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Stratigraphy of the Douglas Creek Member, Green River Formation, Piceance Creek Basin, Colorado

by

CHARLES W. CLINE

Brigham Young University
Department of Geology
Provo, Utah

STRATIGRAPHY

OF

DOUGLAS CREEK MEMBER, GREEN RIVER FORMATION,

PICEANCE CREEK BASIN, COLORADO

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ABSTRACT

The Piceance Creek Basin is located in northwestern Colorado, ten miles west of the town of Meeker, Colorado. The basin has an areal extent of 4,560 square miles. This report covers the northern 1,600 square miles of the basin.

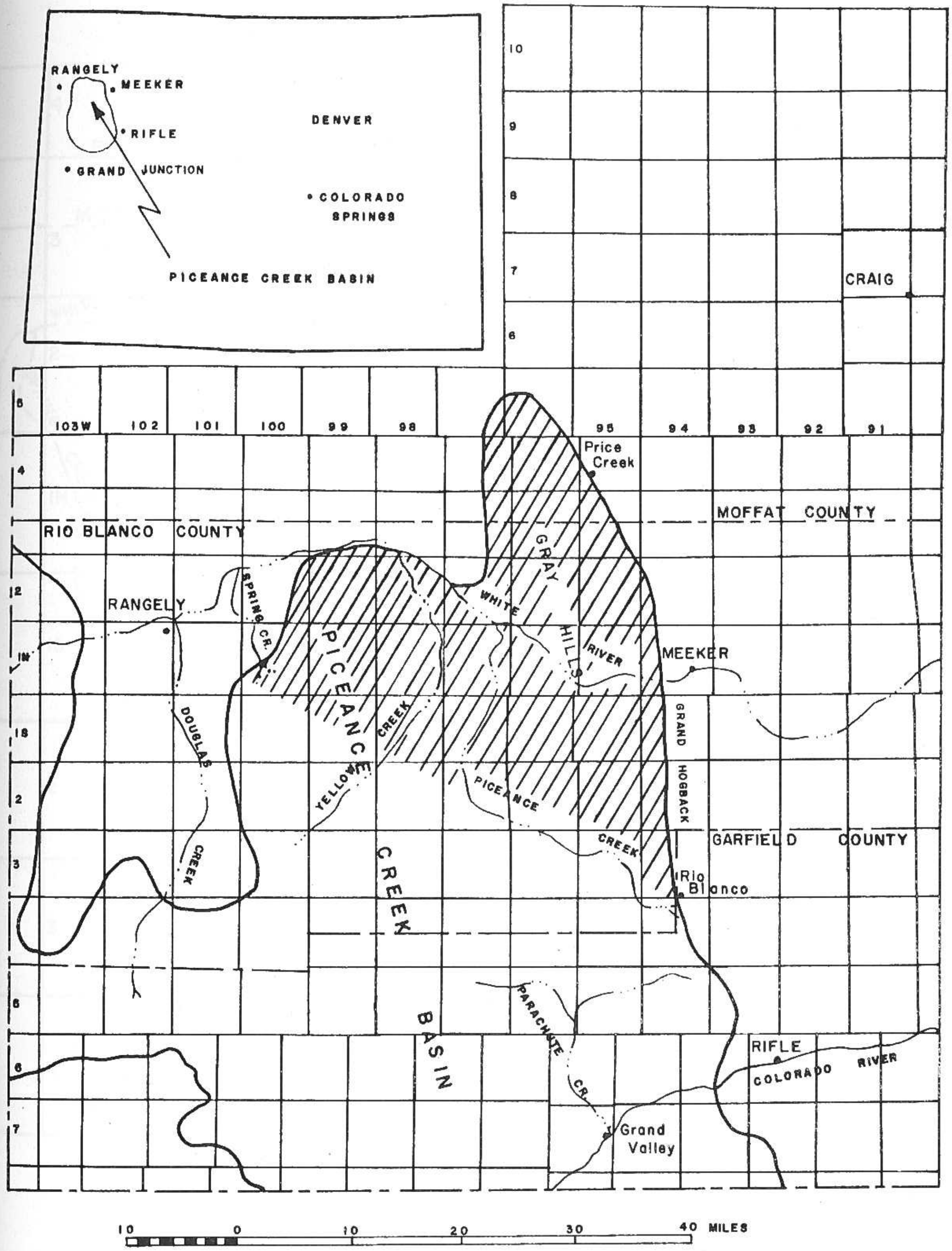
The Green River formation, of upper middle Eocene age, is well exposed around the rim of the Piceance Creek Basin. This report deals with the lower member, Douglas Creek, of the Green River formation. The Douglas Creek member is composed of quartz sandstone, shale, marlstone, mudstone, and various types of limestones.

The sediments of the basal member of the Green River formation were laid down in a shallow, relatively quiet, fresh-water lake. The strandline of this ancient lake shows minor regressions and major transgressions.

The quartz sandstone beds thicken north and south of Fourteen-mile Creek (figure 1) and thin rapidly basinward, to the west. The quartz sandstone facies of the Douglas Creek member interfinger with shale and limestone facies basinward.

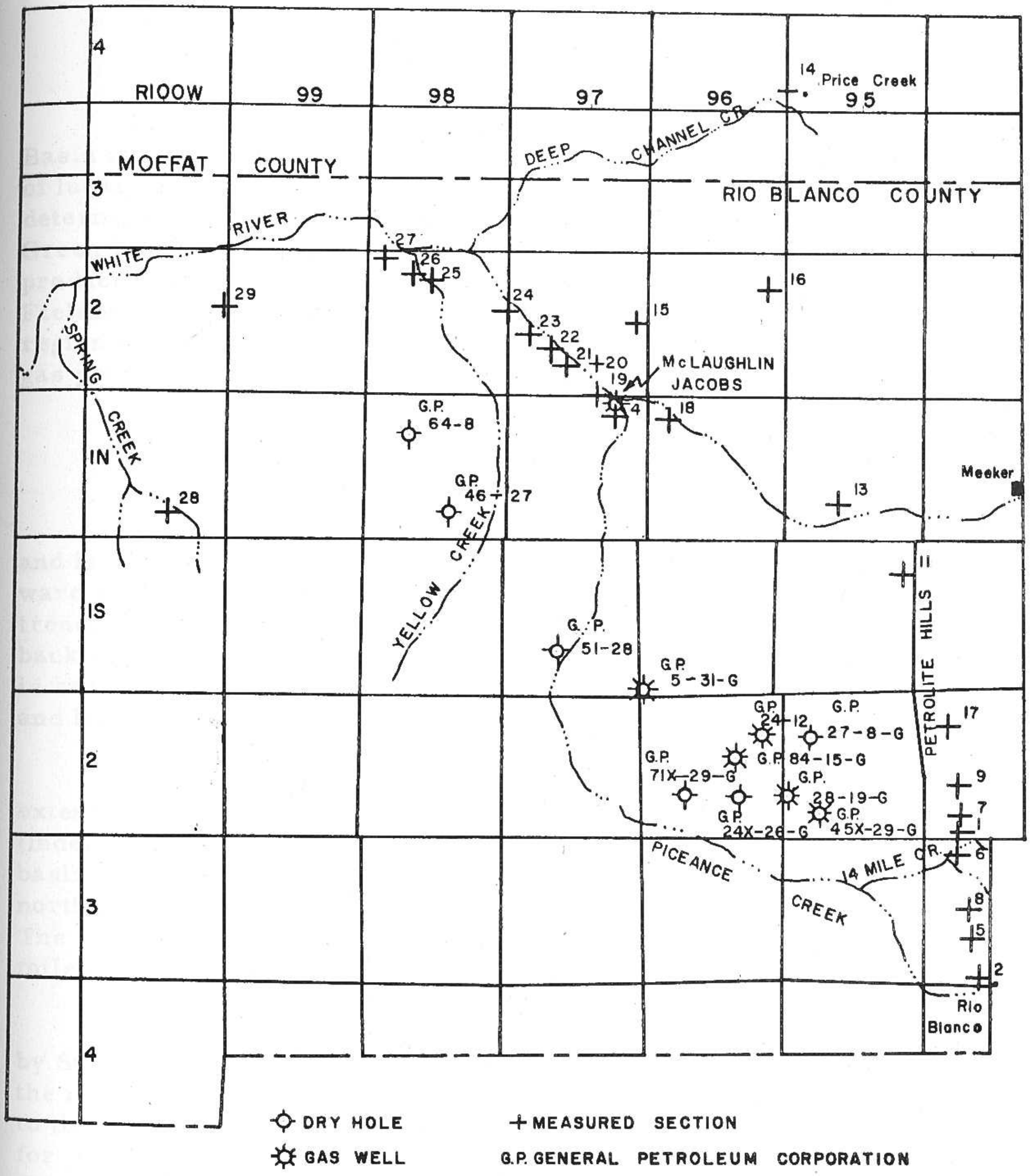
Source area for the basal Green River sediments appears to have been east of the basin in what is now the Park Range of the Southern Rocky Mountain Province. Studies indicate that two main streams brought sediments into this ancient lake, one from the northeast, the other from the southeast.

The basin represents one of the richest oil-shale reserves in the United States, with an estimated reserve of over 1,200 billion barrels of oil. This estimate reflects the total oil content of the deposit with no allowance made for mining and processing losses. The basin also offers considerable oil and gas possibilities, with the Piceance Creek Gas Field presently furnishing 16,000 MCF of gas per day for the Pacific Northwest Pipeline.



AREA IN WHICH STUDY WAS MADE IS CROSS-HACHURED

INDEX MAP



LOCATION OF WELLS AND MEASURED SECTIONS

FIGURE I

INTRODUCTION

PURPOSE AND SCOPE OF WORK

The Green River formation, as exposed in the Piceance Creek Basin in northwestern Colorado, offers an excellent opportunity for study of lucustrine-type sedimentation. This study was made in an effort to determine the facies relationships in the Douglas Creek member of the Green River formation. The study entails a correlation of the basal gas-producing sandstones and shale sequence in the Piceance Creek Gas Field with the limestone and shale sequence exposed in the Yellow Creek region to the northeast. It is hoped that through such a study the oil and gas potentials of the basal Green River member can be better evaluated.

LOCATION AND ACCESSIBILITY

Piceance Creek Basin is in the Middle Rocky Mountain Province and is both a structural and topographic basin. The basin extends northward in the Gray Hills region to near the eastern limit of the east-west trending Uinta Mountains, and is bounded on the east by the Grand Hogback and on the west by the Douglas Creek Arch. In general the basin is saucer-shaped, bordered by steep cliffs of the Green River formation and bad-land topography carved in the underlying Wasatch formation.

Piceance Creek Basin is located in northwestern Colorado and extends from T. 5 N. to T. 8 S., and from R. 94 W. to R. 101 W. (Index Map). This report is primarily concerned with the part of the basin which extends from Rio Blanco on the south to Price Creek on the north, and from Powell Park on the east to Spring Creek on the west. The studied portion of the basin includes approximately 1,600 square miles.

Piceance Creek Basin can be reached from Meeker, Colorado, by State Highways 64 and 13. State Highway 64 parallels the basin on the north, and State Highway 13 parallels the basin on the east. Access to the area has been improved by stockmen who have built roads suitable for jeep travel. One such road follows the eastern rim of the basin. Construction of the Pacific Northwest Pipeline has made portions of the northern rim accessible to jeep travel. Localities of measured sections can be reached on these roads.

Field work is limited in northwestern Colorado to six or eight months of the year, for winter snow generally lasts from November until March. Summer months are generally dry, consequently little time was lost due to bad weather.

A thick growth of oak brush covers much of the basin and hinders field work.

FIELD METHODS

The field work lasted from July until late September in the summer of 1956. Stratigraphic sections were measured at selected localities around the rim of the basin. Locations of these sections were plotted in the field on aerial mosaics furnished by General Petroleum Corporation. Thicknesses of beds were determined by use of a steel tape or a hand level. Attitudes were taken with a Brunton compass. Field samples were collected from some of the unique lithotopes and biotopes.

In a lucustrine-type sedimentation such as in the Piceance Creek Basin, correlation from one section to another is frequently difficult. Therefore a preliminary correlation diagram was constructed in the field at the end of each field day.

LABORATORY METHODS

Fourteen particle-size analyses of the quartz sandstones were made utilizing the following method. Weighed dry samples were placed in dilute hydrochloric acid and allowed to stand until the quartz grains separated following etching of the calcium carbonate cement. Generally samples disaggregated in the dilute acid in 24 hours. The residue was then washed, dried, re-weighed and placed in a standard seive set with screen openings corresponding to the Wentworth scale (Wentworth, 1922). Histograms were constructed to show size distribution of the particles within the characteristic quartz sandstones. Two different methods were used to compare the results of these tests. First, histograms from different beds of one section were compared; and second, histograms from the same interval in different sections were compared.

Thin sections were prepared of oil-stained sands by standard methods.

Analyses of quartz sandstones were made to determine the presence or absence of heavy minerals. Disaggregated quartz sandstone samples were separated in a solution of bromoform.

Micropaleontologic work on collected samples consisted of separating the microfossils from the surrounding mineral grains and rock fragments. Microfossils were disaggregated by the writer in the following manner. Samples were broken into fragments less than one inch in diameter and allowed to stand in a water soluble detergent solution. In some instances the solution and fragments had to be boiled before the fossils separated from the matrix. Generally the ostracodes would separate from the rock particles in 24 hours.

After the fossils were disaggregated the samples were picked and all ostracodes placed on faunal slides for microscopic identification.

Three final correlation diagrams of the area were made using a scale of one inch equaling 1 and 3/4 miles. A sand-shale ratio map and a limestone percentage map were drawn from field and laboratory information.

PREVIOUS WORK

Peale (1874) was one of the first men to recognize the Green River group, which then included the Green River and Wasatch formations. A few years later Peale (1876) made a good reconnaissance map of the Green River group of the area drained by the Colorado River. White and Erdlich (1876) mapped the Tertiary and older formations from the head of the Colorado River to Ouray, Utah. Some years later Gale made a reconnaissance map of a part of the Green River formation along the eastern margin of the Piceance Creek Basin (Bradley, 1931). In 1916 Winchester studied the oil-shales in northwestern Colorado and adjacent areas.

