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Preliminary report on Bureau of Mines Yellow Creek core hole No. 1, Rio Blanco County, Colorado*

By

R. D. Carroll, D. L. Coffin, John R. Ege,
and F. A. Welder

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey format and nomenclature.

*Prepared on behalf of the U.S. Atomic Energy Commission.

Contents

Illustrations

Tables

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PRELIMINARY REPORT ON BUREAU OF MINES YELLOW CREEK CORE HOLE NO. 1, RIO BLANCO COUNTY, COLORADO

By

R. D. Carroll, D. L. Coffin, John R. Ege, and
F. A. Welder

Abstract

Analysis of geologic, hydrologic, and geophysical data obtained in and around Yellow Creek core hole No. 1, Rio Blanco County, Colorado, indicate a 1,615-foot section of oil shale was penetrated by the hole. Geophysical log data indicate the presence of 25 gallons per ton shale for a thickness of 500 feet may be marginal. The richest section of oil shale is indicated to be centered around a depth of 2,260 feet. Within the oil shale the interval 1,182 to 1,737 feet is indicated to be relatively structurally incompetent and probably permeable. Extension of available regional hydrologic data indicate the oil shale section is probably water bearing and may yield as much as 1,000 gallons per minute. Hydrologic testing in the hole is recommended.

Introduction

At the request of the San Francisco office of the Atomic Energy Commission (SAN) the U.S. Geological Survey undertook to obtain pertinent data on the U.S. Bureau of Mines (USBM)- Atomic Energy Commission core hole No. 1, which penetrates oil shales of the Green River Formation in Rio Blanco County, Colorado. This project was accomplished in conjunction with personnel of the USBM and their cooperation is gratefully acknowledged. This report presents the results of a preliminary evaluation of available data with particular reference to the aforementioned drill hole. These data are the result of rapid analyses and should be considered subject to future refinement.

Lithologic log and structural analysis of core

Colorado core hole No. 1, Sec. 13, T. 1 N., R. 98 W., Rio Blanco County, Colorado, elevation 6,003 feet, was drilled to a depth of 2,600 feet. The hole penetrated alluvium, the Evacuation Creek, and Parachute Creek Members of the Green River Formation. There is some suggestion that the top of the Garden Gulch Member also may be close to the base of the hole. The low resistivity zone on the electric log may be the so-called Blue Marker representing the Parachute Creek-Garden Gulch contact. The geophysical logs obtained in the hole and the pertinent geologic markers are shown in figure 1 (in pocket). A number of these markers were located from information furnished by the U.S. Bureau of Mines.

A and B grooves are lean oil shale zones which exhibit characteristic low resistivity intervals on the electric logs. Within the latter groove lies a distinct low resistivity layer which is called the Black Marker. A and B grooves bound the Mahogany zone, the most persistent zone of rich oil shale in the Green River Formation. Within the Mahogany zone a thin tuff bed, called the Mahogany Marker, is a correlatable horizon.

Cuttings.--Cuttings were obtained in the hole to a depth of 770 feet. A field examination of the cuttings is summarized in appendix A. Below this depth continuous core was obtained.

Core.--Approximately 1,600 feet of core from the hole was examined. Continuous core was taken from 770 to 2,600 feet. The core is composed of marlstone that contains various amounts of kerogen and shale with occasional siltstone layers, abundant carbonate salt in the lower part, and at least one thin bed of ash-fall tuff. The color ranges from yellowish gray through dark yellowish brown to dusky yellowish brown and dark gray.

Sodium carbonate salts are abundant below 1,738 feet. The salt, as far as can be determined from the core, seems to occur as layers as much as 5 inches thick and generally parallels the bedding between 1,738 and 1,745 feet. Below 1,760 feet the salt seems to be contained mostly in vugs or cavities. The salt is in the "Nahcolite zone" defined by the U.S. Bureau of Mines (fig. 1). The carbonate salts may have been present higher in the core and subsequently been subjected to postdepositional leaching. Vugs also occur in the core from 1,100 to 1,738 feet.

The most notable characteristic of the core is the abrupt change at 1,745 feet that divides the rock above this depth into an upper fractured and broken zone and below this depth into a lower unfractured competent rock. This approximately coincides with the "zone of poor recovery" defined by the U.S. Bureau of Mines, i.e., the interval between 1,182 and 1,737 feet (fig. 1).

Voids or cavities left in the rock by solution of the soluble carbonate salts is a possible explanation for the poor recovery zone. The solution cavities or voids would create zones of weakness. Bedding planes locally dip as much as 25° indicating possible deposition or collapse into cavities. High core loss was usually associated with irregular bedding and vugs in the core. Iron oxide fracture fillings were observed only in the poor recovery zone, suggesting the presence of water.

For detailed analyses of the core, 25-foot core intervals were arbitrarily chosen as the basic logging units.

The results of the core analysis within these 25-foot intervals are presented in graphic form, figure 2 (in pocket). Figure 2 is divided into seven columns that show:

1. The number and dip of fracture planes as rosette diagrams divided into 10° dip increments. The length of each fan represents number of joints.

2. The fracture frequency (fractures/foot of core) as a bar graph. The core fractures or parts readily along bedding planes. The majority of bedding plane fractures dip between 0° and 10°. Bedding-plane fractures were recorded although it was not possible to determine whether they were present in the rock or whether they were induced by drilling stresses. It is considered valid to include the bedding plane fractures in view of their importance with regard to the probable extent of fracturing parallel to the bedding planes due to shock action.

The dip rosette diagrams in figure 2 show that the bedding plane fractures are persistent throughout the core. The low angle bedding planes are planes of weakness and should be considered in predicting effects from a detonation.

