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Ph.D., 1952
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Stratigraphic Relations in the Upper Cretaceous of the Book Cliffs, Utah - Colorado

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

By

Robert Glen Young, B.S.

The Ohio State University

1962

Approved by:

[Signature]

Advisor
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**PLATE 1.**

Book Cliffs at Helper, Utah.

View showing sandstone tongues of Star Point sandstone and lower part of Blackhawk formation. Intervening units are tongues of Mancos shale.

a, Masuk tongue of Mancos; b, Panther tongue; c, Storrs tongue; d, offshore bar sandstones of Spring Canyon tongue; e, basal sandstone of Aberdeen member; f, basal sandstone unit of Kenilworth member resting on coal measures of Aberdeen member.
INTRODUCTION

General Problem

The Book Cliffs of central Utah and western Colorado present unexcelled exposures of Upper Cretaceous continental, littoral marine, and marine strata which can be traced continuously for over 200 miles. These rocks form nearly vertical, barren cliffs in which the stratigraphic relations of the units involved can be readily ascertained in most places. However, due to the steepness of the cliffs formed by the littoral marine sandstones and interbedded shales, many sections along the cliffs are wholly inaccessible and make extremely hazardous any attempt to study the strata which lie above the cliffs. A mis-step or a loose stone might lead to a fall of hundreds or thousands of feet.

Because of the excellent exposures and their geographic extent, the investigation was undertaken in order to ascertain some of the details of the intertonguing of the littoral marine and marine strata. The gross nature of the intertonguing had already been determined by Clark (1928), Speker and Reeside (1925), Erdmann (1934), and Fisher (1936). It seemed that perhaps such a study might show ac-
FIGURE 1.—MAP SHOWING LOCATIONS OF MEASURED SECTIONS.
tual time relationships between the several components of
the coal measures and the littoral marine sandstones. It
was also hoped that more information might be obtained as
to the nature and causes of the frequent oscillations of
the Upper Cretaceous seashore as manifested in the inter-
tonguing of the resulting sediments.

Location

The area covered in this study extends eastward from
the eastern margin of the Wasatch Plateau in central Utah
along the Book Cliffs, which form the northern rim of the
Colorado Plateaus in eastern Utah, as far as Grand Junc-
tion in western Colorado. Traced along the outcrop this
distance is about 220 miles. The width of outcrop studied
varies from a fraction of a mile to about three miles, de-
pending primarily on the degree of dissection of the
cliffs.

Along the entire length of exposure the structure of
these rocks exposed in the cliffs remains simple. The sin-
uous S-shaped pattern of the cliffs is controlled by the
San Rafael Swell in the west and the Uncompahgre uplift in
the east. With only a few minor undulations these Cretace-
ous rocks dip gently off the northern and eastern flanks
of the San Rafael Swell and off the northern and north-
western flanks of the Uncompahgre uplift.

A few faults and folds have locally disturbed the se-
quence exposed in the cliffs, but for long distances the only visible structure is a very gentle northward dip of a few degrees.

**Previous Investigations**

The first white man to have more than a casual knowledge of the Book Cliffs was Antoine Roubidoux, a French trapper who, in 1837, established a trading post on the White River in the Uinta Basin. In order to reach his destination he crossed the mountainous region which lay between the Colorado Plateaus and the Uinta Basin. This meant that he had to find a way to cross the Book Cliffs and Roan Cliffs which form the southern scarp of the Tavaputs Plateau. His route led up Westwater Canyon, in eastern Utah, to the divide; and on reaching this divide he made an easy descent into the Uinta Basin. That he used this trail is indicated by an inscription on a sandstone block near the mouth of Westwater Canyon. This inscription was dated 1837.

One of the first published reports of exploration of the Uinta Basin was that of Fremont, who visited the region in 1843-1844.

In 1853 Capt. J.W. Gunnison, in search of a railroad route to the Pacific Ocean, crossed the Colorado River (then the Grand) near Palisade, Colorado and traveled westward between the River and the Roan or Book Mountains. This is
the first recorded reference to these mountains by this name, and indicates that the name may have been in use previously.

Powell in 1869, while on his first expedition to explore the canyons of the Colorado and Green Rivers, camped near Green River, Utah at the base of the Cliffs. In the report of this expedition he refers to the escarpment as the Azure Cliffs, apparently unaware that Gunnison had already named them the Book Cliffs. Later, however, in his lectures he called them the Book Cliffs. Dutton, in his *Geology of the High Plateaus of Utah* (1880, p. 26), calls them the Book Cliffs and credits Powell with naming them.

Peale of the Hayden survey (1875) was the pioneer geologist to visit the Book Cliffs. He described, in his report, the physical features of the Roan or Book Cliffs and the Little Book Cliffs, but failed to mention the presence of coal in these rocks.

In the early 1900's the government filed a suit against the Utah Fuel Company charging monopoly of coal reserves. In order to obtain an idea of these reserves, two geologists were sent by the government to make reconnaissance reports. In 1906 Taff made a rapid survey of the area between Sunnyside and Castlegate, Utah. The following year he continued his work southward in the Wasatch Plateau coal field. Also during 1906 Richardson made a reconnaissance survey of the coal deposits between Sunnyside, Utah and Grand Junction,
In his report of 1910 Stanton specified that the beds in the Book Cliffs (Laramie) were Mesaverde.

The first geologist to make a modern study of the rocks of the Book Cliffs was Clark (1925), who in 1911-13 mapped the area between Castlegate and Sunnyside, Utah in detail. He traced out the coal beds, and was the first to discover the intertonguing between the littoral marine sandstones of the Mesaverde Group and the marine Mancos shale. He also found that the base of the lowest littoral marine sandstone at Sunnyside was about 500 feet higher stratigraphically than the base of the homologous sandstone at Castlegate.

In 1925 Spieker and Reeside traced the sandstone tongues eastward from Sunnyside to Grand Junction. The following year they traced these beds up East Salt Creek and into the Uinta Basin.

In 1925 Boyer (Spieker 1949, p. 56) discovered the lateral relations between Grand Junction and the western and southern faces of Grand Mesa.

Fisher (1936) mapped the Book Cliffs from Sunnyside, Utah to the Colorado line in 1925 and 1926.

In 1926 and 1927 Erdmann (1934) mapped the Book Cliffs between Grand Mesa (in Colorado) and the Utah line. Neither Fisher nor Erdmann contributed many details to the knowledge of intertonguing in the Book Cliffs since both were primarily interested in the mapping of coals. The
sections prepared by these men did, however, serve to carry a rough correlation of the main geologic units from Sunnyside into western Colorado.

The most recent work on the Book Cliffs is that of Spieker (1949), who has presented a clear over-all picture of the intertonguing and facies relations of the Upper Cretaceous rocks of eastern Utah and western Colorado. Since Spieker's work incorporated most of the published and unpublished data available at that time, it constitutes the best available summary of the previous knowledge of the Book Cliffs.

Field Work

A detailed stratigraphic study of the rocks exposed in the Book Cliffs was begun in the summer of 1950 by the writer. Since the sandstones tongue out to the east, the study was initiated at the western end of the Cliffs and moved progressively eastward. Detailed sections were measured at accessible points and carefully correlated by tracing individual members from one section to the next along the cliffs. It was necessary to use binoculars in order to determine the nature of certain inaccessible features.

At the end of the first summer, the work had progressed as far east as Green River, Utah. From this point it was continued eastward in the summer of 1951 when the
work was completed in the vicinity of Grand Junction, Colorado.

The rock units which were studied in detail are the Star Point sandstone, the Blackhawk formation, and the Castlegate and Sego members of the Price River formation as well as the corresponding units of the Mancos shale. The gross relations of the Neslen and Farrer facies of the Price River formation were observed but no detailed study was made (since time did not permit).

Acknowledgments

The writer is indebted to Edmund M. Spieker for suggesting the problem and for suggestions as to the nature and origin of the intertonguing in the Book Cliffs. He wishes also to express thanks to his wife, Joan, who assisted him in the field for both seasons and typed this report.
Two southward facing escarpments together form the southern edge of the Tavaputs Plateau, which is the name applied to the high southern portion of the rim of the Uinta Basin and the northern rim of the Colorado Plateaus province. The uppermost of these are the Roan Cliffs which are formed in the upper part of the "Wasatch" formation. Below these cliffs are the Book Cliffs developed in the upper part of the Mancos shale and the associated sandstone tongues of Upper Cretaceous age. These escarpments may be so close to each other as to form a single great escarpment such as those near Sunnyside and Cisco, Utah; or they may be separated by as much as ten miles. Where the two are separate, a dip slope usually develops on top of the Book Cliffs escarpment, giving a giant step-like appearance to the front of the Plateau from Castle-gate, Utah to Palisade, Colorado. The total relief of the Book Cliffs ranges from 1400 to 2000 feet.

This general pattern is somewhat interrupted from Green River, Utah eastward to the Colorado line by the appearance of the Buck tongue of the Mancos shale. This unit appears just above the Castlegate sandstone and increases in thickness to the east. Since this shale is less resistant to erosion than the overlying and underlying sand-
A. Dip slope formed by Castlegate member at Cottonwood Canyon.

This view looking southwest shows the tree and grass-covered dip slope formed by the littoral marine sandstone tongues of the Castlegate member. The hill in the distance to the right is formed by rocks of the Price River formation. The steep cliff there is formed by the basal sandstones of the Sego member and the slope at the base is formed by shale of the Buck tongue.

B. Pediment or rock fan near Sunnyside, Utah.

View looking north toward Sunnyside showing covered rock fan sweeping up toward the Cliffs on the east. This surface has not been dissected.
stones, it tends to be more rapidly eroded. The result is the subdivision of the Book Cliffs escarpment into two lesser escarpments separated by a dip slope developed on the Castlegate sandstone. This surface, which is as much as two miles wide, is relatively flat and supports a fairly heavy cover of vegetation fully utilized by local ranchers for grazing (see Plate 2A). To this surface they have applied the name "Castlegate Pavement". This bench disappears near the Colorado line because of the feathering out of the tongue of Castlegate sandstone into the Mancos shale.

The term "Book Cliffs" has been in use for many years. It first appeared in print in 1854 in the report of Gunnison's expedition. Later, in 1861, in the War Department map of Gunnison's expedition the name "Roan and Book Cliffs" was used in a general sense to designate both the Book Cliffs and Roan Cliffs escarpments.

The origin of the term Book Cliffs is unknown, but several ideas have been advanced. Lakes (1905, p. 379) states that the name was derived from the way in which the beds of alternating shale and sandstone are piled on one another like books on a table. Gannett and Campbell (1877, p. 346) state that the name was given because of the resemblance of the sandstone cap and underlying curved shale slope to the edge of a bound book. Still another idea is expressed by local residents who believe that the term stems
from the resemblance of these Cliffs to a series of bound volumes standing together with their backs toward the observer, as on a shelf in a library. The lettering then would be represented by the sandstone beds.

Powell (1869, p. 98), whom Dutton credits with naming the Book Cliffs, restricted the term "Book Cliffs" to the lower escarpment and the term "Brown (Roan) Cliffs" to the upper escarpment. On his first trip down the Green and Colorado Rivers in 1869, he called the Book Cliffs the "Azure Cliffs". Later, however, he used the present term.

In 1875 and 1876 Peale used these terms in a general way, applying the term "Roan or Book Cliffs" to the lower escarpment in Utah and in Colorado west of East Salt Creek. To the cliffs between East Salt Creek and Palisade he applied the name "Little Book Cliffs" because of a lessening of height of the escarpment. There seems, however, to be no justification for this subdivision of the Book Cliffs.

There are numerous reentrants in the cliffs at points where steep, short canyons emerge from the edge of the Tavaputs or Roan Plateau. The carving of these steep, rocky canyons, in most of which there is no permanent stream flow, is accomplished by the heavy runoff resulting from occasional heavy rains. The result of the carving of these canyons is the production, in the region between Green River and the Colorado line, of a series of salients and re-entrants of an imposing nature. Access to the cliffs is by

-13-
means of these canyons. However, between Green River, Utah and Sunnyside, Utah the escarpment is almost inaccessible except along a few canyons where it is broken by normal faults.

Most of the larger canyons are reached by roads which can be traveled by truck. A few of the larger canyons are used to gain access to the high country to the north. In several canyons good roads have been constructed which cross the divide into the Uinta Basin. In others, roads have been constructed for the purpose of transporting coal from the mines located in the canyons. In many cases the access roads end at the mouths of the canyons, and many canyons can not be reached by road.

**Valleys**

Nearly everywhere at the foot of the Book Cliffs lies a great shale "valley" which is known in different regions as Price River Valley, Castle Valley, Clark Valley, Gunnison Valley, and Grand Valley. This is not a stream valley as the word implies since most streams flow across it instead of along it. This valley is from three to 20 miles wide and closely parallels the cliffs. Its altitude varies from about 6400 feet at the base of the cliffs near Helper, Utah to about 4000 feet near Green River and 4500 feet at Grand Junction. The valley is relatively level, but near
the cliffs it is deeply dissected by erosion and changes into badlands topography. The whole surface may at one time have been covered by a mantle of gravel possibly resulting from pedimentation. Much of this gravel has now been stripped away with only a few smooth topped remnants remaining as evidence of their former great extent. It is, therefore, probable that this "valley" was produced mainly by the process of pedimentation working on the soft Mancos shale and by later dissection of the pediment surfaces.

Pediments

Conspicuous features of certain portions of the Book Cliffs are the terraces or pediment remnants which slope gently downward from the face of the cliffs to the valleys below. These remnants have been described by Clark (1928, p. 11), Spieker (1931, p. 48), Glock (1932, pp. 29-37), Erdmann (1934, p. 59), Rich (1935, pp. 1012-1017), and Fisher (1936, pp. 5-6).

The opinion of these writers is that these terraces are remnants of rock fans like those which are now forming in some of the canyons. They are rock benches with a thin veneer of gravel which has prevented their destruction. This veneer of gravel is as much as 100 feet thick near the cliffs but may be very thin at some distance from the cliffs. All stages can be found from high detached
PLATE 3.

A. Beheaded pediment near Coal Creek Canyon.

This pediment or rock fan surface on the east side of Coal Creek Canyon is one of four surfaces present in this vicinity.

B. View of Mt. Garfield near Palisade, Colorado.

In this view the basal sandstone of the Rollins member is seen capping the mountain. The massive sandstone below it is the basal unit of the Riverside member. The Palisade member is obscured by talus in this area. Steep irregular cliff near the middle of the shale slope is a possible pediment or rock fan remnant.
remnants near the cliffs to apron-like surfaces which sweep up to the escarpment and appear as if they were still in the process of development. However, the majority are separated from the cliffs by a small shale valley and are thus beheaded (see Plate 3A).

The writer agrees with Spieker, Fisher, and Glock in recognizing at least three terrace levels. Glock suggests that the three levels are due to re-grading necessitated by the retreat of the escarpment. Rich believes they may also be due to stream diversions.

Pediment remnants are confined to two portions of the Book Cliffs. However, pedimentation may have occurred throughout the length of the cliffs. The best preserved surfaces are those between Helper and Sunnyside, which were described by Rich (1935, pp. 1012-1017). Another region in which they are present, but less well developed, is in western Colorado. The position of these remnants is significant in that they are found only in the regions which are today experiencing the greatest rainfall of the area included in this study.

The annual rainfall for the cliffs as a whole is small, ranging from six to 15 inches. The two areas in which pediment remnants are preserved are in the northernmost portions of the "S" curve formed by the Book Cliffs. In these two regions the Book and Roan Cliffs are very close together, with the result that the relative relief is greater.
than in other areas of the cliffs. Here then, we find the greatest precipitation. Sunnyside has the greatest precipitation and also the best developed pediments or rock fan surfaces. Here many of the pediment surfaces are not beheaded.

Green River, on the other hand, has an annual rainfall of five to seven inches. Probably as a result of this small amount of moisture, there are no pediment remnants in evidence.

No well defined pediment levels can be seen near Grand Junction, but high on the shale slopes of Mt. Garfield, near Palisade, are boulder-capped benches which Spieker (personal communication, 1951) believes may mark the contact of a former pediment surface with the cliffs (see Plate 3B).

**Drainage**

Three major streams and their tributaries drain the region in which the Book Cliffs are located. The northwest portion of the area including Castle and Clark Valleys is drained by the Price River which rises in the Wasatch Plateau to the west. The Price River flows southeastward through Castle Valley and then through a deep canyon into the Green River 12 miles above the town of Green River, isolating the Beckwith Plateau from the remainder of the Tavaputs Plateau.

Near the town of Green River the southward flowing
Green River emerges from the Cliffs. Because its course is directly across the Tavaputs Plateau it effectively divides the Plateau into two parts—the East and West Tavaputs Plateaus.

Emerging from the mountains near Palisade, Colorado the Colorado River flows southwest across Grand Valley before entering the canyon country to the south.

Many smaller streams, a few of which are permanent in the vicinity of the cliffs, cross the valleys at the base of the cliffs. Few of these, however, contribute anything to the master streams except in the season of heavy rains. At this time these normally dry washes are filled to overflowing with muddy, turbulent torrents of water which carry huge boulders and vast quantities of other debris. Such floods play havoc with bridges, irrigation systems, highways, and railroads. They make it almost impossible for a dirt road to be maintained for long across these shale flats and when a road is abandoned it soon becomes impassable.