One of the most complete reports on the basin was published by Bradley in 1931. In this report he divided the Green River formation into four members in descending order: Evacuation Creek, Parachute Creek, Garden Gulch and Douglas Creek members.

During recent years considerable interest has been given to the oil-shale in this basin. The following is a list of different U. S. G. S. Oil and Gas Investigation Maps of the region. Duncan and Belser (1950) mapped the eastern portion of the basin from T. 1 S. to T. 4 S., R. 98 W. to R. 94 W. The Naval Oil Shale Reserves unit located in the southeastern corner of the basin was mapped by Duncan and Denson (1949). The DeBeque oil-shale area on the southern portion of the basin was mapped by Waldron, Donnell and Wright (1951). The Cathedral Bluffs region was mapped by Donnell, Cashion and Brown (1953).

A number of oil companies have holdings in the basin and are interested in the oil, gas and oil-shale reserves.

STRATIGRAPHY

NOMENCLATURE

The Green River formation was named by Hayden (1869) from excellent exposures near the town of Green River, Wyoming. Berry (1925) assigned the age of the formation to middle Eocene on the results of his flora studies. Age of the Green River formation was given by Osborn (1929) as the upper part of the lower Eocene. A study by Mr. Celdon Lewis (personal communication) on the nomenclature of the Uinta formation shows that the Green River formation in the Green River Basin is not entirely contemporaneous with the Green River formation in the Uinta and Piceance Creek Basins. The Green River formation south of the Uinta Mountains is time equivalent to the upper Green River and lower Bridger formations north of the Uintas. Thus the Green River formation of the Piceance Creek Basin should be assigned to the upper middle Eocene epoch. It is also interesting to note from Mr. Lewis' work (personal communication) that in at least one locality in the Uinta Basin the upper 300-400 feet of the Green River formation grades laterally into typical Uinta lithology. Key beds, interpreted as time lines, carry through this lateral change in lithology. This would suggest that in part, the Green River and Uinta formations in the Uinta Basin are contemporaneous and do not represent time breaks.

In the Piceance Creek Basin the Green River formation was divided into four members by Bradley (1931). These are, in ascending order, the Douglas Creek member, a sandstone-shale-limestone unit; the Garden Gulch member, a shale and marlstone unit; the Parachute Creek member, an oil-shale unit; and the Evacuation Creek member, a sandstone and marlstone unit (Duncan, 1950).

Bradley named the Douglas Creek member from the type section at the head of Douglas Creek in northwestern Colorado.

SEDIMENTARY ANALYSES

GENERAL

The writer will discuss vertical changes in sedimentation under three general headings: coarse clastic terrigenous deposits; fine clastic terrigenous deposits; and calcareous deposits. Horizontal variations in sedimentation will be discussed in the section on facies changes.

COARSE CLASTIC TERRIGENOUS DEPOSITS

In this paper the writer will restrict the term sandstone to a consolidated rock composed of grains greater than 1/16 mm and less than 2 mm in diameter. The adjective preceeding the term sandstone will describe the chief mineral of the rock.

Quartz sandstones are the dominant deposit of this group and form bold cliffs around the rim of the basin. These sandstones are principally medium-brown to buff on the weathered surface, yellow-brown to medium-brown on the fresh surface, and show a marked contrast to the underlying variegated mudstones of the Wasatch formation. Frequent local variation in the color of the sediments was observed throughout the area, but these changes could not be traced laterally.

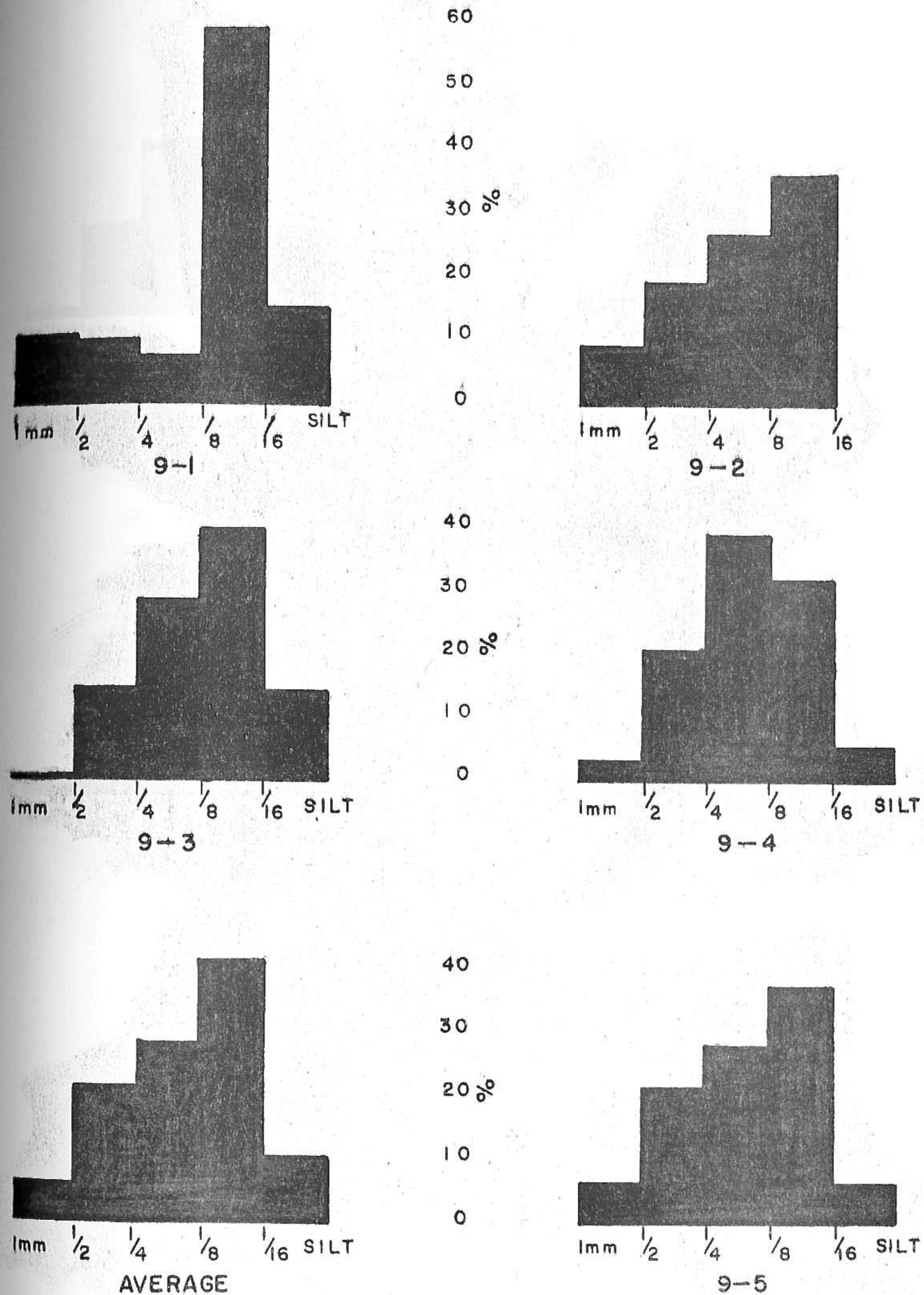
Two common types of sedimentary rocks found in the coarse clastic deposits are, (1) the oil-stained quartz sandstones of the Petrolite Hills region (figure 1), and (2) the "salt and pepper" beds found throughout the basin. The term "salt and pepper" will be applied to sandstones that are black and white and composed chiefly of quartz and chert fragments. Good exposures of these beds can be seen in measured section 17 (plate 1).

The coarse clastic sediments consist primarily of allogenic quartz grains with varying amounts of black and gray chert. Heavy mineral analyses conducted on five quartz sandstone samples from different horizons indicated no minerals with a specific gravity greater than 2.86. Analyses of thin sections of oil-stained sandstones agreed with those of the heavy liquid separation.

Sizes of the individual grains range from coarse to very-fine sand, with fine to very-fine sand dominant (Wentworth, 1922). Histograms constructed from the results of particle-size analyses show a marked lateral change in grain size and only a slight vertical change in grain size.

Measured section 9 (plate 1) was selected for analyses in an attempt to determine if any radical change in size distribution occurred vertically through the section. Five samples were selected from various horizons within the section for particle-size analyses. A comparison of the six histograms (figure 2) constructed from the results of this study shows a remarkable consistency in the size range. Fine to very-fine sand is predominant with a slight increase in size vertically.

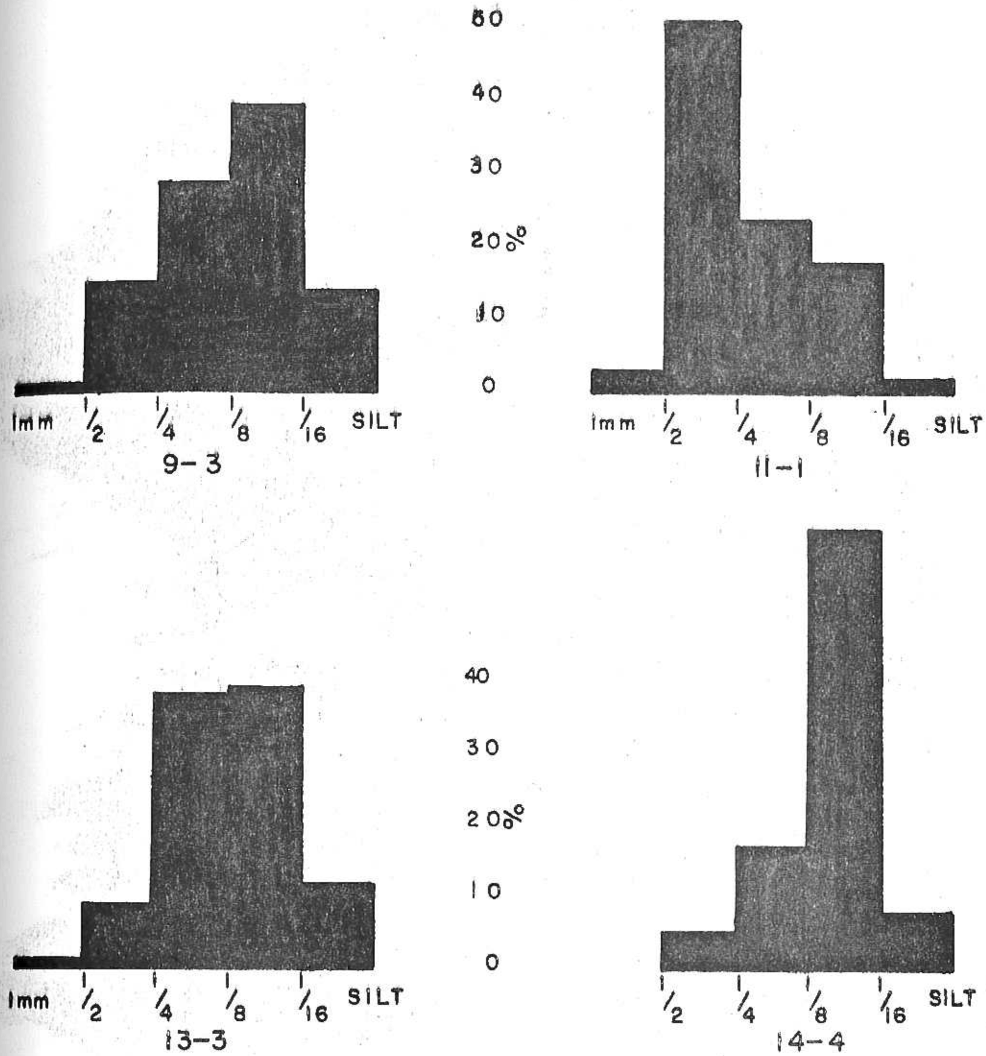
To determine the lateral change in grain size, samples were collected from approximately the same horizon around the eastern rim of the basin. This horizon is lettered C on plate 1 and is approximately 200 feet above the Wasatch-Douglas Creek contact. Because of the