3. The broken core (percent of broken core/core unit) as a bar graph.

4. The core loss (percent of core loss/core unit) as a bar graph.

5. Index number.

6. Fracture fillings and percent of fillings coating fracture planes for each core unit.

7. Description of core in terms of lithology, bedding, structural and sedimentary features, color of the rock, and changes in color and "heft" (weight) of the rock. Zones of weathering or alteration were looked for but not found.

Structural analysis of core.--The "index number" was derived to describe the engineering character of the shale. It combines the effects of jointing, core loss and breakage into one significant figure. The percent of core loss and broken core were multiplied by a factor of 0.1 so as to place them numerically in the same magnitude as fracture frequency, i.e., to convert the percent figures to the range between 0 and 10. The index number states that the higher the numerical value the greater the degree of fracturing, breakage and loss in the core.

Figure 3 shows the cumulative percent curve for the index numbers. The abscissa represents hole depth and the ordinate represents cumulative percent. The index number can be considered significant in the oil shale because it characterizes the rock properties. A great many geologic parameters affect the bulk response of a rock to shock. They include rock type (lithology and bonding), rock structure (bedding, jointing, parting, faults and shears, flow banding), rock texture and fabric (grain size and shape, crystal or particle arrangement, pore space), and rock alteration (weathering, zeolitization, argillation, silicification). The oil shale core log, however, indicates no zones or significant weathering or alteration. Lithologically the oil shale is nearly homogeneous. Consequently the most significant geologic features controling changes in the bulk physical properties of the rock are fracture frequency, core loss and broken core. These may be considered indirect measures of the engineering properties, i.e., the structural competency of subsurface intervals. Therefore, the index numbers of figure 2 characterize the structural competency of the oil shale, with increasing index number indicating decreasing structural competence.

Major changes in slope in the cumulative plot of figure 3 can be expected to differentiate the major zones of structural competency. The greater the slope the greater the index number and the less structurally competent the zone.

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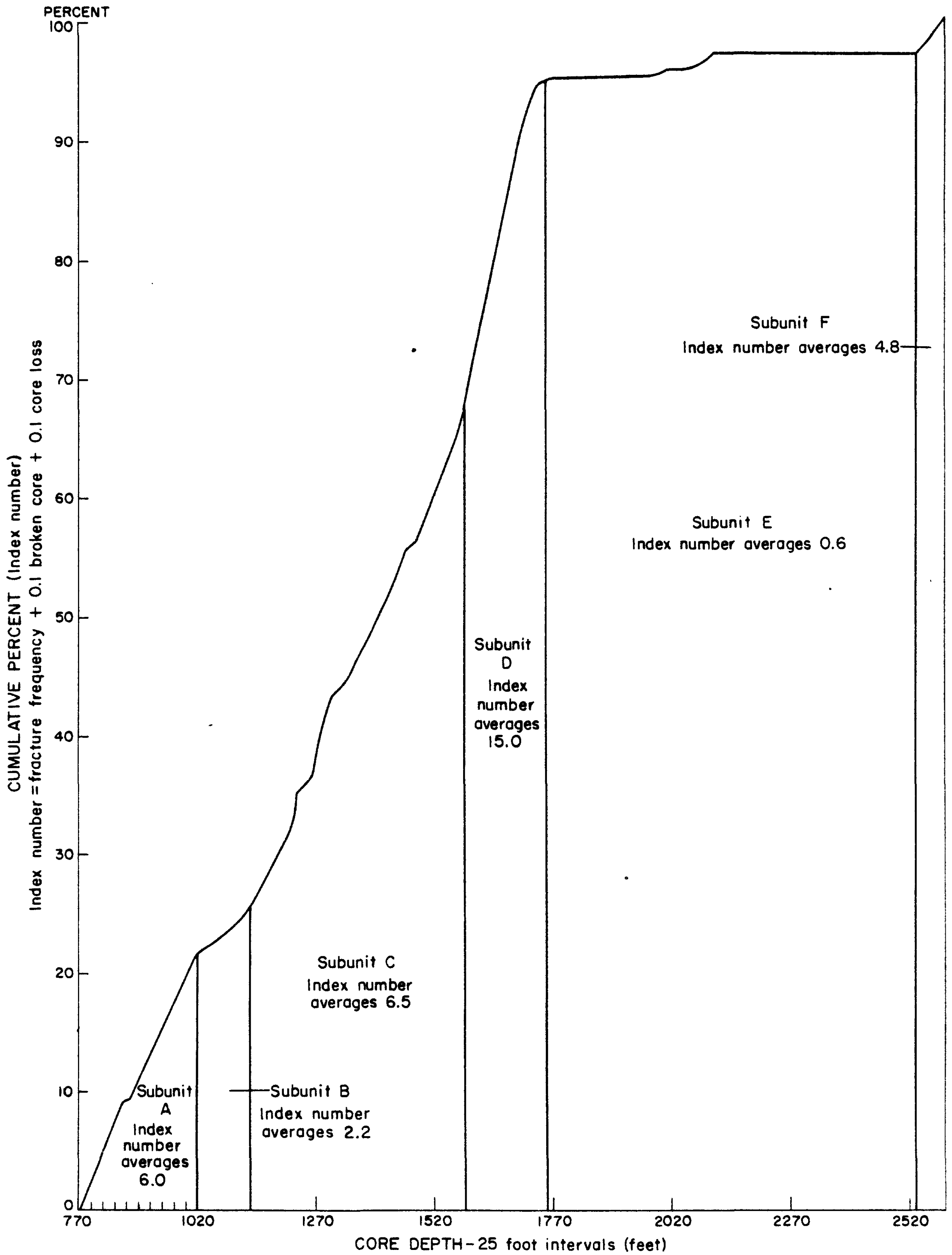

Figure 3.--Cumulative percent curve dividing Yellow Creek No. 1 core into subunits based on index numbers

On the basis of the plot of figure 3 the core has been divided into six subunits. These subunits, called engineering units to avoid confusion with the term geologic unit, are shown in figure 3 and pertinent data on these units are itemized in table 1. These units are also shown in figure 1 at the appropriate intervals on the geophysical logs.

