

Measured Section 11
NW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 27, T. 2 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Covered: inferred gray mudstone, stringers of siltstone and sandstone	50
Sandstone: light brown, fine- to medium-grained, moderately sorted, poorly sorted, and conglomeratic at base, massive, locally cross-bedded, trough- and tangential-wedge, base of unit uneven	25
Covered: inferred shale with sandstone stringers. . .	40
Sandstone: rust brown, fine- to medium-grained, moderately sorted, porous, locally silty, limonitic, carbonaceous, massive, flat- bedded in upper part, scour and fill, trough- cross beds, lenses and zones of siltstone and shale	30
Interbedded siltstone and shale, beds range from 3 inches to 1 foot, contains filled scour channels. Siltstone: light gray, laminated, sandy, ripple-marked, small cross-beds. Shale: light gray, carbonaceous, contains blebs of sandstone and siltstone.	15
Sandstone: light brown, fine- to medium-grained, porous, silty, flat-bedded, ripple-marked, cross-bedded, upper part massive, siltstone and shale stringers	30
Covered: inferred gray shale with sandstone stringers	60
Sandstone: light gray, fine- to medium-grained, poorly sorted, silty, flat-bedded, cross- bedded, zones of shale-pebble conglomerate. . . .	15
Sandstone: light gray, fine- to medium-grained, poorly sorted, silty, porous, lenses and wedges of shale, massive and irregularly bedded.	15

	Feet
-Top of Wasatch Formation-	
Mudstone: variegated, red and gray.	35
Sandstone: light brown, fine- to medium-grained, subangular, silty, flat-bedded, trough- cross-beds, base of unit flat	2
Covered: inferred variegated mudstone, stringers of fine-grained, poorly sorted, flat-bedded sandstone	95
Sandstone: light brown, fine- to medium-grained, subrounded, well sorted, trough and wedge cross-beds (Sample PRC-63-6).	20
Base of Measured Section	

Measured Section 12
 From NW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 25, T. 2 N., R. 95 W.
 To SE $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 22, T. 2 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Sandstone: gray, fine- to medium-grained, moderately sorted, carbon granules, flat- bedded, thin-bedded, unit cut by con- tinuous 1-foot sandy siltstone stringers.	50
Siltstone: gray, massive, very calcareous at base . .	15
Covered: inferred variegated mudstone	40
Sandstone: light brown, fine- to medium-grained, moderately sorted, flat-bedded, locally cross bedded, zones of shale-granule conglomerate, fine-grained upward, unit continuous (Samples PRC-63-2 and PRC-63-11.	43
Sandstone: pale orange, very-fine-grained, well sorted, calcareous, laminated, ripple-marked. . .	2
Mudstone: gray and pale green, peletal.	47
Sandstone: rust orange, fine-grained, moderately sorted, limonitic, massive.	5
Mudstone: gray, silty and sandy	20
Sandstone: pale orange, fine-grained, medium grained at base, moderately sorted, zones of shale-granule conglomerate, locally carbon- aceous, massive few ripple-marks and cross- beds.	30
Not sampled.	150
Sandstone: brown, fine- to medium-grained, poorly sorted, porous, conglomeratic and trough cross-bedded at base, flat-bedded, thin-bedded	18
Gray and brown mudstone.	50

	Feet
Sandstone: brown, medium-grained, moderately sorted, unit lenticular	20
Variegated mudstone.	90
Sandstone: brown, fine- to medium-grained, poorly sorted, porous, friable, locally carbonaceous, trough cross-bedded at base, tangential-wedge cross-bedded above, finer grained upward.	48
Variegated mudstone.	50
Sandstone: brown, medium-grained, conglomeratic, poorly sorted, porous, carbonaceous, chert-pebble and cobble conglomerate at base, highly cross-bedded, unit continuous (Sample PRC-63-10).	10
Variegated mudstone.	95
Sandstone: rust orange, fine-grained, locally very calcareous	25
Gray mudstone.	18
Sandstone: brown, fine-grained, moderately sorted, silty, calcareous, shale lenses, ripple-marked, and cross-bedded at base.	55
Variegated mudstone.	55
Sandstone: brown, fine- to medium-grained, conglomeratic at base, siltstone stringers.	45
Drab mudstone.	35
Sandstone: brown, fine-grained, poorly sorted, silty, calcareous, flat-bedded, thin-bedded, laminated at base	28
Siltstone: gray, coarse, sandy.	5
Sandstone: light gray, fine- to medium-grained, moderately sorted, silty, massive, some tabular cross-beds.	5
Shale: gray, flaky, silty	7

	Feet
Sandstone: brown, fine- to medium-grained, poorly to moderately sorted, locally conglomeratic, massive, locally laminated and cross-bedded . . .	9
Variegated mudstone.	130
Sandstone: light brown, medium-grained, poorly sorted, calcareous, unit lenticular	2
Base of Measured Section	