HISTOGRAMS OF SIZE-PARTICLE ANALYSES

MEASURED SECTION 9

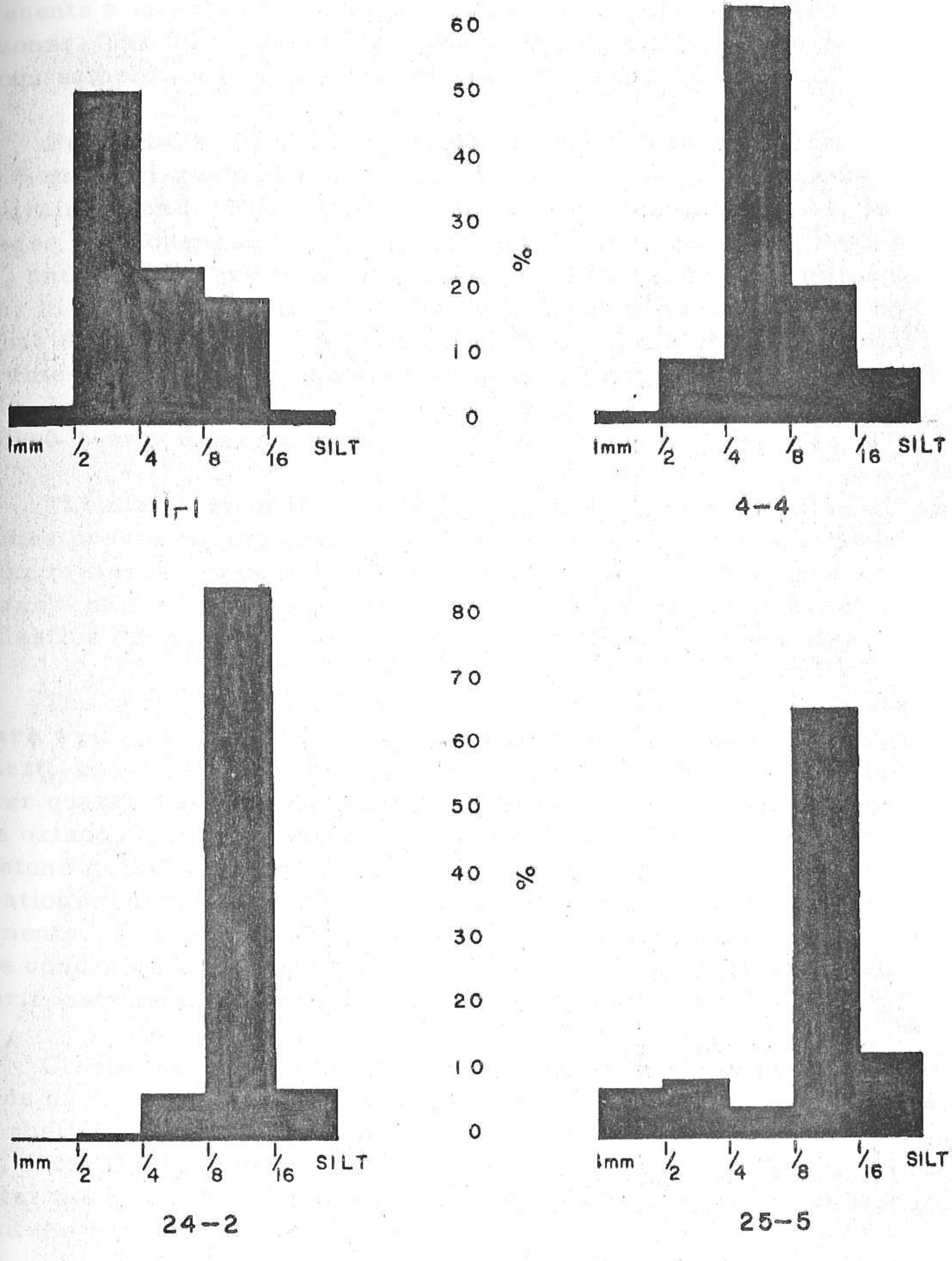
FIGURE 2



HISTOGRAMS OF SIZE-PARTICLE ANALYSES

EAST SIDE PICEANCE CREEK BASIN

FIGURE 3



HISTOGRAMS OF SIZE-PARTICLE ANALYSES

NORTH SIDE PICEANCE CREEK BASIN

FIGURE 4

lateral inconsistency of sandstone beds along the northern rim of the basin, it was impossible to collect samples from the same horizon. Thus figure 4 represents a lateral comparison of particle-size analyses from different horizons. The following break-down of the percentage size-range of the various samples will help show this lateral change in grain size.

Percentages of different grain sizes in measured section 9 are: 14.7 % medium-grained sand, 28.7 % fine-grained sand, and 39.7 % very fine-grained sand. Nine miles north, in measured section 11, the percentages have changed to 50.8 % medium-grained sand, 24.1 % fine-grained sand, and 17.8 % very fine-grained sand. Four and a half miles further north, in measured section 13, the percentage of medium-grained clastics has decreased to 8.5 %, with 38.0 % fine-grained sand, and 38.8 % very fine-grained sand. Another 18 miles north, at Price Creek (figure 1), 5.2 % of the clastics are medium-grained, 16.9 % fine-grained, and 61.0 % very fine-grained.

The diameter of the clastic fragments on the north side of the basin becomes progressively smaller toward the west (figure 4). At Piceance Creek, measured section 4, the particles are mostly fine-grained (63.5 %). Ten and a half miles further west, at Yellow Creek, measured section 25, the clastics have graded into a very fine-grained quartz sandstone (66.0 %).

The quartz and chert grains range from subrounded to subangular and are well-sorted. The writer interprets the degree of rounding, amount of chert, and excellent sorting as indicative of reworked deposits of earlier quartz sandstones. Krynine (1941) calls such deposits second-cycle orthoquartzite. Pettijohn interprets the presence of chert in quartz sandstone in the following way. "Its (chert) presence is one of the best indications that the containing rock has been derived from pre-existing sediments. In most cases the presence of chert probably is the record of the condensation of a great body of limestone in which it was once a minor constituent." (Pettijohn, p. 99, 1949).

Clastic sediments are bound together with calcium carbonate. Degree of induration seems to be determined by the percentage of ostracode shells in the matrix. The origin of the calcium carbonate is twofold: first, from the ostracode shells; and second, from ground water. In general the quartz sandstones are friable where they crop out along the rim of the basin.

All gradations in bedding can be seen in these lucustrine deposits. The thickness of the beds ranges from a few inches to many feet. Bedding is regular with only local irregularities within the quartz sandstones and along the bedding planes. Current and oscillation ripple marks were noted, with the oscillation type dominant. Mud cracks are abundant along bedding planes. Quartz sandstone beds show cross-bedding through a limited vertical and horizontal range.

The following faunule was collected from this section:

Candona pagei Swain (10953-398)

Erpetocypris ? sp. (10953-398)

Cypridea bisulcata Swain (10953-398)

Cyprois cf. marginata (Strauss) (10953-398)

Unio clinopisthus White (10945-13)

Unio haydeni Meek

Goniobasis carteri Conrad

Goniobasis cf. arcta Meek (10954-133)

Goniobasis nodulifera Meek

Viviparus wyomingensis Meek (10946)

Viviparus paludinaeformis Hall

Helix viparia White (10946)

Physa pleromatis White

Fragments of bones were found in the quartz sandstones at Price Creek. Bradley (1931) suggested that such particles are crocodile and turtle bones.

Porosity and Permeability. -- The excellent sorting of the subangular to subrounded quartz grains offers optimum condition for high porosity and permeability. A study of the surface exposure shows good effective porosity and permeability of the quartz sandstone.

Secondary Structural Features. -- Slickensides along the bedding planes are conspicuous on the east rim of the basin. These slickensides help show the differential bedding movement along the Grand Hogback in post-Eocene time. Other secondary structural features include jointing and small fractures.

FINE CLASTIC TERRIGENOUS DEPOSITS

General. -- Sedimentary rocks included under this term are shale, marl and mudstone. Marl includes rocks which are semifriable mixtures of from 25-75 % clay and the remainder calcium carbonate. Mudstone includes rocks that are consolidated, without laminations or fissility, and are composed of fragments which range in size from silt to clay. The term shale is applied to rocks that are composed of silt- to clay-sized particles and show fissility (Pettijohn, 1949).

In general the fine clastic sediments are gradational between the quartz sandstones of the basal Douglas Creek member and the paper shales of the overlying Garden Gulch member. Paper shale is defined as finely laminated clays, silts, muds and marls that part along closely spaced bedding planes.

Shale. -- Shales of the Douglas Creek member range from light yellow-brown to gray on the weathered surface and are medium-brown on the fresh surface. The few oil-shales which occur in the Douglas Creek member weather to a light-gray and are dark-brown on the fresh surface. The shales form slopes and are usually covered with float from the beds above. Within the shale units are thin beds of quartz sandstone and thin ostracodal limestone bands. Most shale beds are highly fractured with crystalline gypsum filling the fissures.

Along the eastern rim of the basin a thin layer, which is composed of lignite particles and fine quartz grains, is found within the shale. These lignite beds are restricted to the Petrolite Hills region and do not form a conspicuous part of the shale.

Another local variation in the shale units was observed in the upper horizons of measured section 14 (figure 1). These shales are gray on the weathered surface and light green on the fresh surface. A good exposure of this green shale unit can be seen north of the Keystone Ranch in the Gray Hills, where the unit crops out 838 feet above the Wasatch-Douglas Creek contact.

Shales along the eastern flank of the basin show slickensides from bedding adjustments caused from the folding of the Grand Hogback monocline.

The following microfossils were found in the shale units:

Candona pagei Swain

Erpetocypris ? sp.

Cypridea bisulcata Swain

Cyprois cf. c. marginata (Strauss)

Marlstone. -- Marlstones range from gray to light-brown on the weathered surface, are medium-brown on the fresh surface, and are easily differentiated from the characteristic blue-gray marls found higher in the section. The weathered marlstones of this unit resemble the mudstone and shale. Thin beds of sandstone and limestone also occur within the marlstone units. Weathered marlstone slopes are partially covered by talus from the overlying quartz sandstone cliff formers. Fossils were not found in the marlstone beds.

Mudstone. -- Mudstones of the Douglas Creek member are principally yellow-brown on the weathered surface and medium-brown on the fresh surface. Many local variations in color were noticed in this unit, but these mudstones can be readily distinguished from the variegated mudstones of the underlying Wasatch formation. The unit grades both laterally and vertically into quartz sandstones and shales, and the outcrops are generally covered by float. As in the other fine clastic deposits, thin bands of sandstone and limestone are found within the mudstone units. The bedding of the mudstones ranges from a few inches to a few feet. Fossils were not found in the mudstone beds.

In describing the different units in the Douglas Creek member, the writer interpreted the lithology of the covered units by examining the float and by digging through the cover to examine the underlying beds where possible.

CALCAREOUS DEPOSITS

General. -- Two types of calcareous deposits, oolitic limestone and organic limestone, are included in this section.

Oolitic limestone. -- The oolitic limestones very from light- to medium-brown on the weathered surface and are medium-brown on the fresh surface. The oolitic limestone beds are restricted to the northern portion of the basin. Oolitic deposits show all gradations from oolitic quartz sandstone to arenaceous oolitic limestone, and from oolitic ostracodal limestone to ostracodal oolitic limestone.

The oolites range in size from 1/4 mm to 2 mm with the majority being between 1/2 mm to 1 mm in diameter. The oolites are composed of concentric layers of calcite around very fine quartz grains. A polished section was stained with cobalt nitrate to determine if the concentric layers are aragonite or calcite. The stained section shows a preponderance of calcite. The oolites are cemented with a calcium carbonate paste. Thickness of the beds is generally less than one foot. Beds form sedimentation breaks within the fine clastic deposits. Oolitic limestone beds also can be found capping the quartz sandstone beds along the northern rim of the basin.

Pseudo-oolitic deposits are found in conjunction with the true oolitic beds. Pseudo-oolites are subspherical quartz grains incrusted with a thin coating of calcite. The pseudo-oolites closely resemble the true oolites and require close examination to distinguish between the two.

Ostracodal limestone. -- Ostracodal limestone beds are by far the most abundant organic limestone units and are found throughout all sections. The color of the weathered surface ranges from light-brown to medium-brown, with little change in color on the fresh surface. Ostracode shells are incrusted with a film of calcium carbonate which makes specific identification difficult. The beds grade laterally and vertically into quartz sandstone and oolitic limestones.

Ostracodal units are generally thin-bedded and can be found capping many of the quartz sandstone beds as well as forming thin stringers in the shales and mudstones. Near the Douglas Creek-Garden Gulch contact, thin-bedded ostracodal limestones form "flagstones" in the monotonous shale sequence.

Another interesting type of ostracodal deposition is found in particular quartz sandstone beds along the northern portion of the basin. Thin layers or stringers of ostracodes are found within the quartz sandstone units. Fossiliferous layers are approximately one inch thick, and individual layers are separated by one to two feet of quartz sandstone. In measured section 20, this rhythmic pattern of deposition was found 56 feet above the Wasatch-Douglas Creek contact. In this unit the thin, one inch, fossiliferous beds are separated by one foot beds of quartz sandstone, and the total thickness of the unit is approximately 25 feet. This same rhythmic pattern was noted in measured sections 19, 21, 23 and 25, but was found to be little help in correlating between sections. The writer interprets this rhythmic pattern as a catastrophic killing of the ostracodes, followed by a normal depositional period. However, samples were not collected so size-frequency curves could not be plotted.

The following ostracodes were collected from this lithology:

Candona pagei Swain (10951-79)

Erpetocypris ? sp. (10951-79)

Cypridea bisulcata Swain (10951-79)

Cyprois cf. c. marginata (Strauss) (10951-79)

Gastropodal limestone. -- A highly fossiliferous limestone bed crops out in the lower horizons along the northern rim of the basin. This same bed is present in some of the wells in the Piceance Creek unit, but was not found along the eastern portion of the basin. The color of the weathered and fresh surfaces ranges from medium-brown to blue-black. Gastropods found in the blue-black limestone beds are white and give the deposit a unique appearance.

This fossiliferous limestone bed is composed of ostracodes, gastropods, and pelecypods, with the gastropod *Goniobasis* forming a conspicuous part of the lithology. The fossils are silicified steinkerns or internal molds of the original gastropod, *Goniobasis*. The writer will refer to this type of bed as the *Goniobasis* limestone bed in this report. It is interesting to note the change in color and composition of this bed where it is exposed. In the Piceance Creek area, measured section 4, the bed is a good fossiliferous limestone with a medium-brown color. From the west side of White River Dome to Yellow Creek (figure 1), the *Goniobasis* limestone bed is blue-black and is partly silicified. In measured section 25, just west of Yellow Creek, the bed is weathered to an unconsolidated limestone bed, with only a few *Goniobasis* steinkerns remaining. In less than a mile to the west this weathered limestone grades back into the blue-black *Goniobasis* limestone bed. At Spring Creek, measured section 28, the bed has changed to a medium-brown *Goniobasis* limestone that shows a marked resemblance to the same bed at Piceance Creek.

It appears that after the limestones were formed, the fossils were etched and then replaced by silica. The blue-black beds represent a higher degree of replacement of the calcite by silica.

The *Goniobasis* limestone bed is relatively stable in thickness all through the Piceance Creek Basin. The bed ranges from one to three feet thick.

The following fossils were found in this lithologic unit:

Candona pagei Swain

Erpetocypris ? sp.

Cypridea bisulcata Swain

Cyprois cf. marginata (Strauss)

Unio clinopisthus White

Unio haydeni Meek (10943-44)

Goniobasis carteri Conrad (10946-11)

Goniobasis nodulifera Meek (10948-21)

Viviparus wyomingensis Meek (10949)

Viviparus paludinaeformis Hall (10944-5)

Helix viparia White

Physa pleromatis White (10943-44)

Algal limestone. -- Algal limestone beds form another distinctive organic deposit. These beds have a light-brown color on both the weathered and fresh surfaces, and have a characteristic meringue-type weathered surface. Algal "reefs" described by Bradley (1931) are not as abundant in the northern part of the basin as in the Parachute Creek region to the south. A characteristic algal limestone bed can be seen in measured section 14, at Price Creek, 512 feet above the Wasatch-Douglas Creek contact.