Subunits A and C have similar index number 6.0 and 6.5, respectively, and have undergone core loss, core breakage, and fracturing. The major difference is that unit C has a 12.4 percent greater core loss and a lower measurable fracture frequency than subunit A. In addition, subunit A includes portions of the Evacuation Creek and Parachute Creek members. The former contains barren shale and marlstone and a higher proportion of sandstone. The latter is essentially continuous oil shale. Subunit C is in the upper part of the "zone of poor recovery." Subunit B has an index of 2.2 and is characterized by low core loss and core breakage. It lies between subunits A and C. Subunit D has an index number of 15 and represents a strongly fractured and broken interval characterized by an extremely high core loss. This probably is a structurally weak area and lies in the lower part of the "zone of poor recovery." Subunit E has an index number of 0.6, is characterized by solid, continuous core containing abundant nahcolite, and is a structurally competent zone. Subunit F, at the base of the hole, has an index number of 4.8. It is characterized by fracturing into "discs" 4 inches or less in length and slight core loss. The "discs" form parallel to the bedding.

Table 1.--Engineering properties for subunits A through F, Yellow Creek Core Hole No. 1, Rio Blanco County, Colorado

Sub-unit	Core interval (feet)	Thickness (feet)	Average fracture frequency (fractures/foot)	Average percent of broken core <3 inch pieces (percent)	Average percent of core loss (percent)	Average index number (index number = fracture frequency + 0.1 percent broken core + 0.1 percent core loss)
A	770-1,020	250	1.9	19.3	22.0	(1.9 + 1.9 + 2.2) = 6.0
B	1,020-1,120	100	1.6	4.0	2.0	(1.6 + 0.4 + 0.2) = 2.2
C	1,120-1,595	475	1.1	19.5	34.4	(1.1 + 2.0 + 3.4) = 6.5
D	1,595-1,745	150	2.2	71.5	56.5	(2.2 + 7.2 + 5.6) = 15.0
E	1,745-2,545	800	0.5	0.8	0.1	(0.5 + 0.08 + 0.01) = 0.6
F	2,545-2,600 (TD)	55	3.7 (4-inch "discs")	10.8	0	(3.7 + 1.1 + 0) = 4.8

Assay log

The assay of the oil shale in gallons per ton must be made on the basis of geophysical log results pending actual retort analyses at a future date. Sufficient data are believed available to allow some estimate of oil yield to be made from the geophysical logs. These estimates are shown in tables 2 and 3.

The necessary relationships between physical properties of the oil shale and oil yield have been established by Smith (1958) and Bardsley and Algermissen (1963).

Smith demonstrated a relationship exists between specific gravity of core and oil yield in the Mahogany zone oil shales using core from several locations in the Piceance Creek Basin. Core from one hole located in the Uinta Basin of Utah was also found to fit this relationship. The derivation of this relationship was restricted to oil shale wherein a continuous section averaging 25 gallons per ton was available. Because such sections are associated with the Mahogany zone the core was restricted to this zone. The maximum length of sampled core was 201 feet. Smith's derived assay-oil yield relationship is of the form

$$Y = 326.624 - 205.998X + 31.563X^2 \qquad (1)$$

where

Y = oil yield, in gallons/ton

X = core density in grams/cc,

A standard deviation of 2 gallons/ton was reported by Smith.

Table 2.--Average oil yield determined from geophysical logs from Yellow Creek, Core Hole No. 1, Rio Blanco County, Colorado

Interval (feet)	Length (feet)	Average density (gms/cc)	Average sonic travel time (μ sec/ft)	Oil yield (gallons/ton)		
				Smith Density	Bardsley-Algermissen	
					Density	Sonic Velocity
986-1,100	114	2.35	(87)	16.8	14.8	14.3
1,100-1,184	84	2.19	(105)	26.9	25.2	28.5
1,184-1,354	170	2.32	(91.5)	18.6	16.8	17.6
1,354-1,554	200	2.25	(100.7)	22.9	21.3	24.9
1,554-1,770	216	2.37	(85.8)	15.7	13.4	13.5
1,770-1,876	106	2.23	(93)	24.2	22.6	18.8
1,876-1,996	120	2.25	(95.6)	22.9	21.3	21.1
1,996-2,100	104	2.24	(88.2)	23.6	22.0	15.2
2,100-2,210	110	2.23	(91.5)	24.2	22.6	17.6
2,210-2,340	130	2.12	(115.4)	31.8	29.8	37.5
2,340-2,456	116	2.23	(95.7)	24.2	22.6	20.9
2,456-2,600	144	2.27	(109.4)	21.7	20.0	32.4

Table 3.--Average oil yield assays determined from geophysical logs of oil shale section in Yellow Creek Core Hole No. 1, Rio Blanco County, Colorado

[Intervals averaged are listed in table 1]

Interval (feet)	Length (feet)	Average oil yield (gallons/ton)			Remarks
		Smith	Bardsley and Algermissen		
		Density	Density	Velocity	
986-2,600	1,614	22.2	21.0	21.6	Average of total shale section.
986-2,100	1,114	20.7	19.8	20.3	Average of upper section of hole. Includes rich Mahogany zone section.
986-1,554	568	21.0	19.3	21.0	Average of section in vicinity of rich Mahogany zone section.
1,876-2,600	724	24.9	23.1	24.9	Average of basal section of hole including rich basal zone.
1,996-2,600	604	25.3	23.4	25.6	Do.
2,100-2,600	500	25.7	23.7	27.8	Do.
1,996-2,456	460	26.4	24.5	23.5	Average of section in vicinity of rich basal zone section indicated by density values.