**Climate**

The climate of this entire region can be classified as arid to semiarid. Annual precipitation varies from a high of 15 inches at Sunnyside to a low of about six inches at Green River. As a result vegetation is nowhere heavy, but is comparatively much heavier in the regions of greatest rainfall.
Since the summers are dry and hot and the winters dry and cold, the climate is not particularly inviting to habitation. Temperatures of over 110 degrees during the summer months are not uncommon around Green River. The scarcity of water and vegetation in most of the area has discouraged the settlement of this land which can be made to produce with sufficient water. That this land can produce is evidenced by the intensive farming carried on in the valleys of the Price, Green, and Grand Rivers where water for irrigation is available.
The rocks exposed in the Book Cliffs are Upper Cretaceous. They consist of a succession of sandstones, thin shales, and one or more coal-bearing units, all of which intertongue eastward with marine Mancos shale of an equivalent age. The units involved in this intertonguing are the Star Point, Blackhawk, Price River, and North Horn formations (or their equivalents in the terminology of earlier workers). As a result of this eastward intertonguing, the contact between the littoral marine sandstones and the underlying Mancos shale rises 2700 feet stratigraphically from the western end to the eastern end of the Book Cliffs (Spleker 1949, p. 67). Since the Book Cliffs are the result of the resistant nature of the sandstone tongues, it is evident that the strata exposed in the eastern portions of the cliffs are younger than those in the cliffs to the west.

The eastward intertonguing of the sandstones with shale is a reflection of the movement of the strand line of the Upper Cretaceous sea. Since the Book Cliffs trend in general slightly southeast from the Wasatch Plateau, they present a cross-section nearly at right angles to the old shoreline which had a northeast trend. As the basin filled, the strand line moved farther east. Minor oscillations
A. Grassy member of Blackhawk formation on Mt. Elliot.

This view of the Grassy member shows the transitional nature of the base of the basal sandstone unit. Two thin coals lie near the top of the coal-bearing rocks of this member. A portion of the overlying basal sandstone of the Desert member caps the cliff. Height of this cliff is about 150 feet.

B. Gunnison Butte north of Green River as seen from the southeast.

The steep truncated pyramid on the east end of the butte is formed by the Castlegate member and the basal sandstone of the Desert member. The main portion of the butte is capped by the basal sandstone unit of the Grassy member. A split is seen near the middle of this sandstone. Just below this massive, cliff-forming unit is a thinner sandstone which is a tongue of the Sunnyside member. Near the base of the shale slope are four shale cliffs capped by thin tongues of the Kenilworth member.
of the sea are recorded in the zigzag nature of the strand line, which is represented by the littoral marine sandstone tongues.

**Units Studied**

**Mancos Shale**

The Mancos shale is a very widespread unit in western Colorado, northwestern New Mexico, northeastern Arizona, and eastern Utah. It was named by Cross (1899, p. 4) from exposures near the town of Mancos and along the Mancos River valley in southwestern Colorado. It is exposed as a broad band along the base of the Book Cliffs throughout their length. Since this shale is relatively soft and easily weathered, it everywhere forms the sloping base of the cliffs and the valleys and terraces to the south of the cliffs. The upper portion forms the base of the cliffs (see Plates 1, 4A, 7A, etc.).

That part of the Mancos exposed in the cliffs is drab, gray or may even have a slightly bluish cast. Wash from overlying sandstones has, in many places, coated the outcrops with a buff to gray color. Near the top are a few thin lenses of calcareous sandstone, limestone, and a few concretionary beds. In central Utah, where it is separated from the lower members by the Emery sandstone, this upper portion of the Mancos is called the Masuk member, but to the east it is not easily distinguishable.
and bears no member name.

The thickness of the Mancos, as a whole, ranges from about 5000 feet in central Utah to about 4000 feet in western Colorado. However, that portion of the Mancos exposed in the cliffs rarely exceeds 600 or 700 feet. In most localities it is much less.

The upper part of the Mancos shale is gradational into the overlying littoral marine sandstone tongues, with which it interfingers (see Plates 4A and 6A). These tongues of sandstone thin eastward and gradually grade into the shale. Above each of the flat-topped sandstone tongues is a tongue of Mancos shale thinning westward. The two largest of the shale tongues, which all represent small scale marine transgressions, have been named the Buck and Anchor Mine tongues of the Mancos. The net result of this interfingering is a stratigraphic rise of the upper boundary toward the east. This makes the upper part of the Mancos increasingly younger from west to east. For instance, near Helper, Utah, it is early Montana; near Green River it is medial Montana; and in western Colorado it is mostly late Montana. Therefore, the 4000 feet of Mancos in western Colorado represents a much longer period of geologic time than does the 5000 feet of Mancos of central Utah. Since there is no evidence of erosion, it is obvious that time lines in the Mancos shale must converge strongly toward the east.
The Mancos shale was deposited as muds in the shallow water of the Upper Cretaceous sea beyond the sand-mud transition line. Convergence of time lines indicates that most of the mud must have been deposited near the shore resulting in differential sedimentation. Spieker (1949, p. 68) remarks on the scarcity of limestone in marine Upper Cretaceous rocks of the western states and points out that there seems to be no apparent reason for its absence here. There are a few stringers of limestone and some ironstone concretions, but no great volume of calcareous material. It is probable that conditions for limestone deposition were not favorable in the shallow muddy waters of the Upper Cretaceous seas in the Rocky Mountain region.

The Buck tongue of the Mancos lies above the Castlegate member and below the Sego member. Its western edge is not known exactly but is near Woodside. From there it thickens eastward to a maximum of 380 feet at West Salt Creek. Fossils collected from this unit by the writer and those reported by Fisher (1936, p. 15) indicate it is of Lewis age.

The Anchor Mine shale tongue separates the upper and lower sandstone tongues of the Sego member. In places it is actually two tongues separating three sandstone tongues of the Sego. It appears near Saleratus Canyon and reaches a thickness of 180 feet at Big Salt Wash.
Star Point Sandstone

The Star Point sandstone was named by Spieker and Reeside (1925, p. 442) for a prominent headland of the Wasatch Plateau in Carbon Co., Utah about three miles west of the southwest corner of the Castlegate quadrangle. Clark (1928, p. 116) used this unit as the basal unit of the Mesa- verde Group, a term which is no longer used in the Book Cliffs.

That portion of coal-bearing rocks referred to by Clark (1928, p. 125) as the Spring Canyon coal group of the Blackhawk formation is genetically a part of the same sedimentary cycle as the underlying Spring Canyon tongue of the Star Point sandstone. However, since existing rules of nomenclature do not permit shifting of formational boundaries, the coal-bearing rocks are still included in the Blackhawk formation.

The base of this formation is the contact of the Panther tongue with the underlying Mancos shale. The upper boundary is drawn at the top of the Spring Canyon sandstone tongue and at the base of the coal-bearing rocks of the Spring Canyon coal group of the Blackhawk formation. This contact is easily located but is not everywhere the same horizon. The Spring Canyon tongue is composed of several offshore bar sandstones which rise en echelon toward the east. As a result the coal-bearing
rocks which were deposited behind these bars must also rise toward the east. It thus can be seen that the present Star Point - Blackhawk boundary is a boundary between two facies—the lagoonal and the littoral marine.

This formation is present only in the western part of the Book Cliffs. In the Wasatch Plateau it consists of about 450 feet of medium grained, buff sandstone of littoral marine origin. At the western end of the Book Cliffs the massive sandstone is split into three sandstone tongues separated by thin beds of sandy shale (see Plate 1).

Fossils collected by Clark and Spieker indicate that the Star Point sandstone is medial Montana in age.

For the three main sandstone tongues Clark (1928, p. 16) proposed, in order of decreasing age, the terms Panther tongue, Storrs tongue, and Spring Canyon tongue.

**Panther tongue:** The Panther sandstone tongue was named by Clark (1928, p. 17) for exposures in Panther Canyon where it is about 70 feet thick. This remarkably flat-topped sandstone tongue is a conspicuous cliff-former in the vicinity of Helper, Utah. It can be traced from the front of the Wasatch Plateau, where it is 125 feet thick, to a point a short distance east of Soldier Canyon where it disappears in the Mancos shale. In Soldier Canyon its position is indicated by a band of impure limestone concretions and thin lenses of sandstone. The coarse-
PLATE 5.

A. Panther sandstone member at Storrs, Utah.

This view of the Panther sandstone shows channeling of the upper surface. Note that the channels have been made, filled, and planed off leaving the top of the sandstone flat.

B. Panther sandstone member at Panther Canyon.

In this view in Price Canyon one can trace individual bedding planes in the sandstone from top to bottom. They pass diagonally downward from left to right and grade into shale at the base.
ness and degree of cementation of the sandstone decreases from west to east. Marine cross-bedding is characteristic of the entire sandstone, and in some places the upper surface has suffered some channeling (see Plate 5A). The lower part of the sandstone grades downward into sandy shale and finally into shale. The base of the sandstone is placed at the point at which sandstone becomes dominant over shale. Individual sandstone layers in the tongue vary from one inch to ten feet in thickness. In places, where the beach was very steep, one can see these individual beds pass from the top down through the sandstone and thence into the shale below (Spieker 1949, p. 62) (see Plate 5A).

Storrs tongue: About 120 feet above the top of the Panther tongue is the Storrs sandstone tongue, which is named for its exposures at the town of Storrs in Spring Canyon (Clark 1928, p. 17). The Storrs, like the Panther, is flat-topped and grades downward from thick-bedded, medium-grained sandstone into sandy shale and shale (see Plate 5A). It is about 50 feet thick at Storrs and thins to the east, disappearing about one mile east of Kenilworth, Utah. It is separated from the underlying Panther and overlying Spring Canyon sandstone tongues by westward pointing tongues of Mancos shale.
Spring Canyon tongue: The Spring Canyon sandstone tongue of the Star Point was named by Clark (1928, p. 17) from the exposures of a massive, white-capped sandstone tongue found in Spring Canyon west of Helper, Utah. It has a thickness of about 150 feet in Spring Canyon which increases eastward because of the appearance of shale tongues which split the sandstone into three extensions or minor tongues. The Spring Canyon extensions thin rapidly eastward and disappear into the Mancos. The lower extension disappears at Helper, the middle extension disappears at Deadman, and the upper one at Soldier Creek where it is represented by limy concretions, sandstone, and sandy shale.

Blackhawk Formation

The name Blackhawk formation was applied by Spieker and Reeside (1925, p. 443) to the coal-bearing rocks exposed in the western part of the Book Cliffs and the eastern front of the Wasatch Plateau.

This formation consists of about 950 feet of sandstone, shale, and coal in Spring Canyon and gradually thins eastward by intertonguing with the upper part of the Mancos. The last traces disappear as the feather-edge of a littoral marine sandstone a few miles southwest of Cottonwood Canyon.

Spieker (1925, p. 444) placed the lower boundary of
A. Storrs sandstone member at Storrs, Utah.

In this exposure at Storrs the thin bedded nature of this unit is evident.

B. Cliffs at Castlegate, Utah.

The massive sandstone at the top of this view is the Castlegate member. White-capped sandstone near the base of the slope is the basal sandstone of the Aberdeen member of the Blackhawk formation. All the intervening rocks are coal-bearing rocks of the Blackhawk. The basal Aberdeen sandstone rests on a thin tongue of Mancos shale which lies disconformably on coal-bearing rocks of the Star Point formation.
the Blackhawk at the base of the lowest coal bed exposed in the Book Cliffs. As previously stated this contact climbs toward the east as the result of the appearance of offshore bars. In the area studied the base is marked by the basal coal of the Spring Canyon coal member which here contains three fairly prominent coals. However, farther west still lower coals appear at the expense of the sandstone bars.

In most outcrops the Blackhawk seems to be overlain disconformably by the Castlegate member of the Price River formation. At the western end of the Book Cliffs the disconformity is rather easily seen. In most other areas the contact between the two formations is poorly exposed and a disconformity can only be inferred.

Spieker (1931, p. 36) lists numerous plant fossils identified by Knowlton which indicate that the Blackhawk, like the Star Point, is medial Montana in age. Both belong to the Campanian stage of the European classification.

There are five prominent littoral marine sandstone tongues in the Blackhawk formation, though there are also many lesser ones. These five sandstones project eastward as tongues into the Mancos shale, where they lose their identity by grading into shale. Above each of these sandstones and below the next succeeding littoral marine sandstone, lagoonal deposits of sandstone, shale, and coal were developed behind barrier bars. Where overlain by
A. Offshore bars of the Aberdeen member in Coal Creek Canyon.

This view shows the white-capped basal sandstone of the Kenilworth member (k) resting almost directly on the uppermost of five offshore bar sandstones of the Aberdeen member (a₁, a₂, a₃, a₄, a₅). A coal bed is visible between sandstones a₅ and a₄. The sandstone near the middle of the Mancos shale slope is the upper unit of the Spring Canyon tongue of the Star Point sandstone. Note the lagoonal deposits behind a₅ and the white caps on the offshore bar sandstones.

B. Basal sandstone of Aberdeen member near Kenilworth, Utah.

This is a characteristic exposure of the basal sandstone of the Aberdeen member. The white cap is more easily weathered and is poorly exposed in this view.
lagoonal deposits each of these sandstones is almost in¬
variably white-capped. The bar sands, like those of the
Star Point, appear as sandstone tongues projecting into the
Mancos shale, and are also white-capped where overlapped
by lagoonal deposits (see Plate 7A).

Because of the close relationship of the sandstone and
the overlying lagoonal and offshore bar deposits, the
writer has taken advantage of the cyclic nature of these
deposits and has divided the Blackhawk into six members
(see Table 1). The lowermost of these members (the Spring
Canyon coal member) as previously stated is genetically a
part of the cycle which produced the underlying Spring
Canyon sandstone tongue. Each of the other members con¬
sists of a basal white-capped sandstone and the overlying
lagoonal and offshore bar deposits. Between each member
there is a thin wedge of Mancos shale which thins westward
to a feather edge at the point where the littoral marine
sandstone also disappears into the undifferentiated coal
measures of the Blackhawk. Each of these shale wedges
rests with slight disconformity on the coal-bearing rocks
of the next lower member, and each grades upward into the
overlying littoral marine sand at the base of the next
higher member. Therefore, the shale unit is really the
basal part of each member; but, since its lower limit can
be determined only where it rests disconformably on older
coal-bearing rocks, it is here treated as a tongue of the

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<table>
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<td>Late Montana</td>
</tr>
<tr>
<td>Price River formation</td>
<td>Early Montana</td>
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**Table 1: Rocks Exposed in the Book Cliffs**

- **Price River Formation**
  - **North Horn Formation**
  - **Tuscher Formation**
  - **Ohio Creek**

- **Castlegate Member**
  - **Sunnyside Member**
  - **Kenilworth Member**
  - **Aberdeen Member**
  - **Spring Canyon Tongue**
  - **Storrs Tongue**
  - **Panther Tongue**
  - **Spring Canyon Coal Unit**

- **Price River Formation**
  - **Tuscher Formation**
  - **Ohio Creek**

- **Castlegate Member**
  - **Sunnyside Member**
  - **Kenilworth Member**
  - **Aberdeen Member**
  - **Spring Canyon Tongue**
  - **Storrs Tongue**
  - **Panther Tongue**
  - **Spring Canyon Coal Unit**
Mancos shale.

These six members of the Blackhawk formation are here given the following geographic names, arranged in normal stratigraphic sequence from the highest to the lowest:

Desert member
Grassy member
Sunnyside member
Kenilworth member
Aberdeen member
Spring Canyon coal member

It should be noted, however, that this division into members is possible only where the basal littoral marine sandstones are well developed. At the extreme western end of the Book Cliffs at Storrs, Utah only the basal sandstone of the Aberdeen member is present. Above it are 800 feet of undifferentiated coal measures of the Blackhawk. Below it are about 60 feet of coal-bearing rocks belonging to the Spring Canyon coal member. About a mile east of Storrs the basal sandstone of the Kenilworth appears. Here one can delimit the Spring Canyon coal member and the Aberdeen member plus about 700 feet of undifferentiated coal measures. Near Coal Creek Canyon the Sunnyside sandstone tongue of the Sunnyside member appears, so that at that point the Aberdeen and Kenilworth members can be separated from the undivided Blackhawk. Since the Grassy sandstone tongue of the Sunnyside member begins at

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Sunnyside, the Aberdeen, Kenilworth, and Sunnyside members can be identified there. The sandstone tongue of the Desert member appears near Desert completing the subdivision of the Blackhawk coal-bearing rocks.

It can be seen then that these members are merely eastward projecting tongues of coal-bearing rocks separated by tongues of littoral marine sandstone which appear higher and higher in the section as one goes from east to west along the cliffs.

**Spring Canyon coal member** - The name Spring Canyon coal group was applied by Clark (1928, p. 125) to that portion of the coal-bearing rocks lying between the Spring Canyon sandstone tongue and next overlying massive sandstone, that of the Aberdeen member which he named the Aberdeen sandstone. Since this unit is genetically a part of the Spring Canyon sandstone cycle, it is unfortunate that it was included in the Blackhawk formation instead of the Star Point sandstone (see Table 1). However, since in the Book Cliffs it is distinct from the overlying units of the Blackhawk, the writer feels that it should be given member rank to facilitate subdivision and description.

This member consists of about 60 to 100 feet of coal-bearing shales and sandstones of fresh and brackish water origin resting directly upon the Spring Canyon sandstone tongue. Its upper limit in the Book Cliffs is marked by a slight disconformity at the base of a tongue of Mancos
shale which separates it from the massive sandstone of the Aberdeen member.

To the west and southwest where the massive sandstone of the Aberdeen is absent it becomes a part of the undifferentiated coal-bearing rocks of the Blackhawk formation.