FORMATIONAL CONTACTS

GENERAL

Upper and lower contacts of the Douglas Creek member can best be determined by observing the complete erosional escarpment from a distance. A definite color and lithologic break can be observed above and below the Douglas Creek member. Gray shales of the overlying Garden Gulch member show a marked contrast to the medium-brown to buff quartz sandstones of the Douglas Creek member. Below the medium-brown to buff quartz sandstones are highly colored mudstones and shales of the Wasatch formation.

Quartz sandstones of the Douglas Creek member are cliff formers between the underlying bad-land topography of the Wasatch formation and the vegetated slopes of the overlying Garden Gulch member. A good exposure of this cliff former can be seen by looking north from Rio Blanco (figure 1).

DOUGLAS CREEK-WASATCH CONTACT

The Douglas Creek member lies conformably upon the Wasatch formation throughout the basin. The lower contact of the Douglas Creek member is taken at the first appearance of a well-sorted quartz sandstone above the variegated shales and mudstones. The uppermost Wasatch bed is generally a gray mudstone and makes a sharp contrast to the overlying light-brown quartz sandstone. The contact can be determined by the change in lithology as well as by color.

This contact is well-exposed on the east side of the basin. However, along the northern rim of the basin the contact is more difficult to determine. From the west side of the Gray Hills, measured section 18, westward, the upper Wasatch formation becomes progressively more sandy. These upper sands of the Wasatch formation are poorly sorted and range from medium- to coarse-grained; they should not be confused with the lower sands of the Douglas Creek member. Even though the upper Wasatch beds become progressively more sandy, a good mudstone break still separates the lower quartz sandstones of the Douglas Creek member from the Wasatch formation.

The first appearance of gastropods and pelecypods in the Douglas Creek member cannot be used to pick the contact because these same fossils were found in the upper sandstones of the Wasatch formation.

DOUGLAS CREEK-GARDEN GULCH CONTACT

The Douglas Creek member is overlain conformably by the Garden Gulch member. The contact between these two members is gradational. The upper contact was determined by the change in color of the beds. Upper beds of the Douglas Creek member are composed of shale, sandstone and limestone layers. When the shale units become more predominant than the quartz sandstone units, the color changes from medium-brown to light-gray. The contact is drawn at this color change. The upper break in the quartz sandstone cliff former is also useful in determining this contact.

The contact along the eastern side of the basin is fairly well defined by the lower limit of the vegetation. Thick oak brush covers the shale slopes in contrast to the relatively barren cliffs of the Douglas Creek member. The upper contact is more difficult to determine westward from Yellow Creek (figure 1).

The upturned edges of the Douglas Creek member and part of the Garden Gulch member were truncated during the erosion of a stream-cut terrace which lies approximately 500 feet higher than the present White

River channel. A thin conglomerate now lies unconformably on the truncated edges of these two members. To determine the upper contact of the Douglas Creek member the writer walked the ravines headward until a preponderance of shale was found.

SURFACE CORRELATIONS

GENERAL

Since sections in a lucustrine basin are frequently difficult to correlate, several methods were tried. The most successful methods will be listed. Mr. Celdon Lewis, formerly an instructor at Brigham Young University, suggested that each measured section be plotted and correlated at the end of each field day. Mr. Lewis was working on a similar problem in the Uinta Basin and was familiar with the correlation problems. This correlation method proved to be very valuable.

The writer found that a thorough knowledge of changes in lithology in the Douglas Creek member is extremely important. Thin limestone beds could be used for correlation if sections were measured at relatively close intervals. These limestone beds were used whenever possible in tying the measured sections together. Another method of correlation consisted of walking out key-beds. This was very useful in areas of slight vegetation.

RIO BLANCO TO PRICE CREEK

Measured sections along the eastern flank of the basin were correlated by thin ostracodal limestone beds or continuous quartz sandstone beds. Sections were measured at frequent intervals to increase the accuracy of such work. An examination of plate 1 shows that the base of the Douglas Creek member does not represent a time line. The longest correlation on the eastern side of the basin is from Powell Park, measured section 13, to Price Creek, measured section 14, where for 17.75 miles, thickness of key quartz sandstone beds remained relatively constant.

POWELL PARK TO SPRING CREEK

Where the White River cuts through the central portion of the Gray Hills (Index Map), the Douglas Creek member of the Green River formation is covered. To correlate across this covered part, the writer measured sections in Scenery Gulch, measured section 16, and north of

White River Dome, measured section 15, where good exposures of the Douglas Creek member are found. From Piceance Creek, measured section 4, westward to Spring Creek, measured section 28, correlations were determined by the presence of a Goniobasis limestone unit which is considered a key-bed. This Goniobasis limestone is weathered so that it is difficult to recognize in only a few places within the northern limits of the basin. In such places the writer walked the key-bed between good exposures to be sure of the correlations.

SUB-SURFACE CORRELATIONS

Sub-surface correlations were based on the excellent character of electric logs from the Piceance Creek Gas Field and wells in the Yellow Creek area. The character of the electric logs can be seen on plate 3. Two marked resistivity deviations, or "kicks", in the shale sequence are found on the majority of logs taken in this basin. The deeper resistivity "kick" will be designated as the "B" marker in this report.

Measured section 6 is tied to the Piceance Creek well, 28-19-G, by the change in the shale sequence. This change in lithology of the outcrop seems to correspond with the change in lithology that causes an increasing resistivity on the electric logs. The electric logs from the Piceance Creek well and the two Yellow Creek wells were correlated on the basis of the "B" marker.

In the Piceance Creek well, 28-19-G, the Goniobasis limestone bed was encountered at a depth of 3472 feet. This key-bed was used to tie the well logs to measured section 29 which is located northwest of the Yellow Creek wells.

FACIES CHANGES AND DEPOSITION, DOUGLAS CREEK MEMBER

GENERAL

The term facies will be restricted to the following definition in this paper. "Sedimentary facies is defined as any areally restricted part of a designated stratigraphic unit which exhibits characteristics significantly different from those of other parts of the unit." (Moore, p. 8, 1949)

Facies changes in the basal quartz sandstones of the Green River formation show the oscillatory nature of the strandline of Lake Uinta. A study of facies changes in the basin shows minor regressions and major transgressions of the lucustrine waters of this ancient lake. Lenses and tongues can be found in the basin, but are not large enough to be mapped.

The changing facies also show that more than one source area was contributing to the deposits in this basin. In general the quartz sandstones increase in thickness both north and south of Fourteen-mile Creek, measured section 6, with a marked decrease in thickness basinward (plates 1 and 2).

RIO BLANCO TO PRICE CREEK

Plate 1 represents the correlation of measured sections from Rio Blanco on the south to Price Creek on the north. An examination of this diagram shows the abundance of small sand pods or lenses in the eastern portion of the basin. The most persistent horizons are represented by quartz sandstone beds. One quartz sandstone unit carries throughout the eastern limit of the basin. Thin ostracodal limestone facies persist for five or six miles and then finger into quartz sandstones and mudstones.

Increasing thickness of quartz sandstone facies northward can best be described by following a few of the important units through the measured sections. To help the reader follow this discussion, the different units will be designated as A, B, C, etc., and these letters correspond to letters on plates 1, 2, and 3.

Following the quartz sandstone unit A northward from Rio Blanco, the unit shows a slight decrease in thickness at Thirteen- and Fourteen-mile Creeks, measured sections 8 and 6. Further north in the Petrolite Hills, measured sections 9 and 7, unit A shows a marked increase in thickness. Followed further north into Powell Park, measured sections 11 and 13, the unit shows a slight decrease in thickness. However, from Powell Park northward to Price Creek, the unit again shows a marked increase in thickness. At Rio Blanco unit A has an approximate thickness of four feet; thirty-nine miles north at Price Creek this same unit is 40 feet thick.

The quartz sandstone unit B represents one of the most interesting beds along the eastern part of the basin. Unit B has a thickness of about six feet at Fourteen-mile Creek, measured section 6; three miles north, in measured section 9, the thickness of this unit has increased to 20 feet; another two and a half miles further north, measured section 17, the unit has increased to 32 feet. In measured section 11, the over-all thickness of the unit is 30 feet and is composed of two quartz sandstone beds, separated by a 14 foot sandy shale bed. Unit B shows a rapid increase in thickness from measured section 11 to measured section 13, and a gradual decrease in thickness at Price Creek, measured section 14. It is interesting to note that the grain size of the quartz sandstone in this unit shows a similar trend; that is, an increasing grain size from Rio Blanco to Powell Park, and a decreasing grain size from Powell Park to Price Creek (figure 3).

Unit C is composed of a fine- to very fine-grained quartz sandstone. The unit is approximately 16 feet thick in measured section 9, and the thickness remains relatively constant northward to Price Creek. This unit is unique in that no increase in thickness was noted in the Powell Park region.

POWELL PARK TO SPRING CREEK

An examination of the correlation diagram from Powell Park to Spring Creek (plate 2) shows the persistent "shaling-out" of the quartz sandstones in a westward direction. This diagram shows the many small sandstone and limestone lenses which probably resulted from relatively shallow water deposition, with an oscillating strandline. In general the area is one of transgressing shoreline with only minor regressions. Note the irregular pattern of the Wasatch-Douglas Creek contact (plate 2). It can be seen that parts of the lower Douglas Creek member are contemporaneous with the deposition of the Wasatch formation. The different units will be designated as D, E, and F, to enable the reader to follow the discussion of plate 2.

The correlation diagram from Rio Blanco to Price Creek is tied into the correlation diagram from Powell Park to Spring Creek at measured section 11. In this section the relationships of the different units discussed can be seen. Units A, B, and C, which were discussed in the previous portion, are higher in the sections, stratigraphically, than unit D (plate 2).

In measured section 11, unit A consists of quartz sandstone beds and is 28 feet above unit D. Unit B is represented in this same section by alternating beds of quartz sandstone and shale, and lies 36 feet above unit D. Unit C consists of quartz sandstone beds and is 172 feet above unit D.

Unit D represents an areal extent of about 23.0 miles. This quartz sandstone unit represents the most interesting bed, oil-wise, in this part of the basin. Unit D has an over-all thickness of 124 feet at Powell Park, measured section 11, with a shale break 24 feet thick near the base. Fifteen and a half miles west, measured section 20, the unit has decreased in thickness to 32 feet, and completely disappears between measured sections 24 and 25, about seven and a half miles further west. Quartz sandstone unit D interfingers with shale and limestone units to the west. As this unit is followed westward, the number of ostracodes in the quartz sandstones shows a marked increase.

The shape of unit E indicates an offshore bar. The unit seems to have been formed by offshore currents redistributing the quartz grains brought in by streams. It is interesting to note the over-all convex shape of the deposit, and the increasing abundance of ostracodes basinward. This unit interfingers to the east and west with shale units.

Unit E is approximately time-equivalent to the uppermost quartz sandstone in the Piceance Creek well, 28-19-G, (plate 3). However, to tie these two units together as a continuous sandbar from the limited information available would be highly speculative.

Limestone unit F on plate 3 shows a deposit approximately 11 1/2 miles wide, bounded on the east and west by shale units. This fossiliferous unit is composed of ostracodes, gastropods, and pelecypods that lived in relatively calm, shallow water on a slightly elevated surface.

FOURTEEN-MILE CREEK NORTHWEST TO MEASURED SECTION 29

Plate 3 was constructed from information obtained from well cuttings and electric logs in the Piceance Creek and Yellow Creek units. These well logs were then tied into measured sections along the rim of the basin. This diagram shows the rapid thinning of typical Douglas Creek sediments in a northwestward direction. The Douglas Creek member is approximately 160 feet thick in measured section 6; 7.8 miles northwest at Piceance Creek unit, 28-19-G, this member has decreased in thickness to 109 feet; 11.7 miles further northwest in the Yellow Creek unit, 51-28, the total thickness of this member is only 22 feet. In the Yellow Creek unit, 64-8-G, the basal sands are completely missing and the Douglas Creek member is represented by shales, sandy shales and limestones. In the Yellow Creek unit, 64-8-G, the proportion of limestone has greatly increased.

A comparison of plates 2 and 3 shows that the western limits of the quartz sandstone facies is to the east of measured section 25, and east of the Yellow Creek well, 64-8-G. From this well to measured section 29, in the northwestern corner of the basin, the percentage of quartz sandstone increases. The writer noticed a gradual increase in quartz sandstone in measured section 27, west of Pinyon Ridge, indicating another source area to the northwest. This source area is also indicated by the sand-shale ratio diagram (figure 5).