Bardsley and Algermissen (1963) compared measured values of oil yield directly with the response of density and sonic logs for core data obtained for a hole in the Uinta Basin. These data were obtained over an interval of several hundred feet and were not restricted to the Mahogany zone.

The following oil yield-density relationship was determined

$$Y = 167.92 - 65.15X \qquad (2)$$

where

Y = oil yield in gallons/ton

X = density in gms/cc.

A sonic velocity-oil yield relationship was also determined. It took the form

$$Y = -16.71 + \frac{41.01 \times 10^8}{V^2} \qquad (3)$$

where

Y = oil yield in gallons/ton

V = sonic velocity in feet/sec.

Because sonic velocity logs record the reciprocal of velocity, equation (3) is more conveniently expressed as

$$Y = -16.71 + 0.004101\ T^2 \qquad (4)$$

where

Y = oil yield, in gallons/ton

T = sonic log travel time, in μsec/ft.

These equations are compared graphically in figure 4. It is seen that the density relationship of Smith is slightly more optimistic in [redacted] [redacted]

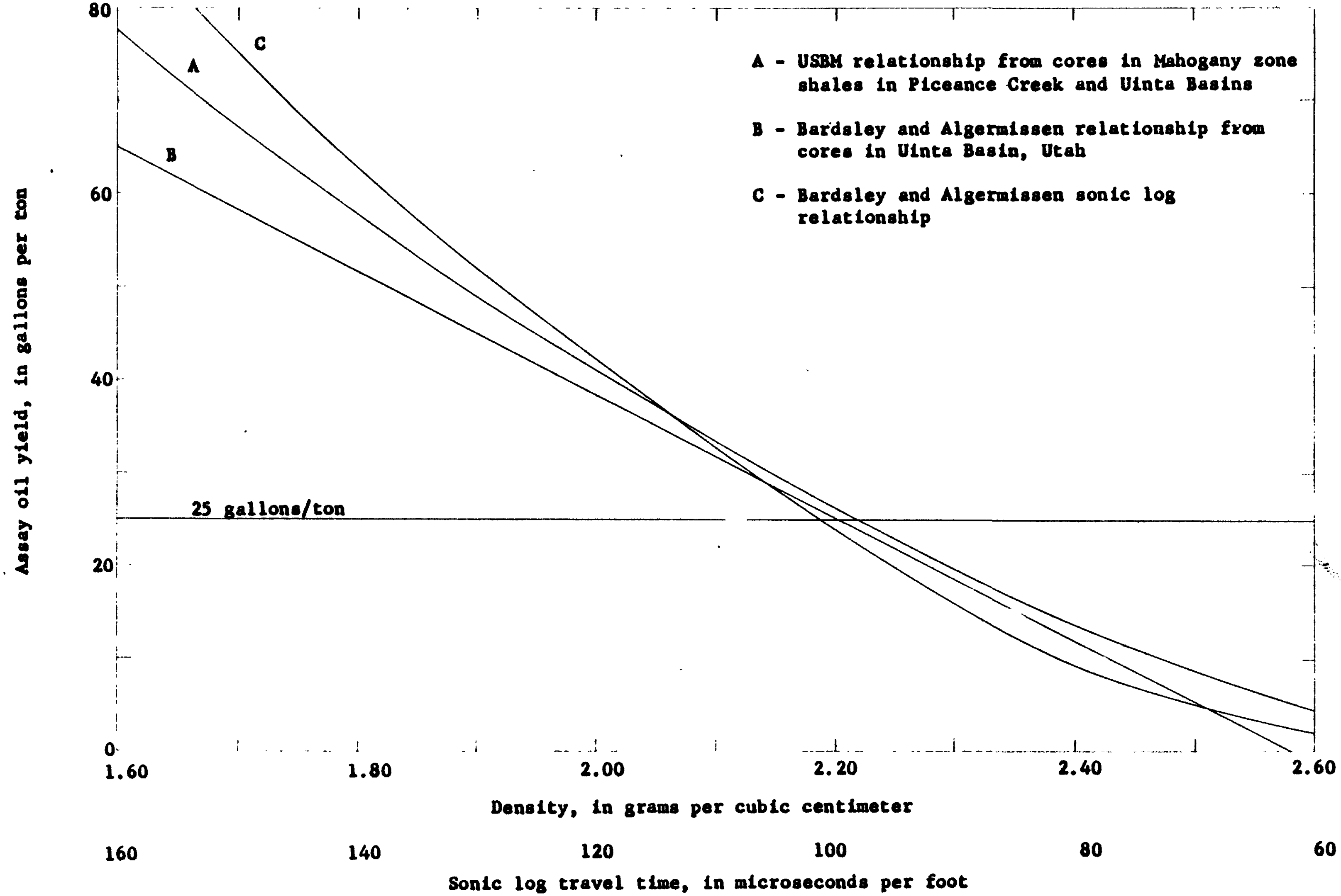

Figure 4.--Relationships between density, velocity, and oil assay established by various investigators.

terms of oil yield for a specific density than is that derived by Bardsley and Algermissen.

Intervals in the hole were selected arbitrarily on the basis of the sonic log response by noting the prominent high and low velocity intervals. These changes are also generally coincidental with high and low density intervals. Calculations were then made by planimetering these intervals on the logs and applying equations (1), (2), and (4). These results are listed in table 2. Because hole caving and fractures affect the response of the logs used, tending to make results optimistic in terms of oil yield, some smoothing was done in these intervals.