Two massive offshore bar sandstones which appear near Helper occupy almost the entire interval between the Spring Canyon sandstone and the massive sandstone of the Aberdeen (see Diagram 1). These are the bars behind which the coal-bearing rocks of the Spring Canyon coal member were deposited and thus they mark the eastern limit of the coal producing swamps of this member. These massive littoral marine sandstones are white-capped for a short distance eastward as the result of leaching by swamp waters. A thin westward pointing tongue of Mancos shale intervenes between the upper bar sandstone and the massive sandstone of the Aberdeen. Because of the similarity between these offshore bar sandstones and the underlying tongues of the Spring Canyon sandstone, they have been thought previously to correlate with the Spring Canyon tongues to the east. They also thin eastward and disappear into the Mancos.

Data by Clark (1928, pp. 125-127) and Spieker (1931, p. 79) show that there are, at least, three important coal beds in the Spring Canyon coal member. The lowest and most important is the Spring Canyon coal which may rest directly
on the Spring Canyon sandstone or may be separated from it by a few inches of shale or fire clay. It is the most extensive coal of this member and ranges in thickness from eight inches to seven feet four inches (Clark 1938, p. 126). The acid waters of the coal forming swamp which produced this coal were responsible for the formation of the white cap of the Spring Canyon sandstone. A study of this leaching indicates that iron was leached from the cement of the white portion of the sandstones, but the calcium carbonate and other salts were not removed. In many cases the iron was redeposited at the base of the leached zone.

The lagoonal sides of both of the offshore bar sandstones are also white-capped and bear the feather edges of coal beds which thicken westward. It thus seems evident that the major coal swamps formed when the lagoons were almost completely filled with sediment. Brackish waters would be excluded and fresh water plants would flourish.

**Aberdeen member:** The name Aberdeen was first used by Clark (1938, p. 16) in describing the exposures of massive sandstone near the Aberdeen mine north of Kenilworth, Utah. As here defined the term is extended to include the overlying coal-bearing rocks and associated offshore bar deposits. It consists of a basal white-capped sandstone with a maximum thickness of 88 feet; and an overlying series of shale, sandstone, and coal with a maximum thickness of about 100 feet at Kenilworth.
The massive, flat-topped, basal sandstone nearly everywhere is a cliff-former (see Plate 7B). It is a medium-grained, massive, buff sandstone which grades downward and eastward into finer grained, thin bedded sandstone and finally into Mancos shale. Foreshore cross-bedding can usually be seen in the more massive beds. Where the sandstone is overlain by coal-bearing rocks, a white cap 15 to 20 feet thick is usually present, and is a useful guide in tracing this sandstone and locating the coal. This sandstone disappears at Dugout Creek.

The overlying coal-bearing rocks consist of gray to black shale, lenses of argillaceous and pure medium to fine grained sandstone, and four important coal beds. The lower coal bed, the Aberdeen or Castlegate "A", either rests directly on the Aberdeen sandstone or is separated from it by a few inches or feet of shale. This coal bed has been traced westward from Coal Creek Canyon for 20 miles and reaches a maximum thickness of 19 feet at Kenilworth. The Castlegate "B", Royal Blue, and Castlegate "C" beds occur above the Castlegate "A" in that order. Probably each of these lies at a horizon corresponding to the top of an offshore bar.

From Kenilworth to Coal Creek Canyon the coal measures give way to five offshore bar sandstones (see Plate 7A). These littoral marine sandstone tongues, which are white-capped on the lagoonal side, also grade eastward into the
A. Basal sandstone of Kenilworth member near Kenilworth, Utah.

This view shows only the upper or white-capped portion of this massive sandstone.

B. Blackhawk and Price River strata in the Beckwith Plateau north of Green River.

The massive white-capped sandstone near the bottom is the uppermost offshore bar sandstone of the Kenilworth member. Next massive sandstone above is in Sunnyside member. Sandstone capping the mountain is the Bluecastle sandstone of the Farrer facies.
Mancos. The second from the bottom is the most persistent, but disappears at Whitmore Canyon. Dune, backshore, upper foreshore, and lower foreshore laminae were noted in these bar sandstones.

**Kenilworth member**: The unit here named the Kenilworth member of the Blackhawk formation takes its name from exposures near Kenilworth, Utah. It consists of a massive, cliff-forming, basal sandstone, an overlying series of coal-bearing rocks, and the offshore bar sandstones behind which they were deposited. The basal sandstone is gradational into the underlying tongue of Mancos shale, which rests disconformably on the Aberdeen coal-bearing rocks.

Like the basal sandstone of the Aberdeen member, the basal Kenilworth sandstone is flat-topped and is white-capped where leached by swamp waters. It is a medium grained, thick bedded, buff sandstone with a maximum thickness of 85 feet (see Plate 8A). It, too, grades downward and eastward into the Mancos shale. Cross-bedding is a common feature of the more massive beds. This sandstone disappears into the Mancos shale near Sunnyside. Thin sandstone lenses in the Mancos shale between Woodside and Green River may represent the same horizon.

The coal-bearing rocks of the Kenilworth member consist of about 160 feet of gray to black shale with lenses of white and buff sandstone and four mineable coal beds.

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The thickest of these is the Kenilworth or Castlegate "D" bed which is 19 feet thick at Kenilworth. Above the Kenilworth seam are the Gibson, Fish Creek, and Rock Canyon coals in that order. These coals, too, appear to be developed at horizons corresponding to the top of bar sandstones in the Sunnyside region. Clark (1928, p. 128) gives a good description of these coals.

In contrast to the earlier described bar sandstones, those of the Kenilworth are irregularly developed. The five main bar sandstones of this member did not form at one point, but at several different points. The lower two bar sandstones formed considerably inland from the seaward edge of the swamp which produced the Kenilworth coal, while the upper three formed farther east (see Diagrams I and II). A study of these so-called offshore bar sandstones indicates that they are nothing more than small scale littoral marine sandstones. They have the same origin as the more extensive littoral marine sandstones which are used in the subdivision of the Blackhawk. The farthest eastward extension of these coal-bearing rocks is a thin bed of shale and coal which lies on the upper bar sandstone. This bed extends almost to Green River (see Plate 8B). All of these bar sandstones are white-capped where overlain by coal-bearing rocks. The two lower bar sandstones disappear into the Mancos near Horse Canyon south of Sunnyside, but the upper three continue eastward and split into several tongues.
the most extensive of which disappears at Crescent Canyon. A sixth, much shorter bar sandstone, appears near Pace Canyon at the top of the Kenilworth member. It, however, soon disappears near Whitmore Canyon. For a better understanding of the relationship of these bar sandstones to each other see diagrams I, II, and III.

Sunnyside member:—The Sunnyside member of the Blackhawk formation is here named for exposures near the town of Sunnyside, Utah. It is composed of a massive, basal sandstone tongue and the overlying coal-bearing rocks which are replaced eastward by littoral marine offshore bar sandstones.

This basal sandstone is like the other littoral marine sandstone of the Blackhawk in that it is medium grained, buff, and massive. It reaches a maximum thickness of about 50 feet at Pace Canyon. The massive layers show marine cross bedding and grade downward and eastward into the Mancos shale, which in turn rest disconformably on the coal-bearing rocks of the Kenilworth member. Where overlain by coal-bearing rocks the Sunnyside sandstone, too, is white-capped. It first appears at Kenilworth and splits eastward into two tongues which disappear into the Mancos shale near Horse Canyon south of Sunnyside.

The coal-bearing rocks of the Sunnyside member are comparatively thin. They consist of about 25 feet of sand-
stone, shale, and coal which, at a point about four miles northeast of Desert, are completely replaced by the last of a series of offshore bar sandstones. This series of six bar sandstones begins near Sunnyside. The highest and most extensive of these bar sandstones disappears into the Mancos near Horse Canyon east of Green River. The lowermost bar sandstone splits into two tongues and disappears about ten miles south of Sunnyside. About six miles farther south two stringers of sandstone appear at about the horizon of the upper tongue and continue east to Crescent Canyon. The gap in outcrop is probably due to an embayment in the old shoreline. Two important coal beds are present in the Sunnyside member. These are the Upper and Lower Sunnyside coals. The Lower Sunnyside coal rests directly on the white cap of the Sunnyside sandstone tongue northwest of Horse Canyon near Sunnyside. From Sunnyside to Horse Canyon it is overlapped by the first bar sandstone of the Sunnyside and is relatively thin. The maximum recorded thickness of this coal is five feet. Contrary to popular belief, it is not this coal which is mined at Sunnyside but the next higher coal which has been called the Upper Sunnyside coal. This coal lies 30 to 35 feet above the Lower Sunnyside coal and can be traced southward to the Price River. It is about 32 feet thick at Horse Canyon where a split is present near the top. That this coal is a composite of several coal beds can be verified by
tracing it southward, where it splits into three subsidiary beds (see Diagram II). These splits occur where offshore bars appear. In each case the lower part splits off and is overlapped by a bar sandstone.

**Grassy member**—The rocks here designated the Grassy member of the Blackhawk formation receive their name from good exposures in the nearly vertical cliffs east of the railroad siding of Grassy. The member consists of a basal littoral marine sandstone with a maximum thickness of about 60 feet and a series of coal-bearing rocks with a maximum thickness of about 50 feet.

The basal white-capped sandstone of this member first makes its appearance at Sunnyside and fades into the Mancos shale at Coal Canyon. Its lithology is similar to that of the other littoral marine sands of the Blackhawk. It is a medium grained, buff sandstone, which grades downward and eastward from massive into thin bedded sandstone and finally into marine shale (see Plate 4A). This shale rests disconformably on coal-bearing rocks of the Sunnyside member.

No mineable coals are found in the Grassy member though some relatively thin seams are present. Coal-bearing rocks of this member are absent east of Coal Canyon.

Between Green River and Coal Canyon three offshore bar
sandstones make their appearance and form the eastern limit of the coal-bearing unit of the Grassy member. The most persistent of these sandstones is the middle bar sandstone which disappears at Crescent Canyon.

Desert member:—Near Desert siding there appears a littoral marine sandstone tongue. This sandstone tongue and the overlying coal-bearing rocks, which lie between it and the overlying Castlegate member, are here defined as the Desert member of the Blackhawk. This member takes its name from exposures in the nearly vertical cliffs of Mt. Elliot east of Desert, a siding on the D. & R. G. W. R. R.

The basal littoral marine sandstone unit of this member is medium grained and buff colored. It has a maximum thickness of about 70 feet. Eastward it disappears into the Mancos at Saleratus Canyon. This unit is massive near the top, but grades downward into thinner beds and finally into Mancos shale which in turn rests disconformably on the coal measures of the Grassy member (see Plate 4A).

Numerous thin lenses of coal are present in the coal-bearing rocks of this member. Their lens-like nature, plus the absence of a well defined white cap on the basal sandstone, seems to indicate the lack of any large coal swamp at the time of their deposition. No mineable coals are present in the Desert member.

About 50 feet of coal-bearing rocks is present at
Desert but this unit thins rapidly to the southeast and is absent at Green River where the basal sandstone of the Castlegate rest directly on the basal sandstone of the Desert member (see Plate 7A). This was probably a local high during the deposition of the coal-bearing rocks since they reappear near Tuscher Canyon as a thin wedge of sandstone, shale, and coal which thickens to the east. These rocks reach a thickness of about 80 feet near Horse Canyon where they abut against the lagoonal side of the first two of a group of nine offshore bar sandstones. These offshore bar sandstones cause the termination of the coal-bearing strata just east of Thompson Canyon. Exposures in the cliffs between Coal Canyon and Thompson Canyon present an excellent cross-section of a lagoon on a fairly small scale. A cross-section of an even better lagoon is seen directly above these deposits in the Castlegate member of the Price River. This lagoon will be described later.

The uppermost of the nine bar sands disappears into the Mancos shale a short distance southwest of Cottonwood Canyon. This marks the eastermost outcrop of rocks of the Desert member and, therefore, also of the Blackhawk formation.
A. Sego member of Neslen facies in Crescent Canyon.

In this view four littoral marine sandstone tongues are visible. The lower tongue is represented by the thin sandstone stringers near the middle of the shale slope.

B. Disconformity at the base of the Palisade member.

In this exposure near the Farmers mine the basal sandstone of the Palisade member is seen to grade into the thin tongue of Mancos shale. The shale lies disconformably on carbonaceous shales of the Sego member. The disconformity is marked by the head of the hammer.
Price River Formation

The name Price River formation was applied by Spieker and Reeside (1925, p. 445) to a series of non coal-bearing beds lying above the Blackhawk formation. It derives its name from exposures in Price River Canyon west of Castle-gate. This formation comprised the upper part of the Mesa-verde Group of Clark (1928, p. 20). In the western portion of the Book Cliffs it consists of a massive basal sandstone (the Castlegate sandstone member) and an overlying succession of beds of shale, sandy shale, and lens-like beds of massive, coarse to medium grained sandstones.

Farther east, in the Beckwith Plateau, the basal Castlegate member is separated from the remainder of the Price River by a thin wedge of Mancos shale (Buck tongue), which thickens eastward. The Castlegate thins eastward and disappears in the Mancos near West Salt Wash. Fossils found in the Buck tongue indicate Lewis age. Simultaneous with the appearance of the Buck tongue a thick sandstone member (Sego member) appears above the shale. This member includes several sandstone tongues and related coal-bearing rocks (see Plate 9A).

In the vicinity of Thompsons, Fisher (1936, p. 19) subdivided that part of the Price River above the Sego sandstone tongues into two members. The lower, coal-bearing member he called the Neslen for exposures in
Neslen Canyon. The upper, non coal-bearing member he called the Farrer for exposures near the Farrer Mine in Coal Canyon. Erdmann (1934, p. 32) in western Colorado subdivided the Price River equivalents above the Sego member into two units. The lower he called the Mt. Garfield formation for exposures on Mt. Garfield near Palisade. This formation included the coal-bearing rocks and the lower part of the non coal-bearing rocks. He correlated it with Bowie and Paonia shale member of the Mesaverde to the south of Grand Mesa. The remainder of the non coal-bearing rocks he called the Hunter Canyon formation for exposures in Hunter Canyon, and correlated them with the undifferentiated Mesaverde of Lee. Since there is nowhere any well defined boundary between the Mt. Garfield and Hunter Canyon, their usage as formational names is not justified.

The best solution to this confused nomenclature seems to be to adopt the term Neslen parvafacies for all of the coal-bearing rocks of the Price River. The term Farrer parvafacies should then be applied to the non coal-bearing rocks above the rocks of the Neslen facies. Measurements by Fisher and Erdmann show clearly that the passage between coal-bearing and non coal-bearing strata is gradational and does not occur at one wide spread stratigraphic horizon. Since coal-bearing and non coal-bearing rocks as well as littoral marine sandstones are characteristic of certain related environments, it is obvious that any
shifting of one environment would result in a shifting of
the other. The problem of facies will be discussed more
fully later, but for the present it will suffice to say
that the boundary between the Neslen and Farrer parva-
facies should be nearly as zigzag as that between the lit-
toral marine sandstones and marine shales. With this in
mind it can be seen that this boundary rises stratigraph-
ically to the east. The thickness of the rocks of the
Neslen parvafacies remains fairly uniform despite inter-
tonguing to the east with littoral marine sandstones and
marine shales. On the other hand, the rocks of the Farrer
parvafacies should be expected to thin but actually they
thicken eastward. These are called parvafacies since they
are portions of two magnafacies lying within the Price
River formation.

In the region covered by the writer three more pro-
minent littoral marine sandstones appear in the rocks of
the Neslen parvafacies above the Sego member in western
Colorado. To those three sandstone tongues and their as-
associated coal members the writer has applied member names.
The lower member is here named the Palisade member, the
middle member is named the Riverside member, and the upper
is named the Rollins member (replacing the term Rollins
sandstone member of Lee (1912, p. 19).

At the extreme western end of the Book Cliffs the
Price River formation rests disconformably on the Blackhawk
formation. In most other regions the contact appears conformable. This contact will be more fully discussed with reference to the Castlegate member. The contact between the Price River and the overlying North Horn is gradational and is drawn at the first appearance of red beds in the geologic section. East of the Green River the Price River formation is overlain unconformably by the Tuscher formation, which is probably basal North Horn.

The Price River formation ranges in thickness from about 1000 to 2000 feet at the western end of the Book Cliffs and from 1000 to 2500 feet in western Colorado. The Price River is late Montana in age and belongs to the Maestrichtian stage of European terminology. This determination of age is based on fossil evidence reviewed by Spieker (1946, p. 131).

Fisher (1936, p. 15) applied the name Buck tongue to a large, westward-pointing tongue of Mancos shale which separates the Castlegate member from the Sego member in Buck Canyon (see Plates 2A and 9A). The Sego member, itself, is split into a lower and an upper sandstone tongue by another westward pointing tongue of Mancos shale which Erdmann (1934, p. 36) named the Anchor Mine tongue for exposures near the Anchor Mine. Neither of these units is treated here since they have already been discussed with the Mancos shale.
A. Price River formation in Thompson Canyon.

In this view rocks of both the Neslen and Farrer facies are present. The two can be roughly separated on the basis of color. The lighter colored rocks in the lower half of the picture are of Neslen facies while those of the Farrer above are darker.

B. Castlegate member near type locality in Price River Canyon.

The massive, irregularly bedded nature of this sandstone is well shown. The disconformity at the base is not visible in this picture.
Neslen Parvafacies

Neslen parvafacies is the name here applied to the coal-bearing rocks of the Price River formation. Fisher (1936, p. 16) first used the name Neslen as a stratigraphic term. He applied it to the coal-bearing rocks of the Price River formation in eastern Utah. The name is taken from exposures in Neslen Canyon near Thompsons, Utah (see Plate 10A). Since the coal-bearing rocks of the Price River formation are a facies development, they must cross time lines, and hence no stratigraphic name is applicable to the entire facies. It seems logical to the writer that the name be retained, but used in a facies sense.