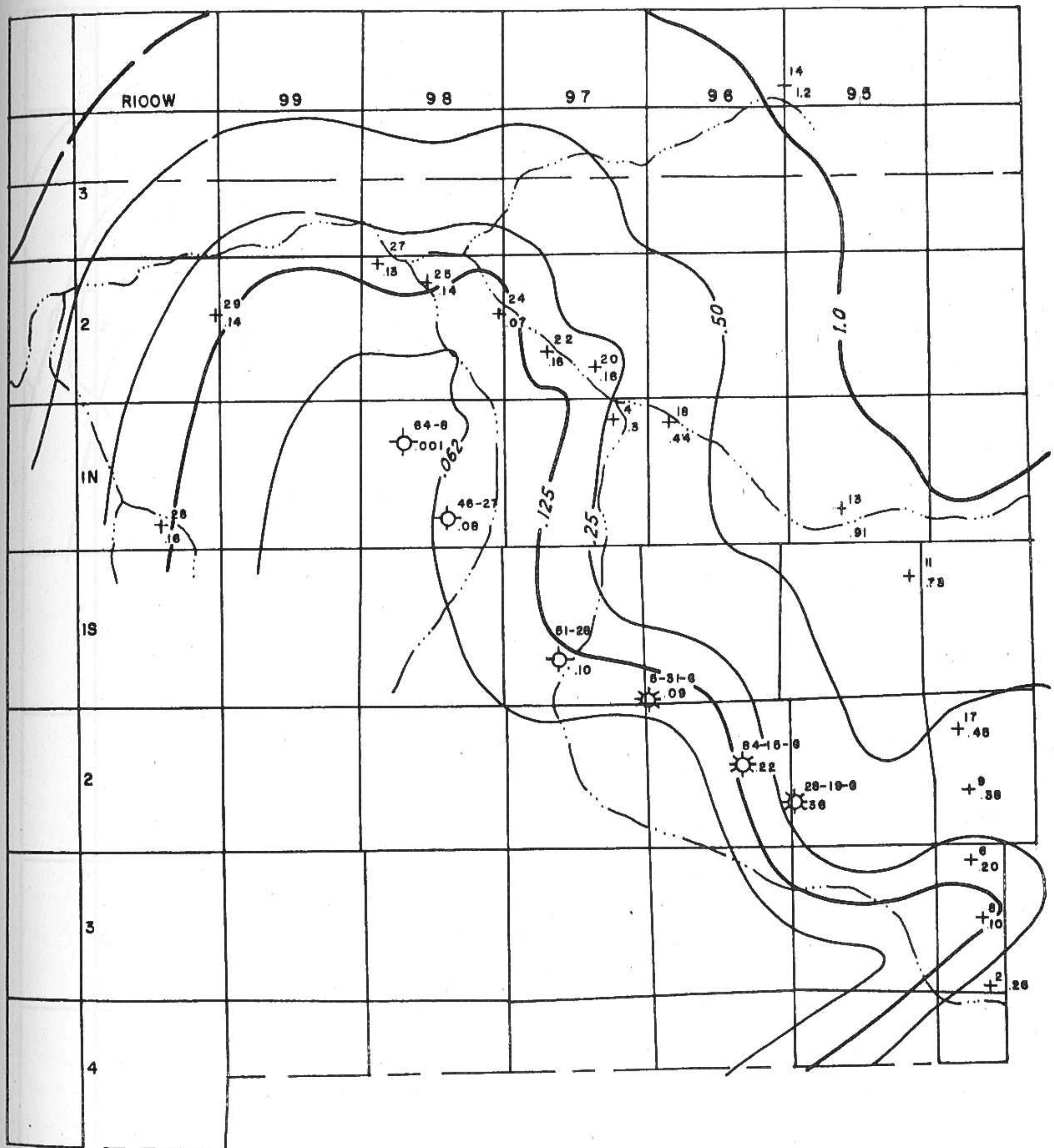
CONCLUSIONS

Rio Blanco to Price Creek. -- An examination of the correlation diagram (plate 1) shows that the upper shales of the Douglas Creek member and the lower shales of the Garden Gulch member interfinger with quartz sandstones to the north and south of Fourteen-mile Creek, measured section 6. Expressed in another way, the upper quartz sandstones of the Douglas Creek member and the lower quartz sandstones of the Garden Gulch member "shale-out" in the vicinity of Fourteen-mile Creek. As the shale and mudstone facies of the Douglas Creek member are traced northward from Rio Blanco, the thickness of these facies decreases and interfingers with the quartz sandstone facies. An examination of the sand-shale ratio diagram (figure 5) shows that in a section 500 feet thick above the Douglas Creek-Wasatch contact, the amount of sandstone is fairly constant from Powell Park to Price Creek, and that the large increase in sandstone is found between Fourteen-mile Creek, measured section 6, and Powell Park, measured sections 11 and 13.

South of Rio Blanco a similar sequence in facies changes can be seen. "The lower sandy member of the Green River formation is exposed along the south and east slopes of the Roan Plateau east of Parachute Creek. It is approximately a stratigraphic equivalent of the combined Douglas Creek and Garden Gulch members and, in addition, includes younger beds that interfinger with the lower oil shales of the Parachute Creek member." (Duncan, 1949).

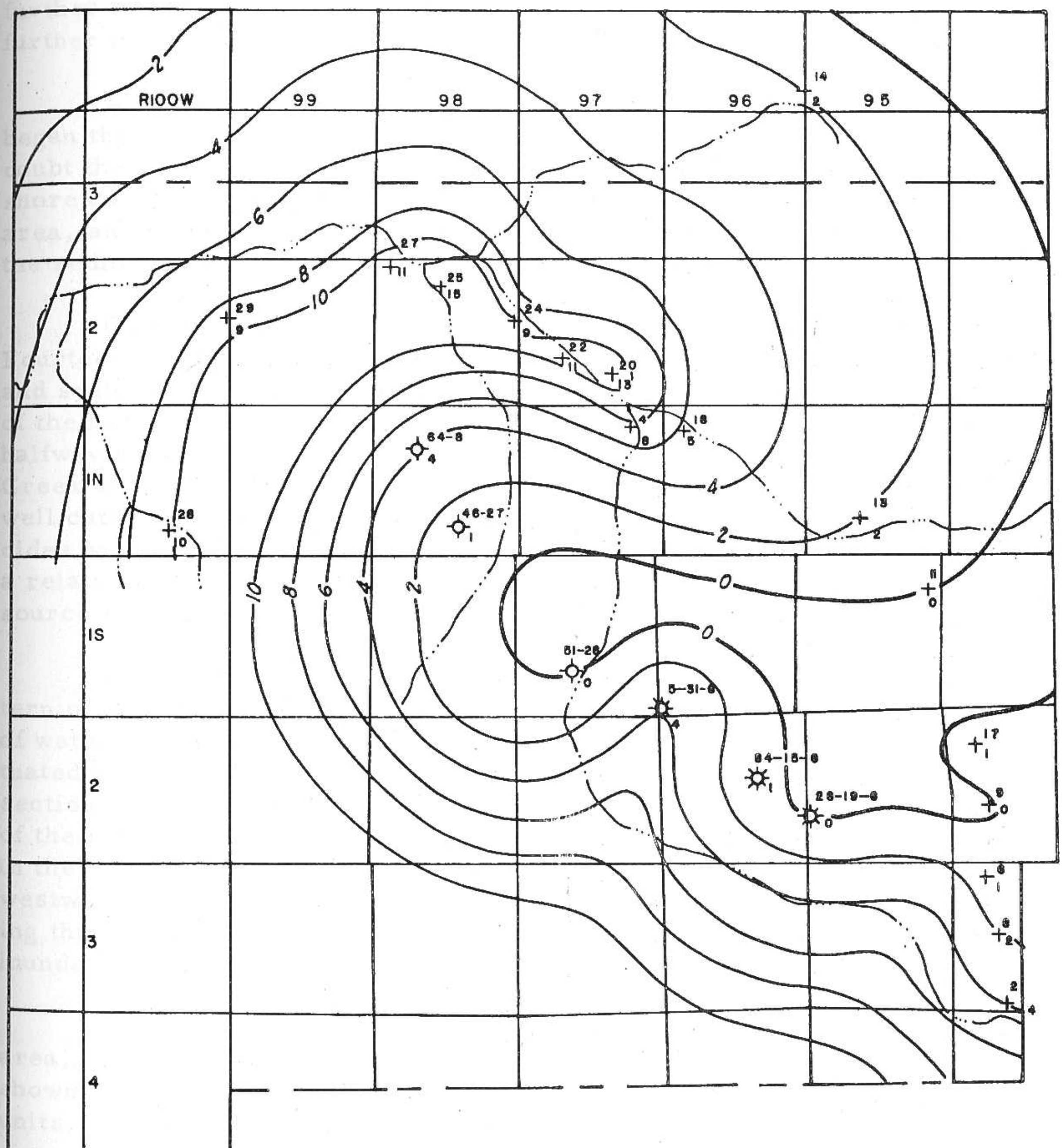
The complexity of the deposition along the eastern flank of the basin can be attributed to several factors: first, the oscillatory nature of the strandline; second, distance from source area; and third, redistribution of the sediments by offshore currents.

During basal Green River time sediments from two different source areas were being deposited on the eastern side of the basin. The sand-shale ratio diagram (figure 5) shows that a stream entered the basin from the northeast. Oil and Gas Investigation Preliminary Map 94 by Duncan and Denson (1949) shows a lower, sandy member that includes part of the Parachute Creek member and all of the Garden Gulch and Douglas Creek members. Evidently this increase in the amount of quartz sandstone indicates another source area to the southeast with the region near Fourteen-mile Creek approximately midway between the two source areas. The writer interprets the decreasing percentage of quartz sandstones in the Fourteen-mile Creek region, measured sections 8 and 6, as indicative of distance from source areas and not depth of water.



SAND/SHALE RATIO MAP

FIGURE 5



LIMESTONE PERCENTAGE MAP

FIGURE 6

Sediments brought in by these two waterways were deposited on the fluvial sediments of the Wasatch formation. The oscillatory nature of the strandline helped determine the distance basinward that the particles reached. During times of regression the coarser particles reached further to the west, and during time of transgression they were deposited further to the east.

After the sediments were brought into the basin, offshore currents began the job of resorting and redepositing the individual grains. No doubt the many isolated lenses and bars can be attributed to these offshore currents. Excellent sorting of the quartz sand grains in the area, and the consistency in size of the individual grains, show that the sediments have been reworked by such currents.

Of special interest is the amount of ostracodes found in the Fourteen-mile Creek region as compared to the sections measured north and south of this area. The only megafossils found on the eastern side of the basin were located in measured section 7, which lies approximately halfway between measured sections 6 and 9. Basinward in the Piceance Creek well, 28-19-G, gastropods, probably Goniobasis, were found in well cuttings. The pattern outlined by the location of these fossils coincides with the theory that the area around Fourteen-mile Creek lay in a relatively quiet portion of the ancient lake and was adjacent to two source areas.

Powell Park to Spring Creek. -- The writer interprets the pattern of unit D as indicating the following type of deposition. The depth of water in the early stages of Lake Uinta was very shallow, and fluctuated between seasons as well as between wet and dry years. The up-section migration of the quartz sandstones shows the slow regression of the strandline. The maximum regression of the shoreline is seen in the vicinity of Yellow Creek, measured sections 24 and 25. This westward migration of the strandline represents a dry period. Following this maximum withdrawal of the lake waters, a period of maximum inundation occurred, and the strandline moved far to the east.

During the time of quartz sandstone deposition in the Powell Park area, limestones and shales were being deposited basinward. This is shown by the interfingering of the quartz sandstone units with limestone units, and the limestone units interfingering with shale units.

Below limestone unit F, measured section 27, the upper quartz sandstones of the Wasatch formation have reached a maximum development. This increase of sand in the upper Wasatch formation suggests the presence of a stream channel that brought sediments in from the north. East and west of this stream channel, normal variegated muds were deposited. This ancient stream did not exist in Green River time. Differential compaction of the sediments left the upper surface of this ancient, sandy channel slightly elevated in basal Green River time; thus serving as an excellent environment for the growth and reproduction of the pelecypods, gastropods and ostracodes.

Other interesting deposits in the upper horizons along the northern rim of the basin are the thin lenses or stringers of oolitic limestones. These lenses or facies do not carry laterally and are found predominantly near the top of the Douglas Creek member. It should be noted that no oolitic limestone beds were found along the eastern rim of the basin. One interpretation of the environment under which oolites are formed is: "The oolite's texture almost certainly is a primary feature that is characteristic of shallow, strongly agitated waters. The uniformity of size of the oolites, the association with well-worn quartz sand grains, the cross-bedded character of some oolitic rocks, and the clear crystalline chemical carbonate cement (and absence of fine interstitial carbonate mud) are supporting evidence for this interpretation." (Pettijohn, p. 301, 1949). Supporting features for this theory are found in the basin.

The writer found deposits along the eastern flank of the basin that contained both oolites and ostracodes. It is not known if such deposits represent similar environment for the formation of the oolites and growth of ostracodes, or if the ostracodes were brought in and deposited after the organisms had died.

Regional. -- Plates 1, 2, and 3 show the irregular pattern formed by the contact of the Wasatch and Green River formations. It appears that the fluvial surface formed during Wasatch time was irregular with many small channels or depressions. Bradley (p. 54, 1931) gives the following explanation for the conditions under which the basal Green River deposits were laid down. "On the other hand, the lake may have started as small ponds and backwaters along the stream courses in the alluvial plain and expanded very gradually, filling the basins and leveling up the plain as it grew, until finally a continuous lake spread over the entire plain from mountain flank to mountain flank."

Fossils found in the Piceance Creek Basin suggest the following type of environment. The ostracode, *Erpetocypris ? sp.*, is found today living in relatively quiet, fresh water, associated with a muddy bottom; *Cyprois marginata* is found in Europe living in small ponds and ditches. The megafossils found in the basin are indicative of a similar environment.

SOURCE AREA

The source for the sediments of the Douglas Creek member of the Green River formation appears to be east of the Piceance Creek Basin in what is now the Park Range of the Southern Rocky Mountain Province. This positive area was formed during the Laramide orogeny and is interpreted as the source for the allogenic sediments of the Douglas Creek rocks.

A study of the contour pattern on the sand-shale ratio map (figure 5) suggests that sediments were brought into the basin from the positive area to the east by several streams. One such stream entered this ancient lake from the northeast in the vicinity of Powell Park. An examination of the size-particle diagram (figure 3) indicates an increase in grain size in this same area.

At Rio Blanco, the pattern developed by the sand-shale ratio contour lines (figure 5) suggests another ancient stream channel to the southeast. This can be seen more clearly by a study of the Oil and Gas Investigation Map of the Naval Oil Shale Reserves by Duncan and Denson (1949). Thus it is probable that two main stream channels entered the basin from the east; one from the southeast, the other from the northeast.

The writer noted an increasing amount of quartz sandstones in the Douglas Creek member along the northwestern portion of the basin in the vicinity of Spring Creek. Southwest of Spring Creek, Bradley (1931) measured 800 feet of basal Green River sediments in the type section at the head of Douglas Creek. This increase of quartz sandstones suggests another ancient stream channel that entered the basin from the north or northwest. The location of the high positive area which acted as the source for these sediments is highly speculative from the limited work done by the writer. If the Uinta Mountains formed a high positive element during Green River time, no doubt part of the sediments were derived from the Uintas. However, the question of whether the Uintas were a high area during basal Green River time is controversial and will not be dealt with in this report.