Measured Section 13, Gentry Ranch
Watering Hole, SW $\frac{1}{4}$, Sec. 3, T. 2 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Limestone: pale orange, sandy and silty, highly ostracodal, laminated, contorted bedding, small-scale cross-beds, symmetrical ripple- marks, few mudcracks, base of unit grades from siltstone, unit continuous	15
Interbedded siltstone and shale with minor sandstone. Shale: gray and brown, flaky, carbonaceous. Siltstone: gray, massive, interlaminations of shale. Sandstone: fine-grained, laminated, flat- bedded.	35
Sandstone: gray and orange, fine-grained, well sorted, very calcareous, locally very limonitic, sparse ostracods, flat-bedded.	13
Gray, silty shale.	4
Sandstone: gray, fine-grained, moderately sorted, sparse ostracods, flat-bedded, trough cross- beds at base.	8
Interbedded shale and siltstone, and minor sandstone .	19
Sandstone: gray, fine- to medium-grained, massive, interlaminations of shale and siltstone	2
Shale: brown, flaky, silty, carbonaceous	5
Sandstone: gray, fine-grained, very calcareous, massive and flat-bedded	3
Siltstone: gray, massive.	4
Interbedded sandstone, siltstone and shale. Sandstone: pale orange, fine-grained, well sorted, laminated. Siltstone: gray, laminated. Shale: gray, carbonaceous.	43

	Feet
Interbedded siltstone and shale. Siltstone: gray, sandy, massive and flat-bedded, locally ostracodal, few small burrow tubes.	
Shale: gray, silty	19
Gray shale	3
Sandstone: gray, fine-grained, well sorted, flat-bedded, ostracod fragments	5
Sandstone: gray, variable grain size, grades from fine silt to medium-grained sand	17
Sandstone: orange, fine-grained, medium-grained at base, well sorted, loosely packed, porous, flat-bedded, unit tabular	4
Siltstone: gray, laminated, grades upward to gray flaky, silty shale.	5
Sandstone: gray and pale orange, very-fine-grained, moderately sorted, flat-bedded, small cross-beds, numerous thin (1-inch) beds of shale and siltstone	12
Siltstone: gray, massive, contorted bedding, interlamination of dark gray shale, few carbon granules	4
Siltstone: pale green, massive.	4
Interbedded sandstone, siltstone and shale. Sandstone: light brown, fine-grained, moderately sorted, massive, locally shale-pebble conglomerate. Siltstone: pale orange, uneven bedding, ripple-cross-beds.	
Shale: light gray, massive, peletal.	9
Interbedded siltstone and shale. Siltstone: gray, pale orange, and pale green, coarse, sandy, beds ½-foot thick.	
Shale: pale green, massive	51
Siltstone: gray, sandy, massive	7
Sandstone: light gray, fine-grained, well sorted, flat-bedded, base of unit scoured	12

	Feet
Shale: gray, massive, locally silty and carbonaceous, grades upward into siltstone.	9
Sandstone: light gray and orange, fine-grained, moderately sorted, locally abundant plant fragments, calcareous, massive.	8
Covered: inferred variegated mudstone, contains fine-grained sandstone stringers.	101
Siltstone: pale orange, flat-bedded, ostracodal, interlaminations of shale	13
Sandstone: gray, fine-grained, moderately sorted, ostracodal, numerous, purplish-gray shale stringers, flat-bedded, laminated, few cross-beds.	27
Shale.	3
Sandstone: brown, fine- to medium-grained, coarse grained at base, moderately sorted, porous, cross bedded, thickness of unit irregular	5
Covered.	16
Sandstone: gray, fine-grained, moderately sorted, massive	9
-Top of Wasatch Formation-	
Covered: inferred variegated mudstone	170
Mudstone: gray, silty	10
Sandstone: rust brown, fine-grained, well sorted, limonitic, flat-bedded, laminated	4
Red mudstone	7
Sandstone: gray, medium- to coarse-grained, poorly sorted, conglomeratic at base, interbeds of red shale, carbonaceous	10
Variegated mudstone.	10
Sandstone: gray, fine- to medium-grained, moderately sorted, massive.	13

	Feet
Covered: inferred gray silty mudstone	14
Sandstone: rust brown, fine-grained, well sorted, limonitic, flat-bedded.	17
Base of Measured Section	