The rocks of this facies were deposited, for the most part, in lagoonal and littoral marine environments. Therefore, it is apparent that at least two facies are represented. However, since these two facies are so intimately related and since to separate them would greatly confuse this report, it seems best to include the two facies in one coal-bearing facies or parvafacies. This coal-bearing facies can be recognized in all the units of the Book Cliffs and thus a name such as Mesaverde magnafacies could be applied to the facies as a whole in contrast to the term Indianola magnafacies for the non-marine, non-coal-bearing facies. The marine shales would belong to a third magnafacies, the Mancos magnafacies.
Lithologically the rocks of the Neslen parvafacies are rather distinct from those of the Farrer parvafacies. By definition, they are coal-bearing though coal makes up only a small portion of the rocks. The bulk of the rock is shale and sandstone. The shales are non-marine and vary from gray to black, depending on their carbon content. The sandstones are of two types. Most common are the thin, lenticular, buff sandstones found in the lagoonal deposits. The most conspicuous, however, are the massive, buff, littoral marine sandstones which are traceable for many miles. These appear at intervals in the coal-bearing rocks, and indicate oscillation of the strand line. They are used by the writer as a means of subdividing the rocks of the Neslen parvafacies into members. Each of these littoral marine sandstones represents a regressive deposit formed after a small scale invasion of the sea due to subsidence of the basin of deposition.

Since these subsidences were on a small scale and probably very rapid, no recognizable transgressive deposits were formed. Instead, there was only a slight amount of erosive action by the waves on the previously deposited rocks. Here, as in the Blackhawk formation, the time of erosion is represented by a slight disconformity at the base of the Mancos shale tongues which underly each of the littoral marine sandstones and which formed simultaneously with the overlying sandstone (see Plate 9B).

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Because these erosional breaks apparently mark the beginning of new cycles of deposition, they are used as a means of subdividing the rocks of the Neslen parvafacies into five members.

The Castlegate member as used in this report belongs to both the Neslen and Parrer parvafacies. However, since it does include coal-bearing rocks throughout a considerable portion of its outcrop, it is here discussed as a member of the Neslen parvafacies.

The five members of the Neslen facies are listed below in normal stratigraphic sequence from top to bottom:

- Rollins member
- Riverside member
- Palisade member
- Sego member
- Castlegate member

Each of these members consists of one or more basal sandstone tongues and associated lagoonal and barrier bar deposits. These members can be distinguished only where the littoral marine sandstones are present. The more landward lagoonal deposits of the Neslen parvafacies, which are not penetrated by littoral marine sandstone, have not been subdivided.

Rocks of the Neslen parvafacies vary in thickness from about 100 feet near Woodside to a maximum of about 1000 feet near the Colorado-Utah line.
A. Castlegate member in Thompson Canyon.

In this view two offshore bar sandstones of this member are separated by a shale zone. A fault has dropped the block on the right.

B. Lower littoral marine sandstone tongue of the Castlegate member near Thompsons.

This view shows the lower offshore bar sandstone tongue a short distance from the above view. Here the basal sandstone is seen to grade downward into marine shale which lies with slight disconformity on coal-bearing rocks of the Desert member of the Blackhawk. Dark seam marks contact.
The units above the Sego member were not studied in detail, but a reconnaissance of these rocks, supplemented by published data by Spieker (1949), Fisher (1936), Erdmann (1934), and Lee (1912) enabled the writer to obtain a general idea of their nature. A brief summary of these units is included in this paper.

**Castlegate member**—Clark (1938, p. 119) applied the name Castlegate sandstone to the massive, basal sandstone of the Price River Formation. It was named for exposures near the town of Castlegate, Utah (see Plate 10B). Since the name Castlegate sandstone does not convey the idea that this unit also contains some coal-bearing rocks, it is here renamed the Castlegate member of the Price River. As redefined, this member consists primarily of a massive, cross-bedded, white or pink sandstone which varies from coarse grained to fine grained as one traces it eastward. This portion of the Castlegate represents an inland flood plain deposit and so belongs to the Farrer facies. It also contains some lagoonal deposits which completely replace the inland flood plain facies near Horse Canyon east of Green River. These lagoonal deposits are, in turn, replaced eastward by littoral marine bar sandstones (see Plate 11A). This portion of the Castlegate, as well as a thin lagoonal deposit at the top of the Castlegate member from Desert east to Cottonwood Canyon, is placed in
Table 2. Cumulative curves of samples of basal sandstone of Castlegate member.
From the western end of the Book Cliffs to Green River, the Castlegate member is composed mainly of non-marine sandstone which formed in response to an orogenic pulse (Spieker 1946, p. 159). The eastward edge of the massive sandstone tongue of the Castlegate member is found at Horse Canyon, where it passes into lagoonal deposits. Three littoral marine bar sandstones which form the eastern margin of the lagoonal deposits interfinger eastward with the Mancos. The upper two bars are the most persistent, but they disappear at West Salt Creek. They can be traced a short distance farther east by means of concretionary zones.

A series of six samples of sandstone of the Castlegate were collected along the cliff and screen analyses were made. The cumulative curves of these sands are shown in Table 2.

Since the samples collected were taken at points increasingly distant from the source of the Castlegate in central Utah, it should be expected that the median diameter of the sand grains would decrease toward the east and away from the source. A look at the curves on Table 2 shows this to be the case. It can be seen that the median diameter decreases rather regularly from .270 at Willow Creek Canyon to .118 at Saleratus Canyon. An increase in percentage of fines is reflected by the steep-
ening of the curves from A to D.

Curves E and F are incomplete in that a large portion of each sample was too fine to be treated by mechanical methods. These could have been treated by elutriation methods but the resultant curves would not be the same scale. Samples A to D were taken westward from the point at which the Castlegate passes into coal measures while E and F were taken from an offshore bar sandstone which formed to the east of the lagoonal deposits. The extremely small size of the sand particles in samples E and F seem to show that only the very fine materials escaped from the lagoonal areas.

Microscopic examinations show that the sand of the inland flood plain portion of the Castlegate (Farrer parva facies) derives its white color both from the presence of kaolinized feldspars and from a calcareous cement. The littoral marine sandstones of the Castlegate member are fine to medium grained and are buff in color. The buff color is due to the presence of iron in the cement.

Cross-bedding in the inland flood plain portion is of the torrential type (see Plate 10B), while that of the littoral marine portion is marine (see Plate 11A).

The thickness of the Castlegate member ranges from about 500 feet at Castlegate to a feather-edge near West Salt Wash. Coal-bearing rocks of this member reach a max-
imum thickness of about 90 feet near Crescent Canyon. No workable coals are known though many minor lenses are to be seen.

As stated previously, the Castlegate member rests disconformably on coal measures of the Blackhawk at the western end of the Book Cliffs. To the east of Kenilworth and west of Thompson Canyon this disconformity may be present, but has not as yet been definitely recognized. It is possible that some reworked Blackhawk material has been mixed with typical Castlegate and redeposited as a transitional zone in some places. Such a zone seems to be present near Sunnyside, but poor exposures prevented an accurate investigation. In Thompson Canyon the lower bar sandstone of the Castlegate rests disconformably on the underlying coal-bearing rocks of the Blackhawk (see Plate 11B). In Coal Canyon the basal contact appears to be disconformable. In the canyons between Green River and Crescent Junction numerous springs are present at this contact, and lend support to the idea of an unconformity.

The contact of the Castlegate member with the overlying sandstones and shales of the Farrer parvafacies in the western Book Cliffs is poorly defined. It is usually placed at the top of the massive, basal sandstone of the Price River formation. Since the top is transitional west of Woodside it is not everywhere of the same age. Where the Buck tongue overlies the Castlegate member east of
Woodside, the Mancos shale rests in most places on coal-bearing rocks. The contact between the two is poorly exposed, but appears to be disconformable. The disconformity noted by Fisher (1935, p. 15) in Horse Canyon is probably at the contact between the coal-bearing rocks and the underlying massive sandstone of the Castlegate.

Fossils from the Castlegate member (Spiker and Resside 1925, p. 446) and Fisher (1936, pp. 14-15) indicate a late Montana age.

Sego member:- Sego member is the term here introduced to replace the name Sego sandstone member of the Price River formation applied by Fisher (1936, p. 15) to a series of interbedded sandstones and shales at the coal mining town of Sego near Thompsons, Utah (see Plate 9A). The Sego member includes the rocks formerly called the Sego sandstone as well as the overlying and closely related coal-bearing rocks. This member is in reality a member of the Neslen parvafacies. Its base is drawn at the gradational contact of the lowermost littoral marine sandstone tongue with the underlying marine shale. The top boundary is placed at the slight disconformity between the coal-bearing rocks and the overlying marine shale tongue at the base of the Falisade member (see Plate 9B). This member has an average thickness of 200 feet. Numerous fossils reported by Fisher (1936, p. 16) indicate Lewis age for the member.
A. Lower portion of Price River formation in Cotton-wood Canyon.

In this view the thin bedded sandstone of the Castlegate member appears in the foreground. Above it can be seen the slope formed by the Buck tongue of the Mancos shale. Above the shale slope are the upper and lower sandstone tongues of the Sego member separated by the shale of the Anchor Mine tongue. Above the upper sandstone tongue lie the coal-bearing rocks of the Sego member and other rocks of the Nealen facies.

B. Sandstone tongues of the Sego member in Westwater Canyon.

The lower sandstone tongue in this view is seen to thicken from left to right as the result of a probable channel deposit.
The littoral marine sandstone portion of this member makes its appearance near Woodside as two sandstone tongues. The actual point of origin of the lower tongue could not be precisely determined since in this area erosion has removed the beds above the Castlegate member. Farther eastward, near Horse Canyon, two more tongues appear between them. A short distance eastward the lower tongue disappears into the Mancos shale, but the three remaining tongues continue eastward into Colorado. The middle and lower tongues are less persistent than the upper. They both disappear into the Mancos north of Nash Canyon but reappear at Cottonwood Canyon (see Plate 12A). This gap is probably due to a local embayment or indentation of the old shoreline since the outcrops in this part of the cliffs trend northeast approximately parallel to the old shoreline. A study of the cross-bedding of the Sego sandstone in this area seems to indicate a northwestern source. The middle sandstone tongue disappears twice more before finally disappearing at Camp Canyon. The lower tongue continues eastward from Cottonwood Canyon and finally disappears at Big Salt Wash (see Plate 13B).

Unlike the lower tongues, the upper tongue is continuous from Saleratus Canyon to a point just east of the Anchor No. 1 Mine.

In most localities all three of these main sandstone tongues are overlain by fresh or brackish water deposits.
A. Sego member in East Salt Canyon.

In this view can be seen the upper and lower tongues of the basal sandstone unit of the Sego members.

B. Sego member and Anchor coal in Big Salt Canyon.

Lower tongue of basal sandstone is represented by thin stringers of sandstone near the middle of the shale slope. Upper tongue forms steep cliff under the coal. Main coal bed is Anchor coal and is near the middle of the coal-bearing rocks of the Sego member. Hill directly above coal exposure is capped by basal sandstone of Palisade member.
of sandstone, sandy shale, or shale (see Plate 9A). Where the overlying deposit is a massive channel sandstone, the actual thickness of the littoral marine sandstone is generally difficult to ascertain (see Plate 12B). Resting disconformably on the brackish or freshwater deposits are thin westward pointing tongues of Manoos shale which grade upward into the next overlying littoral marine sandstone tongue (see Plate 9B). The brackish or fresh water deposits above the lower tongue are formed behind a series of poorly defined bar sandstones between West Salt Wash and Camp Canyon. In the supposed embayment near Cottonwood Canyon, no trace of barrier bars was noted. The non-marine deposits above the middle tongue are spotty, but those above the upper tongue are continuous and important. Where the upper limit of this member is delimited by the overlying marine shale tongue and littoral marine sandstone, these coal-bearing rocks have an average thickness of 60 feet.

The coal-bearing rocks of the Sego member, above the upper littoral marine sandstone, formed behind a series of barrier bars which appear in the cliffs between the Farmers Mine and the Book Cliffs Mine (see Diagram IV).

The littoral marine sandstones of the Sego member vary from massive bedded, medium grained, buff sandstones to thin bedded, fine grained, gray sandstones with shale partings. Quartz particles, which make up the bulk of these sandstones, are angular and many show pitting. These sand-
A. Cross-bedding in sandstone resting on upper tongue of sandstone of Sego member in Westwater Canyon.

The fluvial bedding of this sandstone has enabled the writer to understand rapid changes of thickness of these sandstone tongues of the Sego member.

B. Price River rocks near Hunter Canyon.

In this view the basal sandstone unit of the Palisade member appears at the base of the cliffs above the shale slope. The next sandstone above is the basal unit of the Riverside and the third from the bottom is the basal unit of the Rollins member. Above the Rollins are rocks of the Neslen and Farrer facies. Pediment remnant appears in foreground.
stones reach a maximum thickness of about 50 feet. However, as stated previously, channel sandstones may greatly increase the apparent thickness. Where these brackish or fresh water sandstones are present they are lighter in color than the littoral marine sandstones and give the false appearance of white capping such as that of the typical littoral marine sandstone under coal (see Plate 12B and 9A). Cross-bedding of the channel sandstones is fluviatile in most places (see Plate 14A), and the sand grains composing this lighter upper portion are larger, fresher, and more angular than those of the littoral marine sandstone. Pitting of grain surfaces is common to both, however. In some places these lens-like sandstones seem to exhibit eolian cross-bedding, and the grains are somewhat frosted. However, the presence of flakes of muscovite seems to preclude any great amount of wind action. In several localities channeling effects were noted on the upper surfaces of the littoral marine sandstones. One exposure in Neslen Canyon exhibits a channel cutting completely through the littoral marine sandstone and into the Mancos shale below.

In discussing the coal-bearing rocks of the Sego member, we are primarily concerned with the 60 feet of coal-bearing rocks lying above the upper sandstone tongue of the Sego member. No coal beds of importance are found in the irregular fresh and brackish water deposits below the
upper tongue. These coal-bearing rocks consist of sandstone, sandy shale, carbonaceous shale and one important coal bed. Measurements and tracing by Erdman and Fisher established the possibility that this coal bed could be traced from near Green River to a point near Hunter Canyon. However, because of an error by Erdmann at Big Salt Wash, a confused terminology has developed.

Erdmann (1935, p. 78) gave the name Palisade coal seam to a coal mined near Palisade. He traced this coal westward to the Utah line to which point Fisher had traced it from the Green River. Since this coal had been traced along its entire outcrop, it was believed to be the same coal. Therefore, Fisher (1936, p. 46) adopted the name Palisade for the coal seam in Utah. This nomenclature, and the resulting wide extent of the Palisade coal, are not justified because the coal Fisher traced to the Colorado line as the Palisade coal is actually the same as Erdmann's Anchor Mine coal.

Erdmann (1935, p. 36) states that there appears, in the Anchor Mine tongue at Big Salt Wash, a series of coal-bearing rocks above the lower sandstone tongue of the Sego. The most conspicuous unit of these coal-bearing rocks is a coal bed which Erdmann named the Anchor coal (see Plate 13B).

Investigations by the writer show that no such coal-bearing unit exists in the Anchor Mine tongue. Actually
these beds lie above the upper sandstone tongue of the Sego; therefore, the Anchor coal is the same coal which Fisher called the Palisade coal. This coal continues eastward to the vicinity of Hunter Canyon where the coal-bearing rocks are replaced by barrier bars.

What then has happened to Erdmann's Palisade coal bed? Actually it is a higher coal which lies some 100 feet above the Anchor coal bed and can be traced only a short distance west of Big Salt Wash. It is possible that this coal (Palisade of Erdmann) may correlate with the Ballard coal zone of Fisher, though this is purely a guess at present.

The apparent cause for this confusion is the fact that the lower sandstone of the Sego thins rapidly from East Salt Wash to Big Salt Wash and has almost disappeared at Big Salt (see Plates 14A and 14B). In measuring his sections in these neighboring canyons Erdmann apparently failed to note the thinning and neglected the sandstone stringers in Big Salt. He probably assumed that the lowest prominent tongue would be the lower Sego tongue in each section. A new littoral marine sandstone tongue (the basal unit of the Palisade member) is present in the Big Salt section, and this he took to be the upper Sego tongue since the stratigraphic interval and the thickness of the sandstone were about right for the two Sego tongues. Therefore, this seems quite a natural and easy mistake to make if one is not careful in tracing these various units along the
cliffs. The true relationship of these rocks was determined by the writer while tracing out the two prominent sandstone tongues of the Sego member and the basal sandstone of the Palisade member which appears near Big Salt Creek. The writer proposes to use Erdmann's name Anchor Coal for the main coal bed of the Sego member, which takes its name from the Anchor Mine where it reaches a thickness of about five feet. As redefined, this coal bed corresponds to the Palisade coal bed of Fisher and the Anchor coal bed of Erdmann. Its extent of outcrop has already been discussed. Lithologically, the offshore bar sandstones which terminate the coal measures of this member are similar to those of the Blackhawk. White caps on these bar sandstones are rare.

**Palisade member**: The name Palisade member is here applied to the unit of littoral marine sandstone and associated coal-bearing rocks which lies above the Sego member, and is separated from it by a thin tongue of Mancos shale with a disconformity at its base (see Plate 9B). It takes its name from exposures in the cliffs north of Palisade, Colorado (see Plates 3B and 14B). Its average thickness is 100 feet.