There is seen to be discrepancies in some intervals between the sonic and density derived values of oil yield using equations (2) and (4). Examination of the geophysical logs indicates there is a relationship between the density and velocity responses of the logs, however, its exact form may not follow the Bardsley-Algermissen derived relationship. A detailed examination must await laboratory assay data. The effects of environment, e.g., depth of burial, affect the velocity of a formation to a greater extent than the density. This may account for the discrepancies since the sonic velocity relationship of equation (4) was derived in an oil shale section within 500 feet of the surface, whereas the oil shale in Yellow Creek No. 1 is situated at two to four times that depth. It should be noted, however, that over large intervals in the hole the average values using all three equations are comparable.

The density logs indicate two intervals wherein the yield averages in excess of 25 gallons per ton, in the Mahogany zone from 1,100 to 1,184 feet and near the bottom of the hole from 2,210 to 2,340 feet.

Average assays derived from the geophysical logs over several intervals centered on these sections are shown in table 3. If the method of obtaining oil assay relationships from the logs may be considered valid, the thickest and richest oil yield section is not in the vicinity of the Mahogany zone but at the base of the hole. The logs further indicate that the presence of a 500-foot section of oil shale assaying 25 gallons per ton is marginal. The actual laboratory oil assay is required to settle this question. The response of the geophysical logs, however, indicate a more detailed analysis between lithology, oil shale, and the response of the various logs is warranted pending core assay. This is true of all the logs as there are certain features which appear to be lithologically significant, particularly on the radiation logs.

Permeable zones

Permeable zones probably exist throughout the entire section of hole in both the Evacuation Creek and Parachute Creek Members. The drilling logs indicate permeability near 80 feet because of the presence of water in the returns. Without actual hydrologic testing in the hole, however, other permeable zones must be inferred from indirect evidence. This method of approach infers greater permeability with greater fracture frequency. On this basis the zone of poor core recovery (fig. 1) may be a likely permeable section.

Detailed analysis of the core indicates that this zone is included in Subunit C and Subunit D (figs. 1, 2, 3, and table 1). Subunit D (1,595 to 1,745 feet) should be the most porous and permeable interval in the hole. Subunit C (1,120 to 1,595 feet) is indicated to be the next most permeable and porous zone in the oil shale. Subunit A (770 to 1,020 feet) which spans the Evacuation Creek and oil shale contact has an index number close to Subunit C and hence should have a similar fracture porosity.

The interval between 1,745 and 2,545 (Subunit E) should be relatively impermeable. It is in unfractured, tight, and competent shale. In this core interval, however, the rock parts along shale-nahcolite boundaries, indicating potential zones of weakness.

The geophysical logs also indicate that the zone of poor core recovery is probably more fractured than is the rest of the oil shale section. This is most noticeable on the caliper logs. It is significant that this zone is also of relatively low resistivity and comparatively high radioactivity within the oil shale sequence. This, coupled with the high average neutron count rate in this zone, implies that processes other than increased fracturing have been operable in this section.
A conclusion cannot be drawn on the preliminary data examined, however, the following processes which affect the various logs are presented for consideration:

Electric log decreased resistivity can be attributed to

(1) an increase in water content, other things being equal;

(2) an increase in water salinity, other things being equal;

(3) a decrease in the path length available for electrolytic conduction in the rock, or the converse, an increase in the number of path lengths (porosity) available for electrolytic conduction; or

(4) combinations of (1), (2), and (3).

Gamma-ray log increased count rate can be attributed to a relatively greater concentration of radioactive materials in these sections because of preferential environmental features, e.g., adsorption during deposition; or preferential removal of radioactive material from adjacent zones. The deposition of radioactive material by incoming ground waters is another possible mechanism.

The increased neutron log count rate indicates a decreased hydrogen content in these zones. In most lithologies this may be attributed to a decrease in water content, however, the relative abundance of hydrocarbons is another contributing factor to the hydrogen content in the oil shale. A general relationship between leanness of oil shale and neutron count rate was found by Bardsley and Algermissen (1963). Further analysis of all logs is considered desirable in this hole when more detailed data on the core is available.

The above considerations coupled with examination of the geophysical logs (fig. 1) of the zone of poor core recovery indicate that this zone merits a more detailed examination regionally. This is further substantiated by data pertaining to regional structure.

Water-bearing zones, flow rates, and regional distribution of water-bearing formations

Yellow Creek No. 1 Core Hole penetrated the three major aquifers in the northern part of the Piceance Creek Basin (here considered to be that part of the basin in Rio Blanco County). From top to bottom they are: alluvium and the Evacuation Creek and Parachute Creek Members of the Green River Formation. The distribution of these formations is shown in figure 5 (in pocket). These three aquifers yield water to many springs throughout the basin, and, although only a few wells have been drilled, preliminary data indicate that wells tapping the alluvium may yield as much as 1,000 gpm (gallons per minute), wells tapping the Evacuation Creek Member may yield as much as 100 gpm, and wells tapping the Parachute Creek Member may yield as much as 1,000 gpm. Permeable zones in the upper part of the alluvium may be above the water table, permeable zones in the Evacuation Creek Member topographically above the floor of the major stream valleys may be largely drained, and permeable zones in the Parachute Creek Member are probably saturated except near the edges of the basin.

In the Evacuation Creek and Parachute Creek Members in the northern part of the basin, regional movement of ground water is from the highlands near the edges of the basin toward the two major streams draining the basin, Piceance and Yellow Creeks. The ground-water reservoir in these two members is recharged solely from precipitation and probably eventually discharges into the alluvium along Piceance and Yellow Creeks, where the water leaves the basin either by streamflow or by evaporation and transpiration.