The upturned edges of the Paleozoic formations along the western flank of the Park Range seem to have served as an excellent source area for the basal Green River sandstones. The quartz grains of this basal member were probably derived from the erosion of older quartz sandstone beds, such as the Mesaverde formation of upper Cretaceous age, or the Maroon formation of Pennsylvanian age.

Black and white chert fragments found with the quartz grains possibly represent the remnants of an older, eroded, cherty limestone bed. Such cherty limestones are characteristic of the Mississippian system throughout the Cordilleran area.

STRUCTURE

MAJOR FEATURES

The Piceance Creek Basin occupies a simple structural basin. On the western side of the basin, near the head of Spring Creek, the beds dip gently, 2° to 3°, to the east. Along the northern rim of the basin, near Yellow Creek, the beds dip from 19° to 28° to the south, and from 3° to 10° to the south near Piceance Creek. However, the beds flatten rapidly basinward. The compressional forces that formed the Grand Hogback along the eastern side of the basin also affected the Green River beds. These beds dip from 8° to 28° to the west, and flatten basinward a short distance from the rim.

The Green River formation, north of the White River, occupies a shallow syncline which curves around the White River Dome. Along the eastern side of the syncline the beds dip from 8° to 12° toward the west; and on the western side, from 1° to 6° toward the east. This structural extension of the Piceance Creek Basin reaches to the north flank of Cross Mountain, a dome on the eastward extension of the Uinta Mountain anticline.

MINOR FEATURES

Many minor local folds are super-imposed on the major structure of the basin. One such fold is found in the area of the Piceance Creek Gas Field, and it trends generally northwest-southeast. An extension of this same trend is found in the Yellow Creek area.

Three small faults were noted along the northern limits of the basin. One of these lies to the south of the White River, and two to the north. The fault south of the river was traced, continuously, from measured section 23 to measured section 4 (figure 1). The fault approximately parallels the rim of the basin and disappears under stream alluvium of White River, northwest of measured section 23 and southeast of measured section 18. This fault represents a distance of approximately 12 miles. The north side of the fault is downthrown and has a maximum vertical displacement of 65 feet at measured section 22. This fault can be seen in the excellent exposures near measured section 21 (figure 1). Many smaller faults with vertical displacements up to 20 feet are present throughout the zone of faulting.

The fault which lies north of White River was only briefly studied. This fault is well-exposed in the bluffs northeast of measured section 23 (figure 1). The south side of the fault is down-dropped, making the White River channel a small graben in this area. This fault was followed southeast for approximately two miles up the White River.

A third fault is exposed immediately north of White River near the western limit of the Gray Hills syncline. This fault also has the down-dropped side to the south. The writer feels that the two faults north of the White River are related, and probably represent one continuous, but locally poorly exposed, fault.

PALEONTOLOGY

INTRODUCTION

A somewhat limited study of the ostracodes in the Douglas Creek member of the Piceance Creek Basin was undertaken to determine their usefulness in biostratigraphic work. Purpose of the study was threefold: first, to see if fresh water ostracodes could be used as time indicators; second, to see if the environment at the time of deposition could be determined; and third, to see if the abundance or flood of such fossils could be used for correlation.

To the writer's knowledge the only published work on the fresh water ostracodes of the Green River formation in the Piceance Creek Basin is that of Swain (1949). His work consisted of zoning some of the Tertiary formations on the presence or absence of certain ostracodes. The present additional work is just a beginning and, no doubt, further detailed work may alter the results presented.

METHOD OF INVESTIGATION

Only four samples were examined in this study and were collected from the following localities: west side of Powell Park, measured section 13; Price Creek, measured section 14; two miles east of Piceance Creek, measured section 18; and Spring Creek, measured section 28 (figure 1). Sample 13-7 (10953-398) was collected from a quartz sandstone 407 feet above the Douglas Creek-Wasatch contact. Sample 14-8 (10952-414) was collected from a quartz sandstone bed 432 feet above the same contact. Sample 18-1 (10950-18) was collected from a one foot ostracodal limestone bed 19 feet above the Douglas Creek-Wasatch contact. Sample 28-3 (10943-165) was collected from an 11 foot limestone bed, 176 feet above this same contact.

Samples were disaggregated by soaking in a detergent solution for 24 hours, followed by drying for 12 hours. Weighed samples were taken from the dried disaggregate material. All whole ostracodes were picked from a two gram specimen of sample 13-7, a one gram specimen of sample 14-8, and a one-half gram specimen of sample 28-3. In sample 18-1 all identifiable ostracodes were picked from a one gram specimen.

The ostracodes were separated and then identified by reference to Swain's article (1949).

METHOD OF CONSTRUCTING GRAPHS

Individual abundance was determined by counting all whole individuals and converting the results to numbers per gram. Absolute diversity was determined by picking all identifiable species from the samples. Histograms (figures 7 and 8) were prepared to show the number of individuals of each species per one gram sample.

To see the relationship of length to height of the different species all whole specimens from samples 14-8, 13-7, and 28-3 were measured. Figures 9, 10 and 11 show the results of this study.

Figure 9 represents the number of whole individuals plotted against the ratio of length to height for the two species, Candona pagei and Erpetocypris ? sp. Figures 10 and 11 represent graphs of the length of individuals plotted against the frequency for the two samples 13-7 and 28-3.

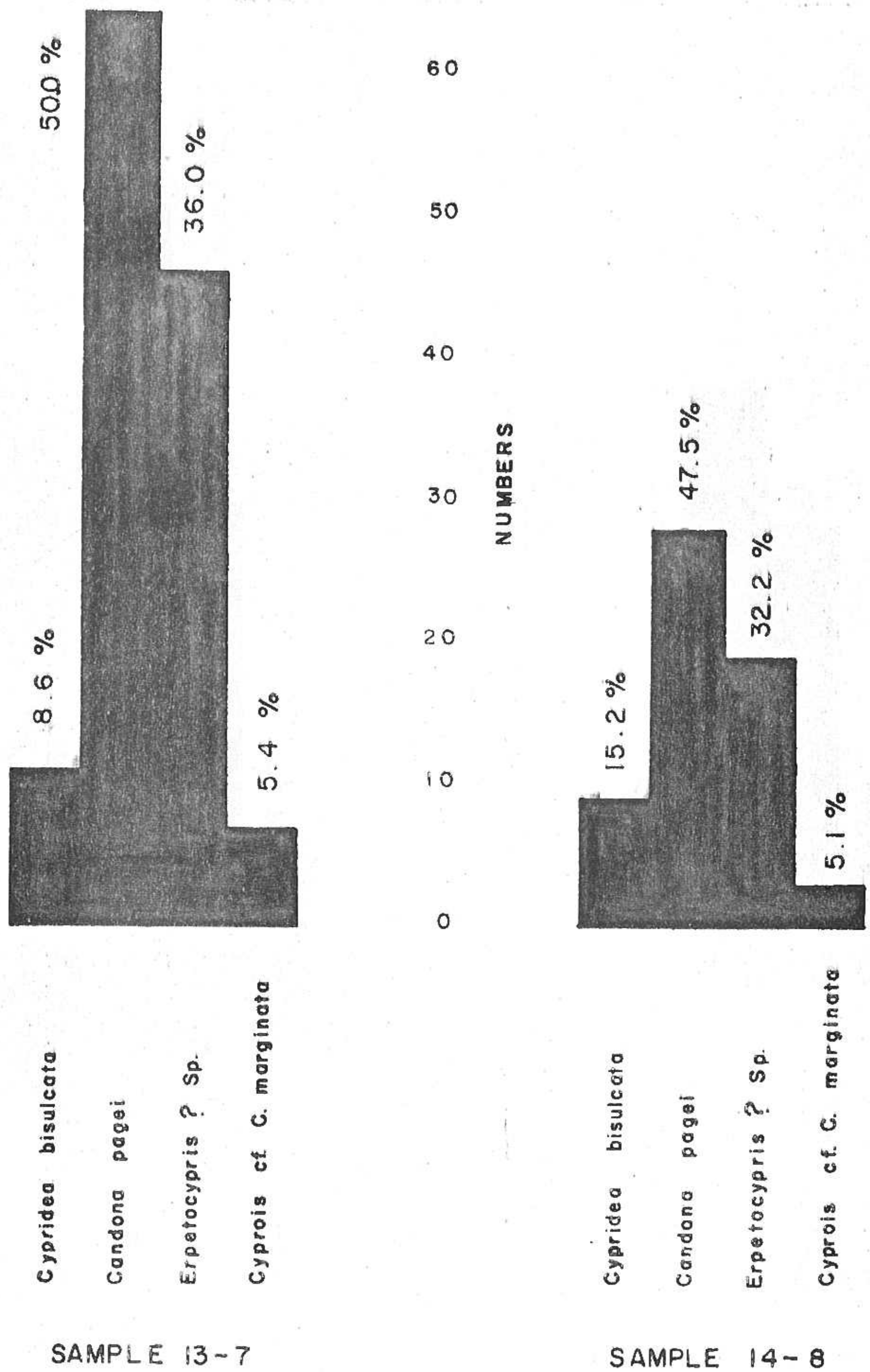
INTERPRETATION OF GRAPHS

A comparison of the histograms (figures 7 and 8) shows that the abundance of individuals varies greatly between samples, but that the over-all character of the four different curves shows a striking similarity. The four samples were collected from different locations, with samples 13-7 and 14-8 representing the same horizon, and samples 18-1 and 28-3 representing two different horizons. From this limited study it would seem that the ostracodal abundance curves for the different horizons in the Douglas Creek member are very similar.

Figure 9 shows that a definite change in the ratio of length to height is found in the two genera, Candona pagei and Erpetocypris ? sp. It is apparent that these two genera can be separated on the basis of the ratio of length to height.

Figures 10 and 11 show the results of plotting the number of whole individuals against the length in mm. An examination of this diagram shows good thanatocoenose curves for the genera Candona pagei and Erpetocypris ? sp. The genera Cypridea bisulcata and Cyprois cf. c. marginata show that the scarcity of individuals affects a curve of this type, and further work should be restricted to the more abundant genera.

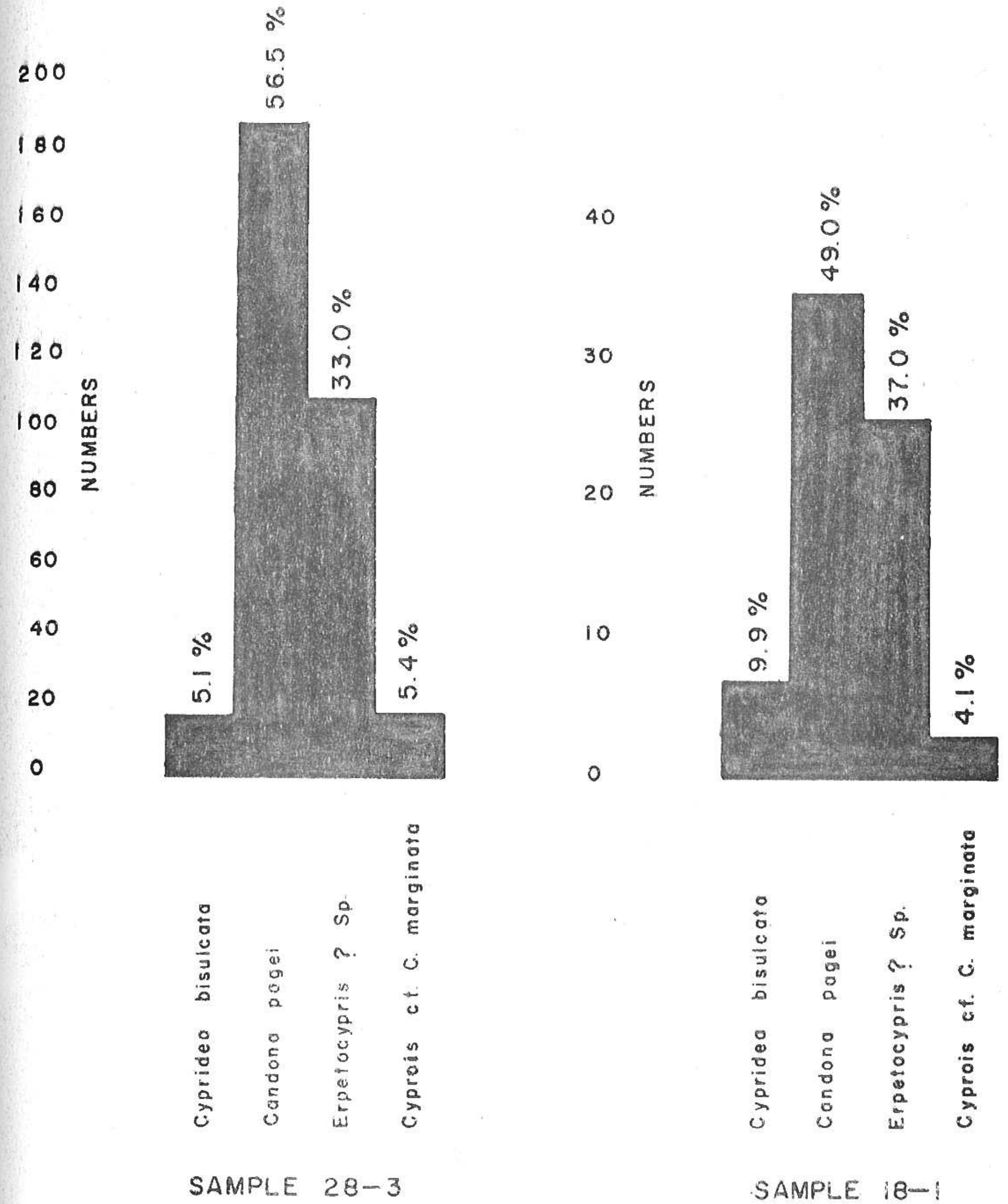
The thanatocoenose curves can be interpreted in two ways: first, a normal death rate over a long period of time; and second, a redistribution of individuals after death. The ostracodes are found in quartz sandstone deposits that show excellent sorting of the sand grains. This type