At the base of this unit is a massive littoral marine sandstone tongue which grades downward and eastward into the Mancos. This sandstone, which is lithologically similar to those of the Blackhawk and of the Sego, first appears near Big Salt Wash and can be traced eastward into
Grand Mesa, where it disappears into the Mancos. Where overlain by coal measures it is often completely white and is referred to by some local miners as the "White Pioneer". A series of offshore bar sandstones appears above it near Watson Creek in Grand Mesa and forms the eastern limit of the 50 feet or so of coal-bearing rocks.

Erdmann (1935, p. 81) describes the main coal zone of this member as a series of overlapping and isolated lenses of coal in a thick deposit of carbonaceous shale. This is the Palisade coal of Erdmann as previously discussed. The term Palisade coal bed is here restricted to the coal of the Palisade member. It lies about 100 feet above the Anchor coal as re-defined, and can be traced from the vicinity of Big Salt Wash to Plateau Creek. Four separate beds can be traced eastward from Hunter Canyon to near Plateau Creek where they pass under the Colorado River and continue under Grand Mesa. Each ranges from one to four feet thick and each presumably corresponds to the top of an offshore bar sandstone in the vicinity of Watson Creek.

**Riverside member**- The littoral marine sandstone and the overlying coal-bearing rocks beneath the next littoral marine sandstone are here named the Riverside member of the Price River formation for exposures near the Riverside mine near the Colorado River. This member has a basal
A. Riverside member in Hunter Canyon.

The honeycombed sandstone in this view is the white-capped portion of the basal sandstone. Topping the hill is the basal sandstone of the Rollins member. Coal-bearing rocks of the Riverside member form the tree-covered slope.

B. Rocks of the Farrer facies in Coal Canyon.

This view shows the barren cliffs formed by sandstones and shales of the inland facies.
sandstone which grades downward into the tongue of Mancos at its base. This tongue rests disconformably on the coal-bearing rocks of the Palisade member. The upper limit of this unit is drawn at the disconformity between the coal-bearing rocks of the member and the overlying tongue of Mancos shale.

In the outcrops seen by the writer this sandstone appears to be composed of two units with a combined thickness of about 130 feet (see Plates 3B, 14B, and 15B). This massive bedded, buff sandstone begins near Hunter Canyon and extends into Grand Mesa. The extent of the sandstone and the position of the associated offshore bar sandstones remain to be accurately determined.

**Rollins Member**—The uppermost of the coal-bearing rocks of the Nelson facies are here defined as comprising the Rollins member of the Price River formation. This member is limited below by a basal littoral marine sandstone (the Rollins sandstone of Lee). Its upper limit is taken as the boundary between the coal-bearing rocks of this member and the overlying non coal-bearing rocks of the Farrer paraffacies. This upper boundary is, therefore, indefinite but will serve temporarily until the remainder of the intertonguing details are determined. There are undoubtedly other littoral marine tongues which appear in the coal-bearing rock above the Rollins sandstone tongue in
Grand Mesa, which will serve to further subdivide the coal-bearing rocks here placed in the Rollins member.

The massive, white-capped, basal sandstone of the Rollins member is a conspicuous element in the cliffs near Palisade and in Grand Mesa. This thick bedded, medium grained sandstone is a cliff-former. It is this sandstone which caps Mt. Garfield near Palisade (see Plate 3B). It first appears near Hunter Canyon (see Plate 14B) and continues south beyond Grand Mesa. It grades downward into a shale tongue which lies disconformably on the coal measures of the Riverside member.

About 250 feet of coal-bearing rocks lie above this massive sandstone near Mt. Garfield. They consist of sandstone, sandy shale, carbonaceous shale, and coal.

Resting directly on the basal sandstone of the Rollins is the Cameo coal zone, the most important coal zone in the eastern Book Cliffs. Erdmann (1934, p. 83) states that the Chesterfield coal of Utah is probably equivalent to the Cameo coal. In most exposures in the area studied the Cameo zone consists of two beds separated by a thick parting. The upper bed is less bony and approaches 20 feet in thickness (Erdmann 1934, p. 84).

About 60 feet above the base of the Cameo coal zone is the Carbonera coal zone (Erdmann 1934, p. 86). It is a series of discontinuous lenses and has a maximum thickness of 10 feet.
The offshore bar sandstones behind which these coal-bearing rocks were deposited undoubtedly exist farther to the east and southeast, but none is present in the region studied.

**Farrer Parvafacies**

As stated previously the term Farrer parvafacies is here applied to the non coal-bearing rocks of the Price River formation. The name Farrer formation was first used by Fisher (1936, p. 19) as a stratigraphic term. He applied it to the non coal-bearing rocks of the Price River formation in Coal Canyon. The name is derived from the Farrer Mine in Coal Canyon. Although it should not be used as a stratigraphic term, it is here retained as a term to apply to the non coal-bearing rocks of the Price River, formed in an inland flood plain environment.

The rocks of the Farrer parvafacies consist of beds of coarse to fine sandstone, shale, and sandy shale. They do not contain appreciable coal although a few thin seams are found at various horizons. The lens-like sandstones of this facies are the most abundant lithologic type. In most exposures they constitute two-thirds to three-fourths of the bulk of the rocks (see Plates 10A and 15B). The sandstones are composed largely of sub-angular quartz grains and are cemented with calcium carb-
onate and ferruginous cements. As a result their color is somewhat darker than that of the sandstones in the Neslen parvafacies. However, most of the sandstones in the western portions of the Book Cliffs are fairly light in color and some are even white because of the kaolinitization of feldspars. Shales of this facies are gray, but in places they take on an olive green cast.

As discussed previously the Castlegate member includes rocks of both Neslen and Farrer parvafacies (see Table 1). West of Woodside the Castlegate, as well as all the rest of the Price River formation, is non coal-bearing and thus could be placed in the Farrer parvafacies. East of Woodside, however, the coal-bearing rocks begin to appear at stratigraphically higher levels. Therefore, the contact between the two facies must rise in a zigzag manner toward the east. This rise should normally be expected to decrease the thickness of the rocks of the Farrer parvafacies. But we find that these rocks increase from a thickness of about 1200 feet in Price River Canyon to about 1500 feet near Palisade (Spieker, unpublished data). This increased thickness of section must be due largely to greater deposition to the east, though pre-North Horn erosion may have removed some of the rocks in the western portions of the cliffs.

It follows then that the base of the Farrer parvafacies is the base of the Castlegate member west of Woodside.
East of that point it is a rather indefinite line marking the transition from coal-bearing to non coal-bearing rocks. The upper boundary of this facies is the upper boundary of the Price River formation. In Price River Canyon the boundary is a transitional one. It is taken as the base of the lowermost red shale bed. East of Green River the Price River is disconformably overlain by a unit which Fisher (1936, p. 20) named the Tuscher. Spieker (1946, p. 142) indicates that the Tuscher is probably basal North Horn. In Colorado Erdmann (1934, p. 53) noted a disconformity between the top of the Price River (his Hunter Canyon) and the overlying Ohio Creek Conglomerate.

Because of the lack of any means of determining time equivalency, no sub-division of this facies was attempted.

**North Horn Formation**

The North Horn formation was named by Spieker (1946, p. 132) for exposures on North Horn Mountain in the Wasatch Plateau. Rocks of this unit had previously been treated as the lower member of the Wasatch formation.

This unit consists of variegated shale and sandstone, conglomerate, and fresh water limestone which represent fluvialite and lacustrine conditions (Spieker 1946, p. 133). A few thin beds of poor coal are present in Price Canyon where the formation is about 2200 feet thick.

In the western portion of the Book Cliffs the North
Horn grades downward into the Price River conglomerate and sandstone and passes transitionally upward into the Flagstaff limestone of Paleocene and Eocene age (Spieker 1946, p. 133). In the vicinity of Green River Spieker (1946, p. 142) found that the basal part of the North Horn is probably equivalent to the Tuscher formation of Fisher. The Tuscher is a light colored, conglomeratic sandstone about 200 feet thick. It rests disconformably on non coal-bearing rocks of the Price River formation, but this disconformity has not been recognized farther to the west. A strong disconformity separates the North Horn from the overlying Colton red beds (Spieker 1946, p. 142). Traced eastward the Tuscher of Fisher is probably continuous with the Ohio Creek conglomerate of Erdmann which may be the same as the Ohio Creek of Lee (Erdmann 1935, chart opp. p. 26). Both are lithologically the same and both rest disconformably on the Price River. At the eastern end of the Book Cliffs the Ohio Creek is overlain disconformably by the Wasatch (Ruby) formation which is probably Colton.

It thus seems that the North Horn thins from 2200 feet near Castlegate to about 200 feet in Grand Mesa at the eastern end of the Book Cliffs.

Fossil evidence by Spieker (1946, p. 134) shows the North Horn to include beds of both Lance and Paleocene age. The lower part has yielded dinosaurian remains, the middle part has yielded no diagnostic vertebrate fossils, but the
upper part contains undoubted Paleocene mammalian remains. Therefore, the Mesozoic-Cenozoic boundary must lie somewhere in the middle part of the North Horn.

**Facies**

Spiker (1949, p. 60) recognizes five environments in the Upper Cretaceous rocks of central and eastern Utah. Of these five, one environment (piedmont) is not present in the Book Cliffs. The other four are presented below.

<table>
<thead>
<tr>
<th>Sedimentary facies</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a. conglomeratic sandstone</td>
<td>Inland flood plain,</td>
</tr>
<tr>
<td>b. variegated beds, clay shale, fresh water limestone and sandstone.</td>
<td>channel and lake,</td>
</tr>
<tr>
<td>c. buff sandstone and gray shale.</td>
<td></td>
</tr>
<tr>
<td>2. coal-bearing successions of buff to gray sandstone and shale.</td>
<td>Lagoonal, estuarian, flood plain, &amp; swamp.</td>
</tr>
<tr>
<td>3. massive &amp; evenly bedded medium to fine buff sandstone (partially white-capped).</td>
<td>Littoral marine.</td>
</tr>
<tr>
<td>4. gray shale and siltstone, evenly bedded.</td>
<td>Offshore marine.</td>
</tr>
</tbody>
</table>

Each of these four environments is characterized by certain types of sediments which constitute a sedimentary facies. Since none of these facies consists of a single lithologic unit, the writer follows Spiker (1949, p. 60) in designating them in environmental terms. Thus the four
Figure 2. Section showing distribution of facies in Upper Cretaceous of Book Cliffs.
facies are designated in this paper by the terms inland, lagoonal, littoral marine, and marine. In discussing the Price River formation the writer was unable to treat each of these facies separately. Therefore, he places the closely related lagoonal and littoral marine facies in one facies which is named the Neslen parvafacies. The inland parvafacies is designated the Farrer facies. The marine facies of the Upper Cretaceous could properly be named the Mancos magnafacies.

These four environments were not stationary but shifted from time to time in response to the subsidence of the basin and the regression of the sea. This shifting was first seaward then landward and resulted in intricate intertonguing between the deposits of the several environments or facies (Fig. 2). Though this intertonguing is common to all facies, it is best exemplified by the intertonguing of the littoral marine and marine facies. Long tongues of littoral marine sandstone extend eastward into the Mancos shale. Likewise, long thin tongues of the Mancos penetrate westward into the coal-bearing rocks and separate the tongues of littoral marine sandstone.

Although intertonguing between the inland, lagoonal, and littoral marine facies is more difficult to follow it is, nevertheless, present and on a scale comparable to that of the littoral marine-marine intertonguing.

These four facies would normally be present only in a
horizontal succession throughout the Book Cliffs. The shifting of environments has caused the succession to be partially repeated in some areas but the normal order is preserved (Fig. 2). These shifts of environment and the accompanying shifts of the strand line—though not steadily—ultimately resulted in the filling of the basin and the elimination of the sea from this region.

The source of the sediment which created these thick deposits seems to have been in the rising Mesocordilleran geanticline to the west and northwest. The nature of the intertonguing as well as observations of cross-bedding in the non-marine deposits have led the writer to assume a somewhat northwesterly source for most of these deposits. This is in accord with the observed fact that these deposits show little variation along northeastward trending exposures which apparently parallel the old shoreline.
Intertonguing

General Nature

As previously mentioned, each of the facies present intertongues with the facies on either side of it. To verify this one needs only to glance at Figure 2. The boundary between the inland and lagoonal facies is poorly defined since the two environments may be gradational from one to the other, and the sediments of the two environments are almost identical. Consequently, only its approximate position is indicated in the figure. The boundary between the lagoonal and littoral marine deposits, and the one between the littoral marine and marine deposits were traced out in detail and are shown in Diagrams I thru IV.

The best known and most easily seen example of intertonguing of these facies is that between the littoral marine sandstones and the marine shale. Clark (1928, Plate 4) was the first to observe this intertonguing in the western Book Cliffs, where tongues of sandstone of the Star Point sandstone and Blackhawk formation disappear eastward into the Mancos. Later work by Spieker, Baker, Reeside, Fisher, and Erdmann showed that the intertonguing continues eastward to Grand Mesa and beyond. In the area studied, no less than 13 major littoral marine sandstone tongues and many lesser offshore bar sandstone tongues penetrate eastward into the shale. The lowest tongue reaches the short-
east distance east while each succeeding one reaches far- 
ther, because of the eastward recession of the seashore.

Since the littoral marine sandstones are in reality old beach deposits, their upper surfaces must mark the contact between the land and the sea. Then by tracing the upper surfaces of the sandstones we are actually tracing out the changing position of the old beach line. As the beach line shifted the sand-mud contact must also have shifted. A study of these sandstones shows that in many places where the beach was steep these two points were not far separate (see Plate 5B). This being the case, each marine transgression should result in the landward migration of both the shoreline and the sand-mud line. As will be discussed more fully later, these transgressions were rapid and no sedimentary record was left. However, as soon as the transgression ceased, regression must have begun almost immediately. The regression was probably caused and certainly accompanied by regressive deposits of littoral marine sandstone and marine shale. Therefore, one finds at the base of each littoral marine sandstone tongue a corresponding thin tongue of marine shale which points westward and which extends almost to the initial point of the littoral marine sandstone (see Diagrams I and II). From these diagrams it becomes evident that the sequence of environments in coal-forming times from west to east was from inland flood plain to lagoonal to littoral mar-
ine to shallow sea. The sand extended out to an unknown depth at which it graded into mud. This is the sand-mud line which now appears at the base of the sandstone tongues. It seems that shore sediment changes in the Upper Cretaceous were more regular than those sediment changes along present day shores in order to produce such widespread tongues of littoral marine sandstone with such uniform thickness.

**Character of Individual Units**

In order to give a more comprehensive picture of the units involved in the intertonguing, a description of each of the specific facies is here presented. Although the main littoral marine sandstone tongues and the offshore bar sandstones are of the same origin and have the same characteristics, they are here treated separately.

**Marine shale:** The marine shale of the Upper Cretaceous of the Book Cliffs is, of course, the Mancos shale which has been described previously. Where deposited fairly far from shore it consists of thinly laminated, light gray to gray-black clay shale. The only breaks in this monotonous succession are a few bentonite seams and an occasional thin limestone stringer.

In near shore areas the character of the Mancos changes somewhat. It becomes more sandy and is lighter in color. Where littoral marine sandstone tongues project into the Mancos they grade laterally and downward into the shale.
It, therefore, stands to reason that the sandstone-shale boundary must be arbitrary. The writer has placed it at the line where sandstone becomes dominant over shale. This of necessity means that many sandstone stringers are thus included in the Mancos (see Plate 4A). Likewise, when the tip of a sandstone tongue disappears into the shale, a more or less sandy zone continues for a considerable distance farther into the shale. Since this zone is lighter in color than the surrounding shale, it is easily distinguished with the unaided eye (see Plate 3B). Also, this sandy zone may bear ironstone concretions, which in some cases contain well preserved normal marine fossils. Plant fragments are common in the thin tongues of the Mancos which separate the sandstones from the underlying coal-bearing rocks.

This shale was deposited in a shallow sea which may account for the paucity of sizeable amounts of limestone. That the bulk of the deposition occurred near shore, is indicated by the downward pointing tongues of littoral marine sandstone which, in turn, indicate a strong convergence of time lines to the east.

**Littoral Marine Sandstones**—The littoral marine sandstones are the most conspicuous element of the Book Cliffs. They vary greatly in thickness but are quite persistent.

They consist of medium to fine grained, buff sandstone which may be either massive or thin bedded. The material composing the grains is largely quartz. The large amount
A. Leaching of upper part of sandstone unit of Aberdeen member at Kenilworth.

In this picture the head of the pick rests on a band of re-deposited iron which marks the depth of leaching of the iron by the waters of coal forming swamps. Zone is seen to be somewhat irregular.

B. Upper foreshore laminae in basal sandstone unit of Kenilworth member.

This picture taken near Kenilworth shows truncated upper foreshore laminae in the leached portion of the basal unit of the Kenilworth member.
of heavy minerals present in some parts of these sandstones is probably the result of the sorting action of the waves on the upper foreshore and backshore portions of the beaches. In most samples studied a few flakes of muscovite were seen, and frosting of the quartz grains appeared to be negligible. The cementing material is primarily calcareous. Where the sandstone is overlain by marine shale large amounts of ferruginous cement may be present in the upper portion, where the sandstone is overlain by coal-bearing rocks, a white cap is regularly present. This cap averages 15 feet thick in most of the sandstones. It owes its origin to the leaching action of the swamp waters which carried away the ferruginous portion of the cement but left the calcium carbonate portion intact. In some places the iron was carried downward and deposited near the bottom of the leached zone (see Plate 16A). The removal of the iron has in places weakened the bond between the sand grains and allowed pitted surfaces to be developed in the white cap portion (see Plate 15A). Another conspicuous feature of these sandstones is the remarkably flat tops they possess in contrast to their gradational bases. The combination of flat top, steep cliffs, and curving base grading into the shale below produces the typical step-like profile of the desert (Spicker 1949, p. 64). Examples of such forms can be seen in Plates 2A, 4B, 9A, and 13A. The flat tops of the sandstones may be preserved by an increase in the amount of ferruginous cement near the tops of the sandstones.
Figure 3. Mode of origin of sandstone tongues and associated deposits.