Parachute Creek Member.--The Parachute Creek Member is composed almost entirely of oil shale. Oil shale is relatively impermeable; however, the rock is fractured, and springs and seeps issuing from the fractures at the surface indicate water movement through the fractures, at least near the surface. Yields from the springs range from a few gallons per minute to about 500 gpm. Subsurface fracturing is indicated by zones of poor core recovery and recovered core that contains fractures. Water movement through the fractures is indicated by oxidization (bleaching) along the faces of the fractures and by deposition of carbonate minerals in and along the fractures. Further evidence for fracturing and water movement in the subsurface is indicated from abandoned oil-test wells that have been completed as water wells. Data are incomplete from these wells, but the casing records show that the wells were cased and cemented to slightly below the uppermost oil-shale beds and plugged above the lowermost oil-shale beds. Three of these wells (A, B, and C of fig. 5) were tested. A summary of the test results (table 4) shows the range of transmissibility of the Parachute Creek Member is small; however, additional tests may show a greater range. Until more data become available it may be assumed that the coefficient of transmissibility represents the transmissibility of the uncased and unplugged portion of the Parachute Creek Member. Because core recovery and well logs indicate that generally the entire thickness of the Parachute Creek Member is not fractured, the determined transmissibility probably represents only the fracture zones that contribute water to wells.

Table 4.--Summary of the results of aquifer tests in the Parachute Creek Member of the Green River Formation

Location	Water-bearing formation	Coefficient of transmissibility (gallons per day per foot)	Head at end of recovery period (in feet of water above land surface)	Duration of recovery period (days)	Average discharge (gallons per minute)	Duration of discharge (days)
A-Sec. 10, T.1S., R. 96W.	Parachute Creek Member, Green River Formation	2,000	22.8	1.0	57	135
B-Sec. 10, T.3S., R.96 W.	do.	2,000	87.8	2.1	230	.92
C-Sec. 11, T.3S., R.96 W.	do.	1,000	1/ 2.5	.78	64	1.0

1/ Discharge point is 2.5 feet above land surface, well flows 20 gpm. Well was tested by pumping at 64 gpm and measuring recovery of water level after pumping stopped.

Present data are insufficient to define the contribution of water from various zones of the Parachute Creek Member.

Fractures in the Parachute Creek Member not only contribute water to wells and springs but also cause poor core recovery and lost circulation. Lost circulation, however, was not a serious problem during the drilling of Yellow Creek No. 1 core hole into the Parachute Creek Member. The small losses of drilling fluid were easily controlled by adding cedar shavings and cellophane strips to the drilling fluid. In other areas of the northern part of the Piceance Creek Basin, lost circulation in the Parachute Creek Member has been a serious problem and has caused at least two oil-test wells to be abandoned before the objective horizon was reached.

Throughout the area water from the Parachute Creek Member is of the sodium bicarbonate type. Measured conductivity ranges from 300 to 20,000 micromhos per centimeter at 25°C. The lower values are from springs near the edges of the basin and the higher values from springs or wells near the discharge points along Yellow or Piceance Creeks. Fluoride ranges from 0.1 ppm (parts per million) to 30 ppm. Chloride, boron, nitrate, and phosphate are present only in small amounts.

Evacuation Creek Member.--The Evacuation Creek Member is composed mainly of sandstone, barren marlstone, and siltstone. The sandstone is fine to medium grained, cemented with calcite, and is probably of relatively low permeability. The barren marlstone and siltstone are probably relatively impermeable except where fractured. Many of the exposed fractures of this member have been filled with clay-sized material or calcite.

The Evacuation Creek Member forms the surface rock over most of the basin. Downcutting by streams has formed a rough hilly topography, and the part of the member topographically higher than the level of the streams is mostly drained. Water wells are usually drilled in the valleys and usually must penetrate at least 100 feet of the member to yield sufficient water for domestic or stock supplies.

In Yellow Creek No. 1 Core Hole, the upper 90 feet of the Evacuation Creek Member was air drilled. During the drilling, from 50 to 100 gpm of water was blown to the surface with the cuttings. When drilling reached a depth of about 135 feet below land surface, drilling mud was used and formation water stopped coming into the hole. In drilling through the Evacuation Creek Member, drilling-mud losses were small and were controlled by the addition of cedar shavings and cellophane.

Water from the Evacuation Creek Member is of the magnesium, calcium, bicarbonate type; generally magnesium is equal to or greater than calcium. Amounts of sulfate are small and the amount of chloride is very low. Measured conductivity ranges from 1,000 to 2,500 micromhos per centimeter.

Alluvium.--The alluvium along Piceance and Yellow Creeks is generally poorly sorted sand, gravel, clay, and silt. Sorting generally becomes better and grain size larger near the base of the alluvium; in some places beds of clay compose the upper 50 to 80 feet. The thickness of the alluvium is as much as 130 feet, and the saturated thickness may be as much as 100 feet. Measured transmissibility ranges from 20,000 gpd per ft (gallons per day per foot) to 150,000 gpd per ft. Maximum well yields are estimated to be as much as 1,000 gpm.

The alluvium of the valleys tributary to Piceance and Yellow Creek generally is thinner, and saturated thickness is less than in the main valleys. The lithology is similar in the tributary and main valleys, but well yields would probably be less in the tributary valleys.

Along Piceance Creek and along the lower reaches of Yellow Creek, water in the alluvium moves toward and eventually discharges into the stream. Along the upper and middle reaches of Yellow Creek and along most of the tributaries, the water table is below the level of the streambed and flood flows percolate to the water table.

Drilling into the alluvium is almost always accompanied by lost-circulation problems. The permeability of the sand and gravel is relatively high, and even above the water table losses of drilling fluid are common. Heavy drilling mud and the addition of lost-circulation material are often sufficient to allow penetration of the alluvium, but all wells must be cased through the alluvium.

The 45 feet of alluvium penetrated by Yellow Creek No. 1 core hole was partly responsible for a four-day delay in drilling because circulation could not be maintained. Heavy drilling mud, cedar shavings, and cellophane strips did not stop fluid losses, and the problem was finally solved by air drilling.