HISTOGRAMS OF SPECIFIC ABUNDANCE

MEASURED IN NUMBERS/GRAM

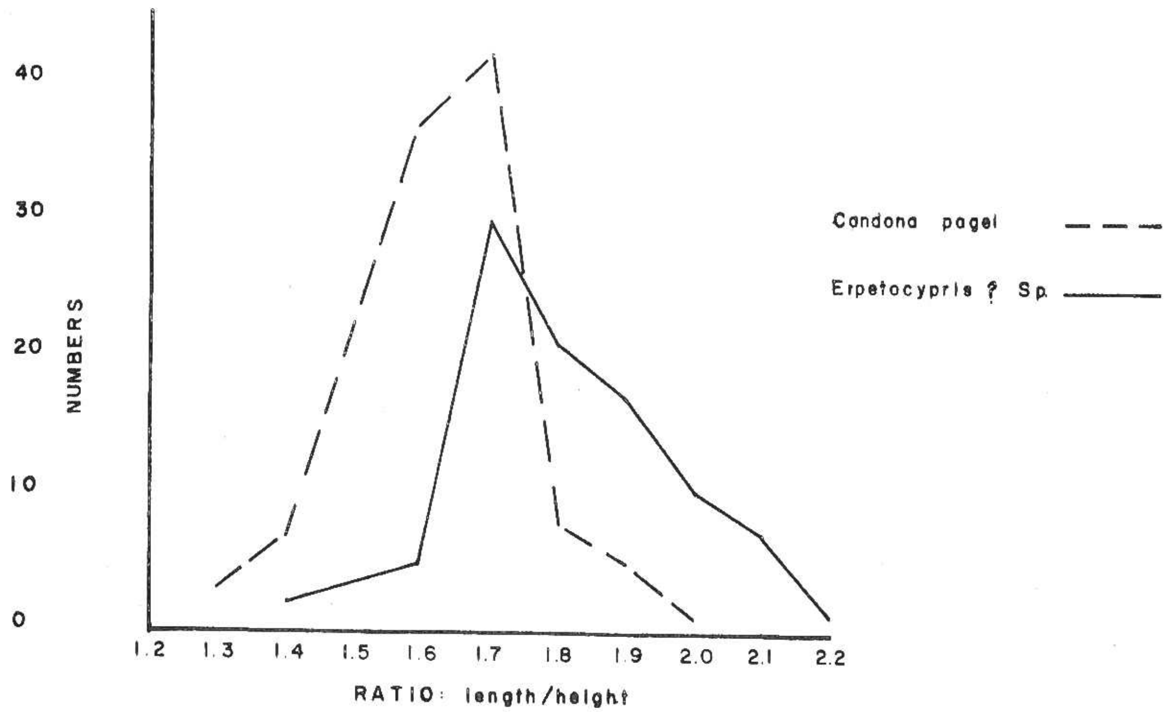
FIGURE 7



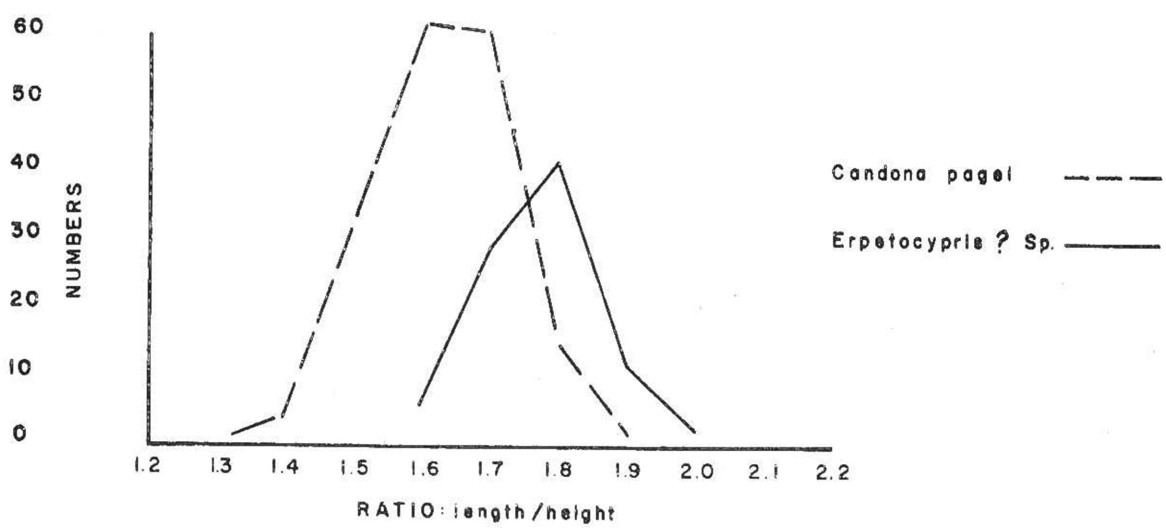
HISTOGRAMS OF SPECIFIC ABUNDANCE

MEASURED IN NUMBERS / GRAM

FIGURE 8



SAMPLE 13-7

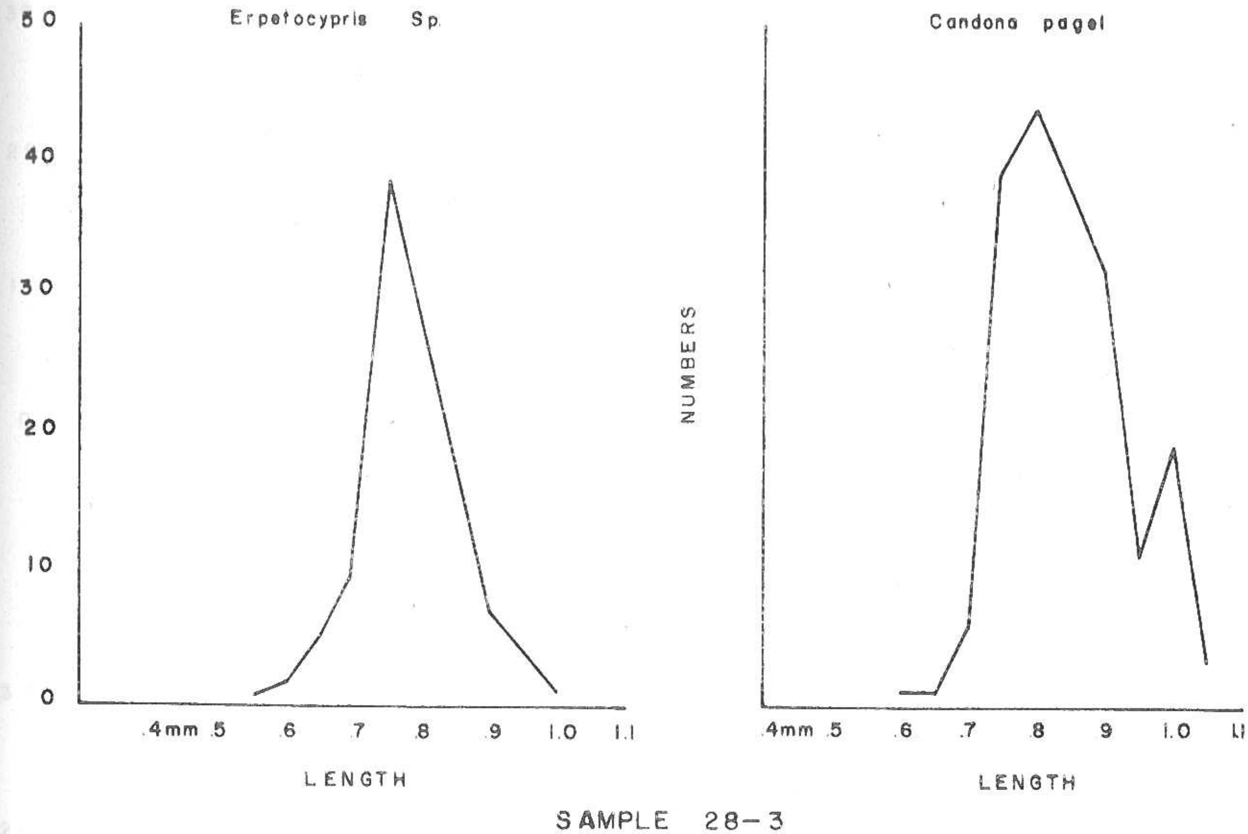


SAMPLE 28-3

GRAPH FREQUENCY DISTRIBUTION OF FORM RATIOS

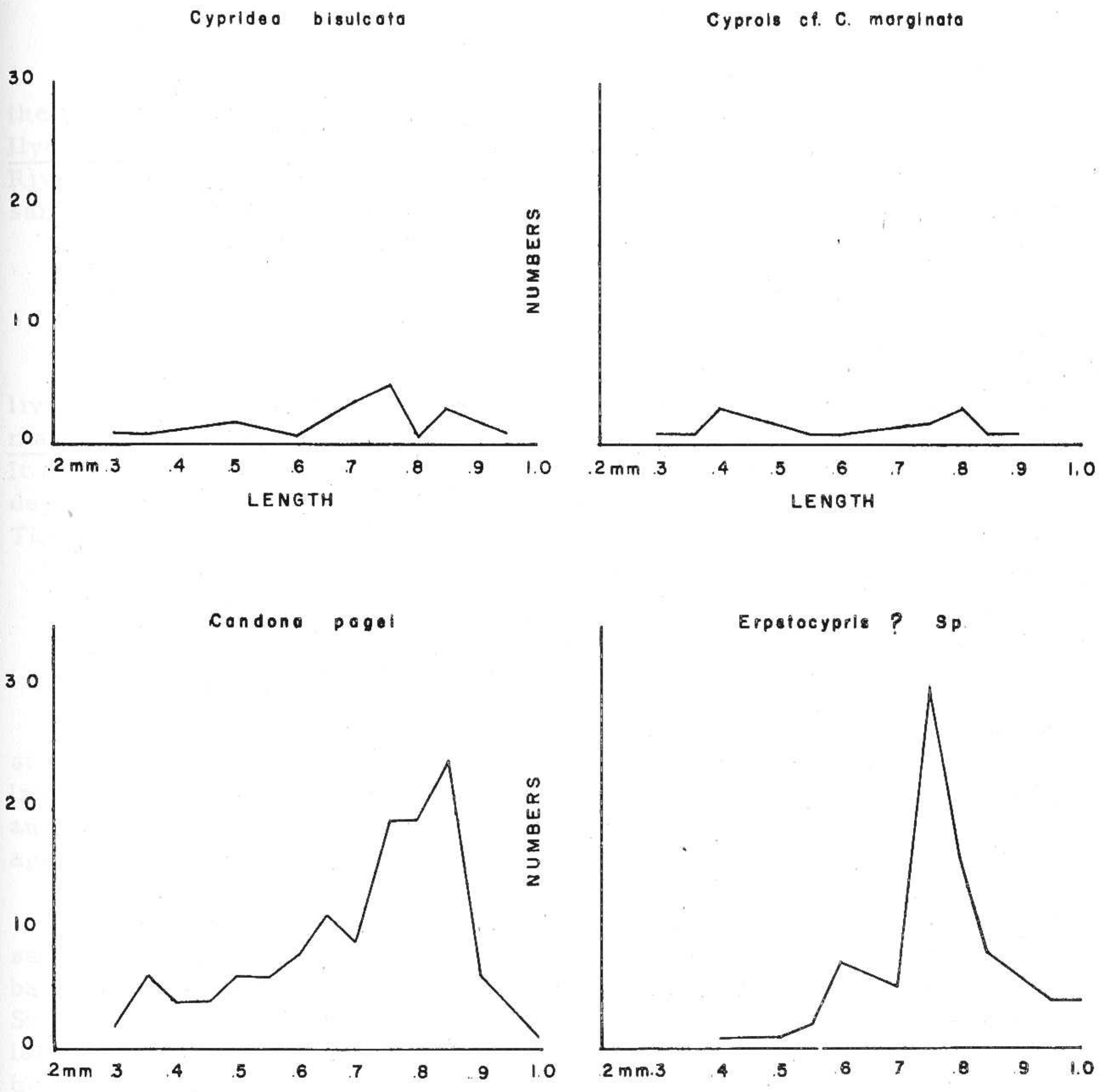
for Candona pagei and Erpetocypris ? Sp.

FIGURE 9



GRAPH SHOWING FREQUENCY DISTRIBUTION OF LENGTH OF TWO OSTRACODE SPECIES

FIGURE 10



SAMPLE 13-7

GRAPH SHOWING FREQUENCY DISTRIBUTION OF LENGTH OF FOUR OSTRACODE SPECIES

FIGURE 11

of deposit is indicative of near-shore deposition with considerable reworking of the quartz grains and ostracodes by offshore currents. Therefore, it is difficult to determine the true meaning of the curve. The many small ostracodal stringers or layers encountered throughout the sections could represent catastrophic killing.

ZONING OF THE GREEN RIVER FORMATION

Swain's zoning (1949) of the Green River formation was based on the presence of Erpetocypris and Cyprois, and the absence of the genus Ilyocypris arvadensis. This zoning seems to be valid in the basal Green River sandstones in this basin because the former were both found in the samples and the latter was missing.

ENVIRONMENT

As stated previously in this paper the genus Erpetocypris is found living on a muddy bottom in relatively fresh water, and the genus Cyprois marginata is found in Europe living in small fresh water ponds and ditches. It seems probable that the type of environment during basal Green River deposition was that of a fresh water lake, with relatively quiet water. The ostracodes inhabited the shallow, muddy bottoms.

LIMITATIONS OF WORK AND SUGGESTIONS FOR FURTHER WORK

The greatest inadequacy of the work lies in the number of samples studied, and the amount of time allotted for studying the samples. The large specimens are more adaptable for picking than the small specimens, and for this reason the large forms represent a slightly greater percentage of the whole than is found in nature.