A. Section showing probable conditions in shore zone of Upper Cretaceous of Rock Cliffs area. The swamp forms after growth of the sandstone tongue has almost ceased.

B. Section showing same zone after sudden subsidence. The sea bottom has dropped about 50 feet but the last beach is only slightly submerged.

C. Section showing same zone with new sandstone tongue forming as an offshore bar. Preexisting barrier on the old beach has determined where the offshore bar will form.
but they were produced as subaerial gradation planes developed across successive beach planes as the land built seaward. These planes were truncated by currents transporting sand seaward and by the action of waves and ocean currents. That these surfaces were subjected to scouring action is shown by local channeling (see Plate 5A).

The transitional bases of the sandstones represent the position of the sand-mud transition which migrated seaward at an essentially constant level as the successive beaches built farther and farther seaward. The bedding planes which run diagonally through the sandstones represent successive beach and bottom surfaces. They are farthest apart near the top surface of the sandstone where they produce massive bedding. Toward the base they converge to form thin bedded sandstone and then pass from the sandstone into the shale. This phenomenon can be observed only where the beaches were sufficiently steep to allow tracing of individual beds from top to bottom of the sandstone. In many places west of Helper the Panther sandstone is of such a nature, and some of the other sandstones show steep bedding in some places (see Plate 5B). As one follows these sandstones seaward (eastward) the bedding planes become more nearly horizontal and closer together (see Fig. 3). Shale partings appear and the sandstone grades finally into shale. If we assume that each of these bedding planes is a fairly well defined time line, then it follows
that the flat top of each of these sandstones must represent innumerable time lines. They split away at regular intervals by running diagonally through the sandstone tongue; and then each flattens out in the shale and runs somewhat parallel to the top of the tongue, but converges slightly toward its fellows seaward because of the decreased volume of sediment.

The mode of production of such a sandstone bed and its associated lagoonal and marine sediments is shown in Fig. 3A. Spicker (1949, p. 65) has concluded that during the deposition of any one sandstone tongue the local basement must have remained stable with little diastrophic movement. In order to produce the next higher shale and littoral marine tongues, subsidence must occur (Fig. 3B). As we have seen before, this subsidence must have been so rapid as to prevent the formation of transgressive deposits. Its only effect was a slight disturbance of the poorly consolidated shales and sandstones of the lagoonal facies.

Sears, et al. (1941, pp. 104-105) in their study of intertonguing of the Upper Cretaceous deposits of the southern San Juan Basin report both transgressive and regressive deposits including littoral marine sandstones. No conclusive evidence for such transgressive littoral marine sandstones was noted in the Book Cliffs of Utah and Colorado. Such a sandstone would differ from the regressive type in that the base would be flat or nearly so while the top would be gradational into the shale. Some possible grades—
Figure 4. Shifting of facies in response to changes in volume of sediment supplied to a sinking basin.

A. Section showing supply equal to the rate of subsidence. There is no shifting of sedimentary facies.

B. Section showing supply less than the rate of subsidence. The result is a transgressive sandstone.

C. Section showing supply greater than the rate of subsidence. The result here is a regressive sandstone.
tion was noted near the tips of some of the sandstone tongues, but the majority retain their flat top character until they finally fade into the Mancos (see Plate 4B). Descriptions and photographs in the articles by Pike (1947) and Sears, et. al. (1941) lead the writer to suspect that the so-called transgressive sandstones of the San Juan Basin are in reality regressive.

It seems probable that all of the littoral marine sandstone tongues of the Book Cliffs are regressive deposits formed by the progressive filling of a shallow marine basin. The shale tongues between them must then be due to sharp pulses of subsidence which allowed rapid transgression of the sea followed by periods of quiet during which the shore line moved eastward. Spieser (1949, p. 65) postulates three possible causes for the regression of the sea: 1) uplift, 2) eustatic depression of the sea level, and 3) the feeding of sediment into a static basin. The first two of these he discards as untenable since they both produce the same result: namely removal of previously deposited sediments. The body of a regressive sand would be eroded and reworked with the resulting deposit having a transverse extent not much greater than the width of the last beach.

The most plausible explanation of the cause of regression is the feeding of sediment into a static basin. In this situation sea level remains constant as the beach
builds seaward (see Fig. 3A). The tops of sandstones formed in this way would be flat while the base would grade downward in the shale. If the supply of sediment should become greatly reduced, swamps would probably form behind the last beach which would serve as a barrier to keep out the sea. It is also possible that barrier bars formed in the shallow water offshore and later formed barriers behind which were lagoons. This would, however, necessitate the filling of the lagoons before sizeable coal-forming swamps could exist. In most cases no lagoonal deposits of creditable thickness have been noted between the sandstone tongues and the overlying coals. In most instances the coals rest directly, or nearly so, on the sandstones. A rapid subsidence of sea level would then allow the sea to sweep in and cover a large part of the lowlands along the coast. A new beach would form at the new shoreline and again regression would be instigated.

Pike (1947, pp. 15-19) states that rate of subsidence is the controlling factor in the intertonguing of the Upper Cretaceous of the Four Corners area. Subsidence of the basin undoubtedly occurred but probably in sharp pulses as previously mentioned. However, if one assumes that there was some slow subsidence other than the rapid pulses, he finds the critical factor controlling the deposition is the supply of sediment available. If the supply of sediment balances the space available as the result of subsidence,
then there would be no shifting of environments and no intertonguing of facies (see Fig. 4A). Such deposits may exist in the Book Cliffs but have not been identified. If the supply of sediment is less than the subsidence, then the result would be a transgressive sandstone, of which there is no evidence in this area (see Fig. 4B). Finally, if the supply exceeds the space available the result will be regression of the shoreline and the formation of regressive deposits. In this case, however, the regressive sandstones will not be flat-topped but will rise stratigraphically seaward. The angle at which they will rise depends on the rate of subsidence. If it is very slow the angle of rise may be small (see Fig. 4C). However, as the rate of sinking increases, the supply-space ratio changes and the angle may approach 90 degrees at which point the two factors would balance (see Fig. 4A). A still greater rate of subsidence would result in the reversal of direction of rise and produce a transgressive deposit (see Fig. 4B).

G. K. Gilbert (1890, p. 39) defines a beach as "The zone occupied by the shore drift in transit". However, Thompson (1937, p. 725) restricts its usage to that area of the shore between the limits of the migrating shoreline. He divides the beach into three parts as follows: 1) the backshore is that part of the beach between the foreshore and the coast line, 2) the upper foreshore is that part of the foreshore which extends from the crest of the beach to
the zone of permanent saturation, and 3) the lower fore-
shore is that part of the foreshore which lies between the
upper limit of the zone of permanent saturation and the low
tide shoreline.

A fourth part of the average beach is the near shore
portion which Krumbein and Sloss (1950, p. 198) restrict
to a zone starting at the low water mark and extending sea-
ward until the depth of water reaches 30 feet. It seems as
though 30 feet is merely an arbitrary depth selected by
Krumbein, for the writer sees no great change in environ-
mental factors at 30 feet.

Since each one of the littoral marine sandstones of
the Upper Cretaceous consists of a series of beaches built
successively seaward, then one should be able to recognize
the component parts of each of these beach deposits. Per-
haps the only means of accurately distinguishing between
them is the lamination characteristic of each. It must be
remembered, however, that each of these portions of the
beach, and likewise their characteristic laminae, are gra-
dational into the next adjacent type.

Backshore deposits are difficult to identify since
marine deposits may be interbedded with those of dunes,
deltas, and lagoons. The most diagnostic primary feature
of these deposits is the presence of filled channels which
form festoons (G.A. Williams, 1961, personal communica-
tion). Deposits of this type were identified definitely
A. Lower foreshore laminae in Rollins member.

This view shows lower foreshore laminae in the basal sandstone unit of the Rollins member.

B. Contorted bedding in the Rollins member.

This picture shows distortion of near shore or lower foreshore deposits as the result of slumping. Note folds and numerous micro-faults.
only at the lagoonal edge of some of the offshore bar sandstones, at which point they are overlain by dune deposits.

Upper foreshore deposits were found by Thompson (1937, p. 731) to be characterized by four types of cross lamin-ation which are a result of changes in the beach profile of equilibrium. C. A. Williams (1951, personal communication) found that such laminae in the Mesaverde rocks of the Black Mesa, Arizona have dips seldom exceeding five degrees. Cross laminae of this type as well as other upper foreshore features described by Thompson (1937, pp. 737-38) can be seen in the upper portions of the littoral marine tongues (see Plate 16B).

Lower foreshore deposits are characterized by two main features (Thompson 1937, p. 738). The first is a low ridge and trough formed at the plunge point of the waves and which is parallel to the shore. The second feature is the declivity of the slope which decreases toward the sea. Because of the stirring action of the plunge point and the change in declivity of slope, the cross lamination is very irregular and may be as steep as 30 degrees (Thompson 1937, p. 739). Such laminae are common in the littoral marine sandstone of the Upper Cretaceous (see Plate 17A).

The lower foreshore deposits grade seaward into almost horizontally laminated beds of the near shore zone. These are often broken by micro-faults and slumping which tend to disturb their structure (see Plate 17B).
Fossils are not common in these littoral marine sandstones. Fucoids and worm tubes are the most common evidence of life. In some localities numerous Ostrea remains are to be found on the upper surfaces of the sandstones.

**Offshore Bars**—Of the same origin as the more extensive littoral marine sandstones are the offshore bar sandstones behind which the coal-bearing rocks formed. They are similar to the larger tongues in all details except extent; and must, therefore, represent sandstones formed by pulses of subsidence on a smaller scale than those which initiated the larger tongues. That these pulses were of lesser magnitude is shown by the fact that they do not, in many cases, reach the previously deposited coal-bearing rocks. Instead, they seem to have resulted merely in the building of a new offshore bar on top of the previous one. The writer is convinced that in many cases the sea must have penetrated farther inland, but no recognizable record is left. Apparently the increased amount of sediment available after these small subsidences must have been sufficient to allow a rapid building up of the offshore bars. It was apparently rapid enough to exclude most of the marine water before any recognizable marine or littoral marine sediments could be deposited behind the bars.

In many cases vast coal swamps must have existed in these lagoonal and lowland areas. They are indicated by thick coal deposits such as the Sunnyside and Kenilworth.
FIGURE 5. SCHEMATIC DIAGRAM SHOWING DETAILS OF INTERTONGUING IN THE LAGOONAL FACIES.

Inland facies

Lagoonal facies

MARINE SHALE
LITTORAL MARINE SANDSTONE
LAGOONAL DEPOSITS
COAL
WHITE CAP

INLAND DEPOSITS
coals. These larger coal swamps did not exist in the brackish waters of the lagoons but flourished only after the lagoons were filled with sediment. Thus all of the major coals of the Book Cliffs lie at horizons which correspond nearly exactly with the tops of offshore bar sandstones (see Fig. 5). There appear to be exceptions to this rule but they probably stem from a lack of information. The Castlegate "A", Aberdeen, Kenilworth, and Sunnyside coals of the Blackhawk, as well as some of those of the Price River, rest directly on the underlying sandstone or are separated from it by only a few inches or few feet of shale. It is the writer's opinion that these deposits must have formed in swamps which extended almost to the very edge of the water. But they were probably separated from it by a very low barrier. These barriers have not been definitely identified, but must have existed. The reason for this belief is that something must have been present at that point to determine the position of the next overlying bar which begins almost at the exact point at which the basal coal unit terminates. Plate 9B shows what may be one of these barriers on top of the upper sandstone tongue of the Kenilworth member at Mt. Elliot. To the west of this point a thin coal is present but not to the east.

Perhaps the initial bar was very small and was reworked into the later one, but this does not seem to be the
The first well defined bar sandstone extends a short distance into the lagoon and rests directly on the feather edge of the underlying coal. The question arises then as to whether these coals extended much farther seaward and were eroded by the transgressing sea which produced the overlying offshore bar sandstone. This is discounted since the sandstone, beyond the point at which the coal terminates, shows absolutely no trace of a white cap which would indicate swamp water leaching (see Fig. 5). The absence of the white cap is not due to erosion since, as a rule, the sandstones show no appreciable difference in thickness from the lagoonal side of the bar to the marine side. This distance may be half a mile or more.

The regularity with which these offshore bars form above or nearly above each other could more easily be explained if there were some indication of a hinge line at these points. No indication of a hinge line has been discovered. The observed pattern seems to indicate that, as soon as one lagoon was filled and a coal swamp had flourished for a while, a subsidence brought a flooding which killed the vegetation and caused a new bar sand to build up on top of the previous one. Such a thing happened three times in the deposition of the Spring Canyon member of the Blackhawk, five times for the Kenilworth member and at least five times for the Sunnyside member of the Blackhawk. The result of this type of deposition is a
cyclic sequence which will be discussed later.

Modern barrier bars of this type are fairly common. Elanton (1951, p. 1425) believes that such bars are formed only on eastward facing shorelines. If this is so, and it appears to be, then the higher tides which are responsible for these bars may have existed in a similar way in the Upper Cretaceous. This may account for the apparent lack of such structures in the areas studied by Sears, Hunt, and Hendricks (1941), Pike (1947), Walton (1948), etc. However, it seems to the writer that some similar phenomena must exist elsewhere in the geologic record.

E. D. McKeel (1951, personal communication) finds in a study of the barrier bars and lagoons of the Corpus Christi area a modern situation which closely resembles that which must have existed in the Upper Cretaceous rocks of the Book Cliffs. He has found types of cross lamination which the writer recognizes in the barrier bar sandstones of the Upper Cretaceous. Present at Corpus Christi also are sand dunes which are driven lagoon-ward by the winds of the Gulf. The lagoonal deposits of both the Corpus Christi area and those of the Upper Cretaceous in the Book Cliffs are apparently similar though those of Corpus Christi lack the coal beds of the Upper Cretaceous.

Krumbein (1941, pp. 795-799) summarizes several papers on Barataria Bay, La., which deal with the variations in particle size and shape and their distribution in modern
environments which closely resemble those of the Upper Cretaceous.

**Coal-bearing Rocks:** The coal-bearing rocks comprise the rocks of the lagoons, estuaries, flood plains, swamps, and lowlands which are here referred to merely as lagoonal deposits. They have been discussed previously in the descriptions of the Blackhawk and Price River formations. They consist mainly of buff to gray sandstone lenses and gray shale with some coal seams. The sediments range from medium grained sandstone to shales and even some fireclay, though this is not common.

Some portions of the coal-bearing rocks are very evenly bedded and seem to show rather varve-like bedding. Other portions seem to show almost no trace of bedding while still others exhibit deltaic structure (see Plate 14A). The organic content of all these rocks is quite high, and on exposure to weathering they crumble rather rapidly. Possibly because of the high organic content, where these sediments have been associated with burning coals their iron content is rapidly oxidized and bright reds and yellows replace the gray and brown of the original beds.

Marine shale tongues must be present in a few places in these deposits behind the barrier bars where they have not as yet been recognized. Their appearance is so much like that of the non-marine shales that they can only be
recognized by marine fossils, which are scarce. A few thin marine shale tongues in the Sego member bear shark's teeth (*Lamna* sp.) but none have been found elsewhere.

It is probable that the coal deposits, which correspond to the tops of barrier bars of the lagoon, were formed in fresh water swamps. No fossils have been found in the coals but numerous brackish water species of *Corbula*, *Corbicula*, *Nodiola*, *Anomia*, and *Ostrea* were found a few inches above the Kenilworth and Upper Sunnyside coal beds. This may indicate that they were deposited in brackish waters, but the probability is that these brackish water fossils moved in following the marine flood which killed off the coal forming plants. In some cases two or more coals may lie one on top of the other either directly or separated by only a few inches of bone. This would indicate that the marine transgressions in the lagoonal area were only long enough to kill off the vegetation, and that the recession or exclusion of marine waters was followed by the formation of a new swamp of the same extent as the previous one.

The lateral extent of this coal-bearing environment is not known but must have been hundreds of miles. The transverse width varies greatly but probably averaged 50 miles or more (see Fig. 2). It is probable that none of the coal zones is continuous for such distances, but the Anchor coal (redefined) is reported by Fisher (1936, p. 46) and
Erdmann (1933, p. 81) to be traceable for nearly 100 miles from west to east. However, such wide-spread units must be accepted with caution since one burned outcrop, of which there are many in the Book Cliffs, could easily obscure stratigraphic relations. This is particularly true in the lagoonal areas where the coals in most places do not rest on a massive white-capped sandstone which can be used as an index to the position of the coal when the coal is invisible. It seems that both Erdmann and Fisher failed to note that numerous offshore bar sandstones formed on the upper sandstone tongue of the Sego in Colorado. This means that the Anchor coal of the Big Salt Creek area which lies at about the same vertical distance above the upper sandstone tongue as does the Palisade coal of Fisher in eastern Utah, is really higher stratigraphically. Therefore, no correlation should be attempted.