Measured Section 14
 NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 28, T. 3 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Limestone: pale orange, ostracodal, oolitic, pisolitic; lower part dense, ostracodal, silty; top pisolitic, porous, loosely packed. . .	6
Siltstone: orange, flat-bedded, few shale stringers (3-inch) ostracodal, locally abundant ostracods, locally calcareous.	7
Shale: gray, flaky, few thin stringers of fine- grained sandstone and siltstone	28
Siltstone: pale orange, coarse, laminated, flat-bedded, interbeds and laminations of shale, fine-grained, ostracodal, cross- bedded sandstone at top	23
Sandstone: pale orange, fine-grained, discontinu- ous stringers of gray shale, irregular lens of algal(?) limestone at base	4
Covered: inferred interbedded siltstone and shale . .	25
Sandstone: light brown, fine-grained, moderately sorted, cross-bedded, unit tabular.	4
Interbedded siltstone and shale with minor fine- grained sandstone and ostracodal limestone. . . .	24
Sandstone: light gray, grain size variable, grades from medium silt to fine-grained sand, moderately sorted, clean, moderate porosity, few interlaminations of shale	2 $\frac{1}{2}$
Siltstone: gray, stringers of fine-grained sandstone.	18
Sandstone: light gray, fine- to medium-grained, moderately sorted, fine-grained near top and bottom of unit, few low-angle cross-beds.	15
Covered: inferred gray flaky shale.	7

	Feet
Sandstone: gray and orange, fine- to medium-grained, poorly sorted, silty, calcareous, ostracodal and sparse oolites, unit lenticular.	5
Shale: gray, flaky, silty, thin lenses of cryptocrystalline limestone	23
Sandstone: gray and light brown, grain size variable from silt to fine- and medium-grained sand, poorly to moderately sorted, flat-bedded, laminated, few cross-beds at base, shale stringer	22
Siltstone: light brown, coarse, sandy, numerous silty shale stringers	20
Shale: gray and drab, silty, laminae of siltstone . .	7
Sandstone: gray, fine-grained, well sorted, silty at base, massive, flat-bedded, laminated, thin-bedded, limonite concretions	4
Shale: gray, flaky, thin lenses and discontinuous stringers of siltstone and fine-grained sandstone	50
Sandstone: gray, very-fine-grained, moderately sorted, massive, few low-angle cross-beds	4
Covered: inferred siltstone	5
Sandstone: light brown, fine- to medium-grained, medium-grained at base - finer upwards, well sorted, locally poorly sorted, sparse ostracod fragments, locally calcareous, siltstone stringers, flat bedded.	9

Measured Section 15
NE $\frac{1}{4}$, NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 20, T. 3 N., R. 95 W.

Top of Measured Section	Feet
-Sandstone facies (part), Anvil Points Member, Green River Formation-	
Limestone: pale orange, ostracodal, dense flat- bedded, ripple-marked, low-angle cross-bedded, laminated, contorted bedding, base of unit flat (Sample PRC-63-7)	14
Interbedded shale and siltstone. Siltstone: orange, sandy, ostracodal, flat- bedded. Shale: gray, flaky	50
Sandstone: light brown, fine-grained, moderately sorted, flat-bedded, low-angle cross-beds	4
Shale, gray, flaky	17
Sandstone: gray, fine- to medium-grained, moderately sorted, ostracodal, burrow tubes, massive	5
Shale: gray, flaky	20
Sandstone: gray, fine-grained, moderately sorted, locally very calcareous	1 $\frac{1}{2}$
Shale: gray, flaky	15
Sandstone: gray, fine-grained, moderately sorted, grades upward into siltstone	1
Shale: gray, flaky	5
Limestone: orange, ostracodal, sandy, flat-bedded	$\frac{1}{2}$
Shale: gray, flaky and papery	11
Sandstone: gray, fine- to medium-grained, moderately to well sorted, porous, isolated shale-granule interclasts at base, base of unit scoured into carbonaceous siltstone	18

	Feet
Interbedded shale and siltstone.	
Shale: brown, flaky and papery.	
Siltstone: gray, sandy, blebs of very- fine-grained sandstone.	23
Shale: gray, flaky and papery	20
Limestone: orange, sandy and silty, small-scale cross-beds, sparse oolites (Sample PRC-63-1). . .	2
Covered: inferred sandy siltstone	5
Shale: gray, flaky.	4
Covered: inferred sandy siltstone	25
Sandstone: light gray, fine- to medium-grained, moderately sorted, siltstone stringers, massive .	17
Shale: gray, flaky, silty	15
Siltstone: gray, cross-laminated, shale laminae . . .	22
Sandstone: gray, fine- to medium-grained, well sorted, few isolated shale-granules inter- clasts, calcareous, fish scales	3
Siltstone: gray, coarse, friable, flat-bedded, grades upward from shale.	14
Sandstone: gray and brown, fine- to medium-grained, flat-bedded	3
Covered: inferred gray silty shale.	65
Sandstone: light gray, fine- to medium-grained, moderately sorted, friable, massive, few cross beds.	5

- 225 feet to top of Wasatch Formation -

Base of Measured Section