Extended work on this problem should include a systematic sampling, both vertically and horizontally, of the ostracodal layers in the basal Green River sands as well as in the other members of this formation. Such a study would show if the abundance curves change vertically or laterally. A study of this type would also show if the zonations that have been suggested by Swain will hold throughout the formation.

Another interesting study would be to plot diagrams of abundance versus species for several vertical sections through the Green River formation. A comparison of the character of such curves would show if this method could be used for correlation purposes. A study of this type would be similar to that conducted by Israelsky (1949) on the species flood method of correlation.

Israelsky's study consisted of an oscillation chart based on the foraminiferal content of shaker samples from a well in the Lirette Field, Terrebonne Parish, Louisiana. The oscillation chart was constructed by plotting the abundance of each species, or closely related species, against depth of water. With such a chart Israelsky was able to show oscillation in water depth. It was found that wells relatively close together could be correlated with the oscillation charts, and time lines could be established.

ECONOMIC APPLICATIONS

PICEANCE CREEK FIELD, COLORADO

Information for the Piceance Creek Gas Field was taken from a private company report, "Piceance Creek Field, Colorado," by Mr. Elmer R. DeMaris, Manager of Petroleum Engineering, General Petroleum Corporation.

LOCATION

The Piceance Creek Gas Field is located in the northeastern portion of the Piceance Creek Basin, Rio Blanco County, and lies principally in T. 2 S., R. 95 and 96 W. Meeker, the nearest town, is about 18 miles northeast. Grand Junction is situated approximately 100 miles to the southeast.

HISTORY AND DEVELOPMENT

The discovery well in the field was called the Fordham 1-A, and is located in Sec. 9, T. 2 S., R. 96 W. The well was drilled by the White Eagle Oil Corporation and completed in 1930. This well, later designated as the 7-9-G, was drilled to a total depth of 5130 feet; it was plugged back and completed in the interval from 2586 to 2910 feet. The reported initial production was about 2000 MCF per day on an openflow test.

During the year, 1932, a second well was drilled and designated as the 55-9-G. In 1947 three more wells were drilled in the field, 28-19-G, 84-15-G, and 66-5-G. In 1950 an additional nine wells were drilled in the unit with 45-32-G suspended because of circulation difficulties. The other wells drilled in 1950 are 45X-29-G, 27-8-G, 71X-29-G, 24X-26-G, 5-15-G, 24-12-G, 22-3-G, and 5-31-G. In the summer of 1956 two wells were drilled, 55X-12 and 27X-7. Both of these wells, although wet and having a show of gas, were plugged and abandoned.

In the latter part of 1945 and early 1946, a deep test was drilled in the basin. This well, designated as the 84-15-G, is located in Sec. 15, T. 2 S., R. 96 W., and was drilled to a total depth of 12,019 feet. This well was plugged back to 3144 feet, with production from the basal Green River sands.

The field was unitized in 1930, with approximately 78 separate leases covering an area of 61,000 acres and is operated by the General Petroleum Corporation.

A total of sixteen wells has been drilled on the Piceance Creek structure, ten of which have been completed as gas producers. The average depth of these wells varies from 3000 to 3700 feet.

STRUCTURE

The Piceance Creek structure consists of a large anticlinal dome with the major axis trending northwest-southeast. The structure represents one of the major structural features in the basin. The Piceance Creek Dome was located by surface mapping and has between 250 and 300 feet of closure at the surface.

PRODUCING ZONE

The producing horizons in the Piceance Creek Field are located in the lower part of the Douglas Creek member. The gas-producing zone consists of alternating sandstone, shale and sandy shale. The over-all thickness of this unit ranges from 230 feet on the east to 12 feet on the west. The sandstone beds are lenticular, and the individual units are generally under 10 feet thick.

POROSITY AND PERMEABILITY

Porosity and permeability of the productive sands in this basin were determined from core samples analyzed in the Vernon Laboratories of the General Petroleum Corporation. The average effective porosity is 13.5 per cent, and the average permeability is 18.94 md.

STATIC RESERVOIR PRESSURE

The static reservoir pressure is approximately 840 lbs. per square inch at a depth of 3000 feet.

GAS ANALYSES

Following are analyses of gas samples from three wells in the Piceance Creek Field:

	Per Cent by Volume		
(Well)	84-15-G	66-5-G	28-19-G
Air			
CO_2	4.650	4.640	4.630
Methane	94.365	93.940	94.861
Ethane	0.384	0.556	0.148
Propane	0.250	0.309	0.164
Iso-Butane	0.050	0.123	0.066
N-Butane	0.100	0.154	0.082
Residue	0.201	0.278	0.049
Total	100.000	100.000	100.000
Specific Gravity	.6113	.6165	.6054
Calculated B.T.U.	984	991	977

PRODUCTION

For 26 years the gas at the Piceance Creek Field was shut in because of lack of a market. In September, 1956, the General Petroleum wells in the Piceance Creek Field were tied into the Pacific Northwest Pipeline to help furnish gas for the Pacific Northwest. A 10-inch gathering line was constructed from the Piceance Creek Field to the main Pacific Northwest pipeline. This lateral line is 48.27 miles long. The Piceance Creek Field is presently producing about 16,000 MCF of gas per day to the main line.

CONCLUSIONS

The Piceance Creek Gas Field is a combination trap in which the limits of the field are determined by a northwest-southeast trending anticline and thinning reservoir sands in a southwest direction. The following examples will show this. Plate 3 shows a marked thinning of reservoir sands in the Yellow Creek well 51-28, and a complete loss of such sands eight to ten miles further northwest. The effects of the stream channel which brought sediments into the basin from the northeast is shown by the two dry holes, 71X-29-G and 24X-26-G, which were drilled to the southwest of the Piceance Creek wells. In these two wells no significant sands were encountered in the Douglas Creek member, showing the rapid thinning of reservoir sands away from the source area.

The structural control of the Piceance Creek Field is shown by dry hole 27-8-G, which was drilled beyond the down-dip limits of gas occurrence. An examination of figure 5 shows that the reservoir sands must have a sand-shale ratio from .5 to .125 to be productive. The location of wells in this basin as well as other Tertiary basins in the inter-mountain region should be determined by a combination study of the structure and stratigraphy.

OTHER WELLS IN THE PICEANCE CREEK BASIN

A number of other wells have been drilled in the Piceance Creek Basin to test the basal sandstones of the Douglas Creek member as well as older formations. The General Petroleum Corporation has drilled four wells in the Yellow Creek region, all of which were dry. West of Piceance Creek, wells have been drilled by the Carter Oil Company, Equity Oil Company, and Ohio Oil Company, with only the Equity wells being gas producers.

Equity Oil Company has seven gas wells south of the Piceance Creek Gas Field, principally in T. 3 S., R. 95 and 96 W. Information concerning these wells was not available to the writer.

Several wells have been drilled on the White River Dome to the north of the basin. The only current producer is McLaughlin-Jacobs, Sec. 2, T. 1 N., R. 97 W. At the present time (April, 1957) Phillips Oil Company is drilling a deep test in Powell Park, Sec. 27, T. 1 N., R. 95 W.

OIL INDICATIONS

OUTCROPS

Oil-stained quartz sandstones are found along the eastern side of the Piceance Creek Basin. Oil-stained sandstones were found to extend from Fourteen-mile Creek, on the south, to White River, on the north, and to culminate in the Petrolite Hills region (figure 1). Fragments of dead hydrocarbons that resemble the gilsonite found in the Uinta Basin are associated with the oil-stained sandstones.

The oil-stained sandstones weather to a light brown, and are banded on the fresh surface. It is interesting to note that the banding of such beds is caused by the difference in permeability. The light bands represent silty layers, and the dark bands represent the oil-saturated quartz sandstone layers. A good exposure of the oil-stained sands can be seen in measured section 7 (figure 1), seven and a half miles north of Rio Blanco, Colorado. The basal quartz sandstone of the Douglas Creek member is 12 feet thick at this locality and is oil-stained throughout.

Slight oil-stains were found in the quartz sandstone in measured section 21, west of the White River Dome (figure 1). The oil-stained sandstone is eight feet thick and is 17 feet above the Wasatch-Douglas Creek contact.

An interesting association of dead hydrocarbons was observed in a quartz sandstone bed in measured section 7. The gastropod, Goniobasis cf. arcta, is filled by dead hydrocarbons that resemble gilsonite. The quartz sandstones that surround the fossil molds are slightly discolored by oil, but do not show the banded appearance of the highly saturated deposits.

PICEANCE CREEK FIELD

Analyses of cores taken from wells in the Piceance Creek Field show slight oil-stains in the Douglas Creek sands. The oils are described as viscuous, asphaltic and soluble in benzene.

OIL-SHALE

The Piceance Creek Basin offers one of the largest oil-shale reserves in the United States. The main body of oil-shale is in the Parachute Creek member of the Green River formation. The writer did not work with the oil-shale section, so will refer the reader to the many excellent reports that have been published by the United States Geological Survey and the United States Bureau of Mines. The latest report on this area is by J. R. Donnell (1957) and is entitled "Preliminary Report on Oil-Shale Resources, Piceance Creek Basin, Colorado."

The United States Bureau of Mines operated an oil-shale demonstration plant west of Rifle, Colorado, for a number of years. Recently Union Oil Company of California has established an oil-shale plant near the head of Parachute Creek approximately 12 miles north of the town of Grand Valley, Colorado (Index Map). Union Oil Company's plant should be completed and in operation during the summer of 1957.

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CORRELATION CHART OF THE DOUGLAS CREEK MEMBER, GREEN RIVER FORMATION

FROM RIO BLANCO, COLORADO, TO PRICE CREEK, COLORADO

PLATE I

CORRELATION CHART OF THE DOUGLAS CREEK MEMBER, GREEN RIVER FORMATION

PLATE 2

FROM POWELL PARK TO SPRING CREEK

by

CHARLES W. CLINE

1957

VERTICAL SCALE 1" = 40'

HORIZONTAL SCALE 1" = 9240'

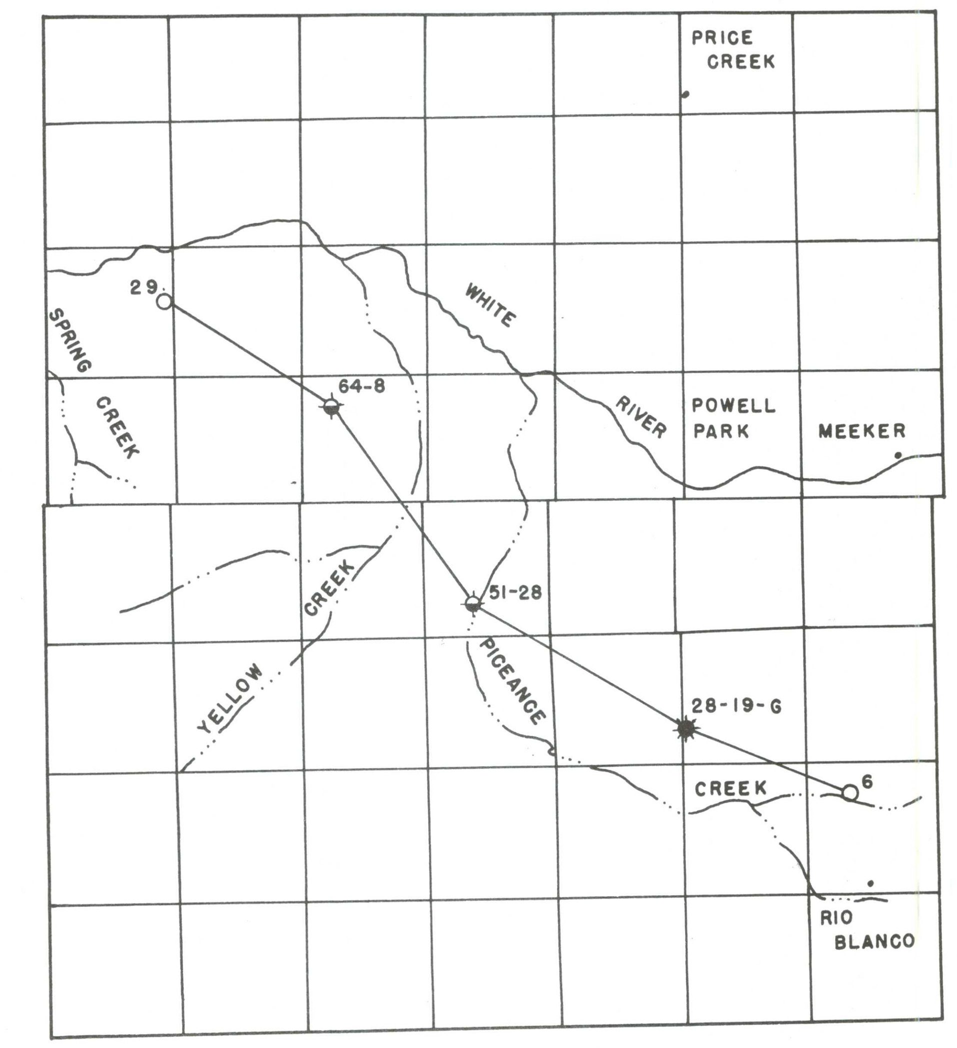
CORRELATION CHART OF THE DOUGLAS CREEK MEMBER, GREEN RIVER FORMATION

FROM 14 MILE CREEK NORTHWEST TO MEASURED SECTION 29

by
CHARLES W. CLINE
1957

PLATE 3

INDEX MAP



EXPLANATION

SANDSTONE

SILTY SHALE

SHALE

CALCAREOUS SANDSTONE

LIMESTONE

DOLOMITE

COVERED SECTION

APPROXIMATE TIME LINES
- ELECTRIC LOGS
- KEY BED
- LITHOLOGY

FACIES BOUNDARIES

FORMATION BOUNDARIES

MICROFOSSILS

MEGAFOSSILS

OIL STAIN

GAS SHOWS

GAS WELLS

DRY HOLES

VERTICAL SCALE 1" = 40'

HORIZONTAL SCALE 1" = 8000'