The purity of the coals of this region has been discussed by Spieker (1931, p. 68), Clark (1926, pp. 81-93), Fisher (1936, pp. 47-55), and Erdmann (1935, pp. 68-92). The remarkably low content of foreign matter in the coal is difficult to explain. Considerable sediment must have been pouring into the nearby sea, and winds must have been active along the shore to produce the eolian deposits mentioned previously. However, it is possible that at the times of great coal swamps erosion in the hinterland and deposition in the shallow sea was at a minimum.
A close scrutiny of the littoral marine sandstone tongues (see Diagrams I and II) gives one the impression that the supply of sand available for the formation of more seaward portions of the sandstone tongues must have been considerably less than for the much thicker landward portions. This would seem to indicate that either erosion or transportation had become inadequate to maintain the previous thickness. Whatever the cause, it appears that as soon as the first offshore bar appeared, at some distance from shore, the seaward growth of the sandstone tongue must have almost ceased. This is evidenced by the rapid thinning and termination of the tongues beyond the offshore bars (see Diagram I and II). It may be that the sandstone tongues had ceased their seaward march before the initial bars could form or perhaps the bars trapped the sediment which would otherwise have contributed to the sandstone tongues. In either case it is difficult to explain how the lagoons could have been filled and a thick coal deposit formed over the lagoonal and bar deposits.

Calcareous concretions at the ends of the tongues have been interpreted by Spieker (1949, p. 68) as indicating fairly long periods of little deposition. If this be true, then it is possible that it was during these periods of time that the main coal-forming swamps must have existed. Since the coals are relatively free of inorganic material and since the calcareous concretions indicate little depo-
position, this must have been a time of almost no erosion or transportation of debris.

**Inland flood plain rocks:** The lithology of the rocks of the inland facies has been discussed in the description of the Price River and North Horn formations. It will suffice to say here that they closely resemble the fresh and brackish water deposits of the lagoonal facies except in the amount of coal present. Coal beds are thin and rare.

Fresh water fossils have been reported by Spicker. Such genera as *Unio, Sphaerium, Viviparus, Goniobasis*, and *Physa* are rather common. Vertebrate remains are also important locally.

Since the lithology of these rocks is so similar to that of the lagoonal rocks it is apparent that, though intertonguing is present, it is difficult to detect accurately.

**Time Lines**

In Diagrams I, II, III, and IV the tops of littoral marine sandstones were chosen for horizontal datum-lines. These, if the above interpretation of their origin is correct, should closely approximate time lines. As stated before, this upper surface must represent many time lines at its landward end, but the number lessens as one follows it seaward. The reason for this is simply that this surface must have remained virtually unmodified during the
period of time in which the individual beaches (each represented by an individual bed in the sandstone tongue) were forming beyond it (see Fig. 3). Therefore, the time line which follows from one end to the other of any tongue must be a line which represents the surface of that sandstone tongue at the time of the formation of the last beach. In other words such a littoral marine sandstone is a series of beaches built seaward whose tops, represented by bedding planes, are in reality time lines which combine into a single time line at the top and converge sharply at the base.

That these time lines continue into the shale below can be easily seen. Though they can not be traced far into the shale they apparently continue to converge and must in many cases actually come together. This means, as previously stated, that because of this convergence the Mancos shale must be thinner to the east. The thickness of the Mancos shale in western Colorado is about 1000 feet less than in central Utah (Spieker 1949, p. 67).

The eastward convergence of the littoral marine sandstones in the Book Cliffs is readily seen in Fig. 5. This convergence of time lines can only mean differential sedimentation.

The position of time lines in the coal-bearing rocks is more difficult to reconstruct since they were deposited behind a barrier and do not grade into the littoral marine...
rocks. It is probable that time lines in the lagoonal deposits beneath the main coals are continuous with those of the individual beaches in the littoral marine tongues. The coals contain time lines which may be represented by time lines of beaches near the tips of the sandstone tongues. However, it is more likely that most of the time lines in the main coals are represented by the last time line at the tip end of the sandstone tongues. This is based on the previously stated probability that the main coals formed during periods of little clastic deposition.
The rocks of the Book Cliffs present a clear picture of cyclic deposition. An examination of Plates 1, 2, and 3 reveals numerous repetitions in the geologic sequence. For example, one can start in the uppermost part of the Mancos shale, in almost any area, and pass upward through littoral marine sandstone, into coal-bearing rocks, and again into marine shale. From the same point, one can proceed westward along a given time line through littoral marine sandstone then into coal-bearing deposits.

A study of Diagrams I and II brings out the fact that cycles of different magnitudes are represented. There are numerous small cycles which can be grouped into larger cycles (megacycles) on the basis of extent of the littoral marine sandstones. All of the cyclothems (deposits of a cycle) should, in theory, have the following sequence of units which is not complete in any of the observed exposures:

\[
\text{cyclothem} = \begin{cases} 
4. & \text{coal} \\
3. & \text{lagoonal rocks} \\
2. & \text{littoral marine sandstone} \\
1. & \text{marine shale} 
\end{cases}
\]

It now becomes apparent that each cyclothem has, somewhere, a littoral marine sandstone unit. Most of these are offshore bar sandstones, and do not usually extend far into the lagoonal deposits. However, at certain horizons, littoral marine sandstones are found which are of a much great-
er extent. These are the sandstones which constitute the basal units of the various members of the Blackhawk and Price River formations. It can be seen that each of these members consists of deposits of many small cycles, and each is composed of the deposits of one megacycle. It was the cyclic nature of these rocks that led the writer to subdivide the Upper Cretaceous formations in the manner employed in this paper. Since there are six megacycles in the Blackhawk, six members have been distinguished. In the portion of the Price River which lends itself to subdivision, four members have been named. However, two of these members apparently consist of more than one megacyclic deposit. The Sego member probably includes deposits of four megacycles and the Riverside may include deposits of two megacycles.

The number of cycles in a megacycle must vary considerably. The exact number in any megacycle is difficult to determine, because of the scarcity of perfect exposures of the coal-bearing rocks. For the same reason no attempt was made to further subdivide the lagoonal deposits into smaller units. Except for the basal cyclothem of each megacyclic deposit, the littoral marine sandstone tongue and probably the marine shale of most cyclothems are absent in the lagoonal area. This leaves two units of the cyclothem to be distinguished in the lagoonal areas—the lagoonal and coal units. Not every coal bed in these rocks represents the
number four unit of a cyclothem. Those which accumulated at the end of a cycle should be thicker and more continuous. It seems probable that at the end of each cycle, which is a series of changes instigated by a single sharp pulse of basin subsidence, there would be a period of very little clastic sedimentation. That there were such periods of almost no sedimentation is attested to by the presence of thin limestone stringers and zones of limestone nodules in the marine shale opposite the tips of the major sandstone tongues. During these periods of quiet, vast coal swamps must have flourished in the coastal area, and must have persisted until the next pulse of subsidence.

The lesser coals are probably the result of short-lived swamps which flourished during short periods of quiet between sharp pulses of subsidence. Some of these subsidences were of considerable magnitude but most appear to have been a series of subsidences of small magnitude occasionally punctuated by a greater subsidence. These greater subsidences determined the duration of the megacycles. Each megacycle consisted of one or more cycle. Therefore, each megacyclothem consists of one or more cyclothem, and a cyclothem may have one or more microcycle, though microcyclic deposits are difficult to recognize.

The writer believes that the megacyclothem boundaries are indicated by thick shale tongues between groups of closely related sandstone tongues and their lagoonal depo...
posits (here given member rank). He also believes that each sandstone tongue represents the number two unit of a cyclothem. The microcycles were probably caused by such slight subsidences that no sandstone tongues were formed. That they occurred is evidenced by alternating lagoonal deposits and thin lenticular coal beds which are numerous in some sections.

In the Spring Canyon coal member of the Blackhawk, three thick coals are present as well as several others of lesser thickness and extent. These three coals lie at horizons which correspond to the tops of offshore bar sandstones in the vicinity of Helper (see Diagram I). Because the writer feels that presence of a sandstone tongue indicates a cycle of deposition, at least five cycles are believed to be represented in the Spring Canyon cycle which includes rocks of both the Blackhawk and Star Point units. The following is the probable sequence in this megacycle near the seaward edge of the lagoonal deposits (just west of Helper):

- Spring Canyon coal member
- Spring Canyon cycle (megacyclothem)
- Spring Canyon sandstone tongue

\[
\begin{align*}
\text{Spring Canyon coal member} & \quad \begin{cases} 
4. \text{ coal (upper Spring Canyon)} \\
3. \text{ lagoonal} \\
4. \text{ coal (middle Spring Canyon)} \\
3. \text{ lagoonal} \\
4. \text{ coal (lower Spring Canyon)} \\
2. \text{ sandstone} \\
1. \text{ shale} \\
2. \text{ sandstone} \\
1. \text{ shale} \\
1. \text{ shale}
\end{cases}
\end{align*}
\]
Figure 5. Proposed correlation between units of upper Cretaceous and Pennsylvanian cyclothem.
Still farther inland the lagoonal unit drops out leaving the coal unit, which is thin and discontinuous. It may, in some instances, extend a considerable distance inland and be associated with deposits of the inland facies.

At, and seaward from the shoreline, the cyclothem consists of the sandstone and shale units. The sandstone member persists for a short distance seaward before disappearing into the shale. The sequence as described above is shown diagramatically in Fig. 6.

The cyclothem here described does not exactly fit the description of the "ideal Pennsylvanian cyclothem" as defined by Weller (1930, p. 102) and elaborated by Wanless (1931), Moore (1931), and others. Krumbein (1951, pp. 375-376) gives an excellent summary of the modern concept of the "ideal cyclothem" of ten members as illustrated in Fig. 6.

As the figure shows, the Pennsylvanian cyclothem begins with a basal sub-graywacke sandstone (member number one), which lies unconformably on the upper member of the previous cyclothem. This sandstone is supposedly non-marine but the writer believes that it corresponds to the littoral marine sandstone (unit two) of the Cretaceous cyclothem. Almost everywhere it is underlain by marine shale (unit one) which formed contemporaneous with the sandstone but farther from shore beyond the sand-mud line. The writer believes unit one to be equivalent to members
six, seven, eight, nine, and ten of the Pennsylvanian cyclothem. Unit three of the Cretaceous cyclothem consists of fresh and brackish water deposits and is probably equivalent to members two, three, and four of Weller's cyclothem. Unit four of the Cretaceous cyclothem is obviously the same as member five of the Pennsylvanian cyclothem.

It is probable that a detailed study of the coal-bearing successions of the Upper Cretaceous formations would enable one to make an even closer correlation between these two cyclothems. However, for the purpose of this paper, only four easily recognized units have been differentiated.

The most gratifying result of this stratigraphic study has been the visualization of a cyclothem which appears to have some validity. The cycle which produced this cyclothem was one which involved the shifting of sedimentary environments in response to a pulse of basin subsidence followed by gradually declining clastic deposition. This whole problem of cyclothems is, therefore, intimately related to the intricate intertonguing of facies exhibited by the Upper Cretaceous of the Book Cliffs.

The geologic cycle which produced the Upper Cretaceous cyclothem began with a rapid transgression of the sea upon the land, as a result of a sharp pulse of subsidence in the marine basin. This transgression was so rapid that only slight erosion of the deposits of the pre-
vious cycle was accomplished. As soon as the transgres-
sion ceased, regression began as the result of deposition.
Beach sands and the associated offshore muds began to ac-
cumulate disconformably on the previous deposits.

When the supply of sediment became greatly reduced,
the seaward growth of the beach sands ceased. After this
slowing down of sedimentation, storm waves built up an
offshore bar some distance from shore in the shallow water.
This bar caused the sediment, still being carried to the
sea, to be deposited in the lagoon between it and shore.
During periods of little erosion, negligible sediment was
supplied to the lagoon in which at times the water was
quite fresh. During these times coal swamps flourished
locally and fairly thick coals were deposited. However,
the major coal forming times must have occurred when prac-
tically all clastic sedimentation had ceased. This aspect
has already been discussed. There were undoubtedly periods
of some erosion which would cause the inland flood plain
deposits to encroach upon the lagoonal area and cover
a portion of the coal-forming swamp and lagoonal deposits.

In some cases, as in some of the lower cycles repre-
sented in the Sego member, coal swamps and lagoonal deposits
of appreciable thickness failed to form. This is probably
due to the lack of well defined offshore bars. As a result,
the littoral marine sandstone unit is followed in most
places by thin lagoonal deposits but the coal unit is mis-
-121-
It is possible that the grouping of these cycles of deposition into megacycles, which is utilized in this paper, has no foundation. However, it is obvious that at certain times in the Upper Cretaceous, transgressions of a somewhat greater magnitude than usual, occurred. Each of these greater transgressions is assumed to represent the initiation of a megacycle. The number of cycles that can be definitely identified in each of the various members depends upon the presence of the littoral marine sandstone units. Three such tongues can be recognized in the Castlegate member while at least 11 can be recognized in the Desert member. This would indicate that the Castlegate must consist of three cyclothsems and the Desert of 11 cyclothsems. It must be remembered, however, that many cycles existed only long enough to produce a feeble sandstone tongue or perhaps none at all. Therefore, it is impossible to determine the exact number of cycles represented. Perhaps these minor cycles should be placed in a third category, the microcycle. Only a detailed study of the deposits of a lagoon will show how many cycles of deposition it endured.

Weller (1930, p. 131) attributed the Pennsylvanian cycles to mild positive and negative diastrophic movement while Wanless and Shepard (1936, p. 1191) concluded that they were related to glacial episodes near the close of the
Paleozoic, Krumbein (1951, p. 379) accepts the idea of mild tectonism as the controlling factor. A study of the Cretaceous cycles seems to preclude any positive movement, but actually demands negative movement in sharp pulses.

In brief, it appears to the writer that the cyclic deposits of the Upper Cretaceous were formed in the same manner as those of the Pennsylvanian. It is probable that the Upper Cretaceous cyclic deposits are at least as widespread as those of the Pennsylvanian, since they do extend throughout most of the Cordilleran region from northern Alberta to New Mexico.
STRUCTURE

General Features

The structure of the Book Cliffs is relatively simple. As stated previously, the dominant feature is that of a monocline dipping northward at an angle of a few degrees. These rocks dip gently off the flanks of two structural highs south of the cliffs. These are the San Rafael Swell in the west and the Uncompahgre uplift in the east. The inward facing escarpments of the Book Cliffs faithfully reflect the control exerted by these two uplifts (see Fig. 1). The cliffs trend east from the Wasatch Plateau on the north flank of the San Rafael Swell. Here the dip is between four to five degrees to the north. Near Sunnyside the cliffs swing to the south along the east side of the Swell and the dips flatten to three degrees or less to the northeast (Clark 1928, p. 23).

At the Green River the influence of both uplifts is about equal and the result is a broad shallow syncline plunging gently northward at an angle of two to four degrees.

The influence of the Uncompahgre uplift produces the northeast trend of the cliffs from Nash Canyon to the Utah-Colorado line. The average dip is about three degrees northwest, and the general monoclinical dip is modified by minor flexures which are mostly northwestward plunging.
anticlines and synclines. Only one of the structures, the Cisco dome in the Nash reentrant, is known to have closure (Fisher 1936, p. 35).

From the Utah-Colorado line to the Colorado River the rocks exhibit, in most places, a monoclinal dip which ranges from six degrees to 27 degrees to the north and northeast (Erdmann 1934, p. 65). The steeper dips are due to local flexures which are really basins, domes of small closure, and faults. Erdmann (1934, p. 65) interprets them as being typical of platform structure.

**Folds**

In that portion of the Book Cliffs west of Green River folds are not common, but they become more numerous to the east. A much faulted anticline near Floy Canyon, which is apparently continuous with the Salt Valley anticline to the southeast, has been described by Harrison (1927, pp. 111-133), by Frommel and Crum (1927, pp. 373-393) and by others.

Cisco dome is one of the larger folds of the area. It is elongated in a northwesterly direction, and is much faulted (Fisher 1936, p. 39). Many dry holes have been drilled on this structure. This dome is responsible for the large reentrant at Nash Canyon.

Other noses are responsible for producing the reentrants at Cottonwood, Westwater, and Bitter Creek Canyons.
The largest anticlinal fold in the Colorado portion of the Book Cliffs is Garmesa anticline (Erdmann 1934, p. 66). It is an asymmetric fold trending northwest, and characterized by five domes. Though closures range from 200 to 300 feet no commercial production of petroleum has been found.

East of Garmesa anticline is the small High Line dome with its axis approximately parallel to that of the Garmesa structure. Its structure is complicated by numerous faults (Erdmann 1934, p. 66).

Faults

Some portions of the Book Cliffs seem to be entirely free of faults whereas other areas are abundantly supplied with them. All of the faults which have been observed are normal dip faults. Since the fault planes are nearly vertical the usual result is merely vertical offset. Where two or more parallel faults are present grabens and horsts are found.

West of Sunnyside no faults of consequence have been reported. However, from Sunnyside south to Woodside numerous normal faults cut the strata of the cliffs. Most of these faults strike east-west but others strike southwest or southeast. Displacement on these faults ranges from a few inches to 200 feet.
The graben faults near Crescent, as stated previously, extend for many miles to the southeast and are probably continuous with the graben structures of Salt Valley anticline. These steep dip faults have a maximum displacement of 1700 feet (Fisher 1936, p. 37).

At Thompson another series of parallel faults cuts the cliffs and produces a small graben. They, too, trend southeast and like those near Crescent do not extend far into the rocks of the Book Cliffs. A few minor normal faults with a southwest trend are to be seen between Sagers Canyon and the Utah-Colorado line.

West Salt Creek in western Colorado probably owes its present course to two parallel normal faults with a southwest trend, which have produced a graben. Several other minor faults occur in the Book Cliffs of Colorado, and all appear to be normal to the regional structure. This Erdmann (1934, p. 68) believes indicates they were formed by tension during folding.
MINERAL RESOURCES

The principal mineral product of the Book Cliffs area is bituminous coal. About 98 percent of all coal mined in Utah is produced in Carbon and Emery Counties in the Book Cliffs and Wasatch Plateau coal fields.