Water in the alluvium generally is of the sodium bicarbonate type. Measured conductivity of water increases downstream and ranges from 700 micromhos per centimeter where Piceance Creek enters the basin to about 10,000 micromhos per centimeter near the mouth of Piceance Creek. Along Yellow Creek in the vicinity of Yellow Creek No. 1 Core Hole the conductivity is about 2,500 micromhos per centimeter.

Joint system

Aerial photographs taken of the ground around the drill site show lineations and drainage features which are interpreted as joints. Two strong joint trends and a minor trend were measured. The two strongest joint sets had average strikes of N. 32° E. and N. 48° W. The weaker trend averaged N. 6° E. Donnell (1961) describes a well-defined system of northwest and northeast-trending joints being present in the Green River strata. Welder (USGS, oral communication) described most of the oil shale joints at the surface as being of the high-angle type. The core indicates that the majority of the naturally occurring joints in the rock are high angle, i.e., greater than 60° dip. The near-horizontal bedding plane fractures in the core may be a combination of both naturally occuring joints and induced fractures caused by drilling stresses.

A statistical analysis of only the high-angle core fractures in the engineering subunits suggest the joint spacing in the rock (listed in table 5). These analyses are speculative and cannot be demonstrated, however, they may indicate relative joint intensities. The intersection of the two major high-angle northeast and northwest joint sets are assumed to produce rhombohedral-shaped blocks. Neither the minor N. 6° E. joints nor the effect of bedding plane fractures has been considered in table 5.

Table 5.--Inferred joint spacings of high angle NE-NW joint sets from Yellow Creek Core Hole No. 1, Rio Blanco County, Colorado

Subunit	Core interval (feet)	Length (feet)	Average joint spacing (feet) for NE-NW joint sets dipping >60°
A	770 - 1,020	250	0.5
B	1,020 - 1,120	100	2.5
C	1,120 - 1,595	475	1.0
D	1,595 - 1,745	150	0.5
E	1,745 - 2,545	800	5.0
F	2,545 - 2,600	55	6.0

Regional structure

The electric log of Yellow Creek No. 1 Core Hole at a depth of about 1,250 feet (fig. 1), shows a pronounced decrease in resistivity which apparently represents a zone of low kerogen content. This zone of decreased resistivity yields a characteristic response on many logs throughout the basin and is referred to as the Black Marker. This horizon was used as a structural datum in this report because it is present on electric logs of wells throughout the subject area. The structure map based on this datum (fig. 5), is generalized because of the relatively small number of wells.

Figure 5 shows the Piceance Creek Basin in Rio Blanco County to be elliptical in outline with the major axis trending northwest. The basin is divided into two subbasins by a structural divide extending roughly east-west across the area. The eastern segment of this structural divide is the Piceance Creek anticline with axis trending northwest. It is joined in the center of the basin by an anticline plunging into the basin; its axis trends slightly north of west. The center of the southern subbasin is near the southern edge of T. 2 S., R. 97 W. and its axis trends nearly east and west. Structural relief of the Black Marker between the low point of this syncline and the top of the Piceance Creek anticline is about 1,000 feet.

The altitude of the Black Marker in the Yellow Creek No. 1 Core Hole is the lowest known in the region. The hole is in the northern subbasin which is irregular in shape and has extensions to the southwest and the southeast.

Examination of the logs of the hole indicate a fracture zone from depths of 1,182 to 1,737 that overlies a nahcolite zone from 1,737 to 2,512. The fracture zone is coincidental with an electric log low resistivity section, whereas the nahcolite zone is coincidental with a relatively high resistivity zone (fig. 1). The anomalous character of the low resistivity zone has been discussed previously. The prominent appearance of this zone on the electric log (between two high resistivity intervals) suggested that it be examined on other logs obtained in the area. Electric logs of oil-test wells in the central portion of the area show zones having similar characteristic high and low resistivity values. Along the eastern, southern and southwestern margins, however, the basal zone of high resistivity appears to be missing. A line marking the approximate limit of the characteristic high and low resistivity values is shown on figure 5.

Numerous possibilities are suggested for the presence or absence of this characteristic log response, among them a possible relationship between ground-water movement and the leaching of nahcolite. Within the zone of characteristic high and low resistivity values, a flowing well in sec. 28, T. 1 S., R. 97 W., yields water with a conductivity of 20,700 micromhos per centimeter. Without the zone, the few wells sampled yield conductivities on the order of 1,000 to 2,000 micromhos per centimeter. There has not been sufficient time, however, to examine all available data to allow a firm conclusion to be reached on the significance of this zone. Apparently further investigation is desirable.

It is significant that the three aquifer tests made on the Parachute Creek Member were in wells outside the approximate limit of the characteristic high and low resistivity values. Therefore, an aquifer test in the central area of the basin is recommended.

Conclusions

Lithology.--The core hole penetrated three lithologic units and possibly bottomed at the contact of a fourth. Alluvium was encountered to a depth of 45 feet, the Evacuation Creek Member of the Green River Formation to a depth of 985 feet and the Parachute Creek Member to the bottom of the hole (2,600 feet). The Garden Gulch Member may be within the near vicinity of the base of the hole. The Parachute Creek Member is composed mainly of oil shale. A thickness of 1,615 feet of this member was penetrated.

The oil shale section is notable for a zone of excessively poor core recovery (approximately 1,182 to 1,737 feet) overlying a relatively tight and impermeable zone containing abundant sodium carbonate salts.

Assay log.--Oil yield estimates based upon geophysical log interpretation indicate that the major section of rich oil shale lies at the base of the hole in the vicinity of 2,210 to 2,340 feet, rather than in the Mahogany zone. On the basis of density log analyses this 130-foot section assays in the neighborhood of 30 gallons per ton. An 84-foot section in the Mahogany zone (1,100 to 1,184 feet) assays in the neighborhood of 25 gallons per ton. The presence of a continuous 500-foot section of oil shale assaying 25 gallons per ton is indicated to be marginal and retort analysis will be required to check these conclusions. Log analyses indicate a probable minimum depth of approximately 1,875 feet to the top of such a section.

Permeable zones.--Permeable zones are indicated at a depth of 80 feet in the Evacuation Creek Member and are inferred on the basis of geophysical log response and fracturing in the Parachute Creek Member. In the latter, the zone of poor core recovery and vicinity (1,182 to 1,737) show indications of greatest permeability in the oil shale. Core analysis indicates that the base of the zone of poor recovery (the interval from 1,595 to 1,745 feet) may be the most permeable section in the oil shale. This is followed by the section from 1,120 to 1,595 feet (the upper portion of the zone of poor core recovery). The interval from 770 to 1,020 feet, which spans the Evacuation Creek-Parachute Creek contact is also indicated by core analysis to be a possible permeable interval.

Water-bearing zones and flow rates.--Drilling results indicate a possible water-bearing zone at a depth of around 80 feet in the Evacuation Creek Member in Yellow Creek core hole No. 1. No flow rate data are available. Studies of ground water in the Piceance Creek Basin and data from Yellow Creek No. 1 core hole have shown three geologic units that contain permeable zones and that yield water to wells and springs. All three units contain intervals that are relatively impermeable. Testing of the individual members and of specific zones within the members is necessary to determine actual water-bearing zones and flow rates.

Joint system.--Inhole and surface data indicate the majority of the joints occurring in the rock are high angle (greater than 60° dip). To what extent the near horizontal bedding plane fractures observed in the core are naturally occurring or induced by drilling is uncertain.

Regional structure.--A structure contour map on the Black Marker at the base of the Mahogany zone, indicates the region under consideration is located in the deepest part of the northern Piceance Creek Basin. The elevation on the base of the Mahogany zone in the Yellow Creek No. 1 core hole is the lowest recorded in the region.

The Yellow Creek core hole appears to penetrate a section of the Parachute Creek Member, which on the basis of electric log character differs significantly from the section on the eastern, southern, and western fringes of the northern basin. The electric log response characterizing the tight, impermeable section below the zone of poor recovery appears absent in these areas. The regional significance of this zone requires more detailed investigation.

General.--All available data both within and without the Yellow Creek No. 1 Core Hole, indicate the probable existence of permeable zones containing water in several intervals. The definition of the water environment, particularly flow-rates in the hole, requires hydrologic testing in the event a device hole is planned. Regardless of the suitability of the hole for nuclear detonation, a hydrologic testing program is strongly recommended for this hole to obtain information of the hydrologic environment both as an adjunct to the general oil-shale program and as an aid to future applications of the Plowshare program to oil-shale development.

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Appendix A.--Description of cuttings from Colorado Core Hole No. 1 Yellow Creek, Rio Blanco County, Colorado

	Thickness (feet)	Depth to bottom of layer (feet)
Quaternary undifferentiated:		
Alluvium:		
Soil, loose------------------------	5	5
Gravel, very fine to medium, angular to rounded, composed of sandstone and marlstone, and fine to very coarse sand----------------------	20	25
Gravel, very fine to coarse, subrounded to well rounded, composed of sandstone and marlstone, poorly sorted, and fine to very coarse sand-----------------------------	20	45
Green River Formation:		
Evacuation Creek Member:		
Siltstone, brown, and fine-grained brown sandstone; calcareous-----	5	50
Siltstone, brown, calcareous; contains plant stems 55 to 60 feet-	27	77
Siltstone (returns wet at 77 feet)-	3	80
Sandstone, brown, calcareous and siltstone (hole is making muddy water with conductivity of 2,450 micromhos per centimeter at 25°C)	50	130
Sandstone, light-green, fine-grained, slightly calcareous-----	5	135
Sandstone, brown, fine to medium-grained, slightly calcareous----	5	140

Appendix A.--Description of cuttings from Colorado Core Hole No. 1 Yellow Creek, Rio Blanco County, Colorado--Continued

	Thickness (feet)	Depth to bottom of layer (feet)
Green River Formation:--Continued		
Evacuation Creek Member:--Continued		
Siltstone, light-green, calcareous, lignitic----------------------------	15	155
Siltstone, lignitic-----------------	10	165
Siltstone, light-green, calcareous, lignitic----------------------------	55	220
Sandstone, light-green, calcareous lignitic, micaceous---------------	35	255
Siltstone, light-green, lignitic----	30	285
Siltstone, light-brown, oxidized----	5	290
Siltstone, light-green, calcareous--	10	300
No sample----------------------------	5	305
Sandstone, fine-grained, friable, calcareous------------------------	5	310
Siltstone, light-green, calcareous--	10	320
Sandstone, light-green, fine-grained, friable, calcareous; contains small angular fragments of brown silt-stone------------------------------	85	405
Siltstone, sandy, calcareous--------	120	525
Siltstone----------------------------	25	550
Siltstone and brown laminated marl-stone------------------------------	5	555

Appendix A.--Description of cuttings from Colorado Core Hole No. 1 Yellow Creek, Rio Blanco County, Colorado--Continued

	Thickness (feet)	Depth to bottom of layer (feet)
Green River Formation:--Continued		
Evacuation Creek Member:--Continued		
Marlstone, brown, laminated, kerogenous------------------------	5	560
Siltstone, gray, lignitic, and laminated kerogenous marlstone---	5	565
Siltstone, gray, lignitic, slightly calcareous------------------------	40	605
Siltstone, and fine sandstone------	10	615
Siltstone--------------------------	35	650
Siltstone; contains trace of brown marlstone------------------------	5	655
Siltstone--------------------------	105	750
Marlstone, brown, and trace of siltstone------------------------	15	765