At present an average of about seven million net tons of coal is produced annually from this area in Utah. That portion of the Book Cliffs coal field in Colorado is, however, producing very little coal at present.

Though the production of coal is relatively low in this area (Utah had produced only 177 million tons up to 1946), the total reserves are large. Erdmann (1934, p. 99) estimated that there were about five billion tons of coal in the Colorado portion of the Book Cliffs. Fisher (1936, p. 45) subdivided the Book Cliffs in Utah, east of Sunnyside, into two subfields. The portion east of Green River he called the Thompsons subfield. At present only one mine is operating in this subfield—an independent at Sego north of Thompsons. The area between Green River and Sunnyside he named the Sunnyside subfield. In this subfield much mining is now being done by the Kaiser Steel Company and other interests. Coals of the Sunnyside member are being mined at Sunnyside, Columbia, and Horse Canyon. These coals are valuable because of their
coking quality. Fisher estimated the total reserves of these two subfields to be about 500 million tons in 1936.

Clark (1928, pp. 101, and 161) estimated that the original coal content of the rocks of the Book Cliffs between Sunnyside and the Wasatch Plateau was about four billion tons. At present several mines are operating in Spring Canyon, one at Castlegate, one in Hardscrabble Canyon, one at Kenilworth, one in Deadman Canyon, three in Coal Creek Canyon, and several farther east.

An extensive search has been carried on for petroleum in this area, but as yet no commercial production has been found. Seeps in several of the mines at the western end of the cliffs are reported.
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EXPLANATION OF DIAGRAMS

The four diagrams found in the pocket represent a diagramatic presentation of the observed stratigraphic relations existing in the Book Cliffs. Correlation between the 46 measured sections was accomplished by actually tracing out the units in the field.

In preparing the diagrams the top of an extensive sandstone tongue was used as a datum. When that sandstone tongue disappeared another extensive sandstone tongue was chosen as the new datum.

An explanation of the symbols used on these diagrams is to be found on diagram IV.
Measured Sections

Section No. 1 Kenilworth, Utah: Section at Kenilworth Mine.

Price River formation:

- Farrer facies: not measured
- Neslen facies: in part
- Castlegate member:

21. Sandstone- gray to pink, medium to coarse grained, calcareous, grains mostly fresh angular quartz, feldspar is altered to kaolin, massive, irregular bedding, weathers gray to white, is cliff former. 400.0

Disconformity

Blackhawk formation:

undifferentiated coal-bearing rocks:

20. Sandstone, shale, and coal- sandstone, gray to buff, medium to fine grained, massive and thin bedded, calcareous cement; shale, gray to black, sandy, soft, in part gysiferous; coal, thin seams, mostly burned and concealed. 488.0

19. Coal- massive, three partings near top (Kenilworth or Castlegate "D"). 19.0

18. Sandstone- buff to gray, medium grained, massive, calcareous cement, upper 15 feet is white cap, marine cross-bedding, base gradational into shale. 60.0

17. Shale- gray (Mancos). 5.0

Total undifferentiated coal-bearing rocks 572.0

Disconformity (slight)

Aberdeen member:
16. Coal- massive (Castlegate "C"?) — — — — — — — 6.3

15. Sandstone and shale—sandstone, gray to buff, fine to medium grained, lenticular; shale, gray, sandy, some carbonaceous; both shale and sandstone have red color from burning of coal. — — — — — — — — — — — — 75.0

14. Coal—massive, some thin partings (Aberdeen or Castlegate "A"). — — — — — — — — — — 19.0

13. Sandstone—buff, white-capped, fine to medium grained, most of grains angular to subangular quartz, about two percent heavies, calcareous and ferruginous cement, marine cross-bedding. — — — — — — — — 65.0

12. Shale—gray, (Mancos tongue). — — — — — — — 55.0

Total Aberdeen member — — — — — — — — 220.3

Total Blackhawk formation — — — — — — — — 792.3

Star Point sandstone:

Spring Canyon members:

11. Sandstone—tan to buff, fine to medium grained, massive, marine cross-bedding. — 40.0

10. Shale—gray (Mancos tongue). — — — — — — — 8.0

9. Sandstone—tan to buff, fine grained, thin bedded, base gradational into shale. — — — — — — — — — — — — 20.0

8. Shale—gray (Mancos tongue). — — — — — — — 25.0

7. Sandstone—tan to buff, fine grained, thin bedded, some marine cross-lamination, base transitional into underlying shale. — 32.0


5. Sandstone—gray to buff, fine grained, thin bedded, thin shale partings. — — — 7.0

4. Shale—gray (Mancos tongue). — — — — — — — 98.0

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Storrs member:

3. Sandstone- gray to tan, fine grained, shaly, base grades into shale, 22.0

2. Shale- gray (Mancos tongue), 120.0

Panther member:

1. Sandstone- gray to buff, fine to medium grained, thin bedded, some thin shale partings, base gradational into underlying Mancos, 85.0

Total Star Point sandstone and Mancos shale tongues, 477.0

Section No. 2 Sunnyside, Utah, Section at Whitmore Canyon.

Price River formation: In part

Farrer facies: not measured.

Neslen facies: in part

Castlegate member:

20. Sandstone- gray to white, medium to coarse grained, torrential cross-bedding, massive cliff-former, grains mostly angular quartz with calcareous cement, feldspars altered to kaolinite, top of unit gradational, 250.0

Disconformity (?)  

Blackhawk formation:

Undifferentiated coal-bearing rocks:

19. Sandstone- buff to white, red or brown where burned, medium to fine grained calcareous lenticular; shale- gray, sandy with plant fragments; shale- brown to black, carbonaceous; coal seams ranging from a few inches to two feet, 198.0

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<table>
<thead>
<tr>
<th>Member/Formation</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunnyside member (in part):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Coal- massive (Upper Sunnyside (?))</td>
<td></td>
<td>7.0</td>
</tr>
<tr>
<td>17. Sandstone- buff, medium to fine grained, calcareous, massive, thick bedded, marine cross-lamination, upper 10 feet white capped.</td>
<td></td>
<td>20.0</td>
</tr>
<tr>
<td>16. Coal- thin, persistent (Lower Sunnyside (?))</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>15. Sandstone- buff, medium grained, calcareous, massive, thick bedded, marine cross-bedding, upper surface flat, upper 10 to 15 feet leached white.</td>
<td></td>
<td>28.0</td>
</tr>
<tr>
<td>14. Sandstone- like No. 15 but not white-capped.</td>
<td></td>
<td>25.0</td>
</tr>
<tr>
<td>13. Sandstone- like No. 14, Base gradational into underlying shale.</td>
<td></td>
<td>40.0</td>
</tr>
<tr>
<td>12. Shale- drab gray (Mancos tongue).</td>
<td></td>
<td>66.0</td>
</tr>
<tr>
<td></td>
<td>Total Sunnyside member (in part) and Mancos shale tongue</td>
<td>189.0</td>
</tr>
<tr>
<td>Disconformity (slight)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kenilworth member:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Sandstone- gray, lenticular, calcareous, shaly, carbonaceous films; shale-gray sandy, some carbonaceous matter; coal seams- thin, lenticular.</td>
<td></td>
<td>35.0</td>
</tr>
<tr>
<td>10. Sandstone- buff, fine to medium grained, calcareous, thick bedded, foreshore cross lamination, top flat, top 10 to 15 feet leached white.</td>
<td></td>
<td>38.0</td>
</tr>
<tr>
<td>9. Sandstone- like No. 10 but not white-capped.</td>
<td></td>
<td>45.0</td>
</tr>
<tr>
<td>8. Shale- drab gray (Mancos tongue).</td>
<td></td>
<td>40.0</td>
</tr>
<tr>
<td>7. Sandstone- buff to gray, fine to medium grained, calcareous, lower foreshore cross laminations, thin to massive bedded, base-gradating downward into shale.</td>
<td></td>
<td>42.0</td>
</tr>
</tbody>
</table>
Feet

6. Shale- drab gray (Mancos tongue). - - - - - - 50.0
5. Sandstone- gray to buff, fine grained, calcareous, thin bedded with shale partings, grades into shale below. - - - - - - 12.0
4. Shale- drab gray (Mancos tongue). - - - - - - 225.0

Total Kenilworth member and Mancos shale tongue - - - - - - 487.0

Aberdeen member:

3. Sandstone- gray, fine grained, calcareous, thin bedded, shaly, transitional into shale below. - - - - - - - 5.0
2. Shale- (Mancos tongue). - - - - - - - - - 120.0
1. Sandstone- gray, fine grained, calcareous, shaly, thin bedded, base transitional into underlying shale of Mancos. - - 4.0

Total Aberdeen member and Mancos shale tongue- - - - - - - 129.0

Total Blackhawk formation and Mancos shale tongue - - - - - - 1003.0

Section No. 3 Woodside, Utah. Section four miles northeast of Woodside, Utah.

Price River formation: in part

Farrer facies: absent

Nealen facies: in part

Oastlegate member:

21. Sandstone- gray to white, fine to medium grained, calcareous, massive, cross-bedded (torrential), weathers buff, scarp former. - - - - - - - - - - 155.0
Disconformity (?)

Blackhawk formation:

undifferentiated coal-bearing rocks:

20. Shale - gray, calcareous, sandy, somewhat carbonaceous; sandstone - gray, fine grained, lenticular, calcareous; coal - in thin seams; shale - brown to black, carbonaceous, sandy. 125.0

Grassy member:

19. Sandstone - buff in lower part, top 15 feet gray to white, medium to fine grained, calcareous, massive, marine cross-bedding, some thin carbonaceous seams. 40.0

Disconformity (slight)

Sunnyside member:

18. Shale - gray, sandy, with thin carbonaceous layers, eight inch coal seams at the top. 5.0

17. Coal - massive. 4.0

16. Shale - gray, with some thin calcareous sandstone lenses. 2.0

15. Sandstone - buff to gray, medium to fine grained, calcareous, massive, thick bedded, somewhat carbonaceous. 15.0

14. Coal - massive. 4.0

13. Sandstone - light gray (white cap) medium to fine grained, massive, calcareous and somewhat carbonaceous. 15.0

12. Sandstone - buff, upper 15 feet gray to white, fine to medium grained, calcareous, massive, marine cross-bedding, base shaly and gradational into shale below. 45.0

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11. Shale—gray, sandy; siltstone—soft, thin-bedded, carbonaceous (Mancos tongue)
   
10. Sandstone—buff, fine to medium grained, calcareous, massive, marine cross-bedding, base gradational into shale below.

9. Shale—drab gray (Mancos tongue)

8. Sandstone—gray, thin bedded, fine grained grading into siltstone and shale at base.

7. Shale—drab gray, sandy; siltstone—gray calcareous near top (Mancos tongue)

   **Total Sunnyside member and Mancos shale tongue**  

   **Disconformity (slight)**

   **Kenilworth member:**

6. Sandstone—gray, lenticular, carbonaceous; shale—gray, sandy, carbonaceous.

5. Sandstone—buff to gray, top 20 feet light gray to white, flat topped, fine to medium grained, calcareous and somewhat carbonaceous, foreshore cross-lamination, base gradational into underlying shale.

4. Shale—gray, sandy; thin calcareous siltstones near top (Mancos tongue)

3. Sandstone—gray to buff, fine to medium grained, calcareous, thin bedded, shaly, shows marine cross-bedding, base gradational into shale.

2. Shale—gray, sandy, thin siltstones near top (Mancos tongue)
Feet

1. Siltstone- gray, fine grained with thin gray shale partings, gradational into Mancos shale below. - - - - - - - - - - 26.0

Total Kenilworth member and Mancos shale tongue- - - - - - - - - 183.0

Total Blackhawk formation and Mancos shale tongue- - - - - - - - - 634.0

Section 4  Thompson Canyon, Utah.

Price River formation:

Farrer facies: not measured

Neslen facies: in part

undifferentiated coal-bearing rocks:

27. Coal- bone, and shale (Chesterfield (?)) coal zone). - - - - - - - - - - - - - - 6.6

26. Shale and sandstone- shale, black, carbonaceous; sandstone, buff, medium grained, massive. - - - - - - - - - - - - - - 26.0

25. Coal and shale- coal, blocky; shale, gray, carbonaceous (Ballard (?) coal zone). - - - - - 5.0

Sego member:

24. Shale, sandstone, and coal- shale, gray, sandy, carbonaceous; sandstone, medium to fine grained, buff to gray, lenticular, cross-bedded; thin coal seams. - - - - - - - - 88.0

23. Coal, blocky (Anchor Mine zone (?)). - - - - - - - - 1.0

22. Sandstone and shale- sandstone, gray, medium to fine grained, thin bedded; shale, gray, sandy, thin bedded. - - - - - - - - 45.0

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<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td>Sandstone, buff, medium to fine grained, massive, cross-bedded</td>
<td>10.0</td>
</tr>
<tr>
<td>20.</td>
<td>Sandstone and shale- sandstone, gray fine grained, thin bedded, calcareous; shale, gray, sandy, carbonaceous, poorly bedded.</td>
<td>38.0</td>
</tr>
<tr>
<td>19.</td>
<td>Sandstone, massive, buff, medium grained, marine cross-bedding, base gradational into shale.</td>
<td>16.0</td>
</tr>
<tr>
<td>18.</td>
<td>Shale, gray (Mancos tongue).</td>
<td>40.0</td>
</tr>
<tr>
<td>17.</td>
<td>Sandstone, gray, medium grained, cross-bedded</td>
<td>8.0</td>
</tr>
<tr>
<td>16.</td>
<td>Sandstone, buff, medium grained, massive, marine cross-bedding, base gradational into shale.</td>
<td>9.0</td>
</tr>
<tr>
<td>15.</td>
<td>Shale, gray (Mancos tongue).</td>
<td>10.0</td>
</tr>
<tr>
<td>14.</td>
<td>Sandstone, buff, medium grained, massive, marine cross-bedding, base gradational into shale.</td>
<td>6.0</td>
</tr>
<tr>
<td>13.</td>
<td>Shale, gray (Mancos tongue).</td>
<td>10.0</td>
</tr>
<tr>
<td>12.</td>
<td>Sandstone, gray to buff, medium to coarse grained, cross-bedded, lenticular.</td>
<td>30.0</td>
</tr>
<tr>
<td>11.</td>
<td>Sandstone, buff to gray, medium grained, massive, cross-bedded, upper part channeled in many places, base gradational.</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Total Neslen facies- **358.6**

Buck tongue of Mancos shale:

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Shale, gray gypsiferous, with few nodules of limestone.</td>
<td>190.0</td>
</tr>
</tbody>
</table>

Castlegate member:

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td>Sandstone and shale- sandstone, gray, medium grained, thin bedded, with marine cross-bedding; shale, gray, somewhat carbonaceous, some thin lenses of coal.</td>
<td>20.0</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Layer</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Sandstone, buff, medium grained, massive,</td>
<td>30.0</td>
</tr>
<tr>
<td>marine cross-bedding, base gradational into shale.</td>
<td></td>
</tr>
<tr>
<td>7. Shale, gray (Mancos tongue)</td>
<td>1.0</td>
</tr>
<tr>
<td>6. Sandstone and shale-sandstone, gray,</td>
<td>9.0</td>
</tr>
<tr>
<td>thin bedded; shale, gray, sandy</td>
<td></td>
</tr>
<tr>
<td>5. Sandstone, buff, medium-grained, massive,</td>
<td>30.0</td>
</tr>
<tr>
<td>cross-bedded, base is gradational into shale.</td>
<td></td>
</tr>
<tr>
<td>4. Shale, gray (Mancos tongue)</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Total Castlegate member 94.0

Disconformity

Blackhawk formation:

Desert member:

3. Shale, sandstone, and coal-shale, gray, carbonaceous, poorly bedded; sandstone, gray to buff, medium to fine grained, carbonaceous; thin coal seams. 20.0

2. Sandstone, buff, fine to medium grained, massive, cross-bedded, parting near middle, base gradational into shale. 40.0

Total Desert member 60.0

Total Blackhawk 60.0
Section 5  Westwater Canyon, Utah.

Price River formation:

Farrer facies: not measured

Neslen facies:

undifferentiated coal-bearing rocks:

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Coal and shale- coal, bony; shale, black, carbonaceous.</td>
<td>7.0</td>
</tr>
<tr>
<td>28</td>
<td>Sandstone and shale- sandstone, gray, medium grained, thin-bedded, lenticular; shale, gray, somewhat carbonaceous.</td>
<td>29.0</td>
</tr>
<tr>
<td>27</td>
<td>Coal, bony, blocky (Carbonera (?)).</td>
<td>2.6</td>
</tr>
<tr>
<td>26</td>
<td>Sandstone, shale, and coal- sandstone, gray to white, fine to medium grained, calcareous and somewhat carbonaceous; shale, gray, poorly bedded; thin coal seams.</td>
<td>76.0</td>
</tr>
<tr>
<td>25</td>
<td>Coal, bony (Chesterfield (?)).</td>
<td>2.0</td>
</tr>
<tr>
<td>24</td>
<td>Sandstone, gray, fine to medium grained, with thin shale partings (Sulphur Canyon sandstone of Fisher).</td>
<td>15.0</td>
</tr>
<tr>
<td>23</td>
<td>Sandstone, gray, fine to medium grained, shale partings.</td>
<td>30.0</td>
</tr>
<tr>
<td>22</td>
<td>Sandstone, shale, and coal- sandstone, gray medium to fine grained, shale partings, calcareous; shale, gray, sandy, carbonaceous; thin coal beds.</td>
<td>43.0</td>
</tr>
<tr>
<td>21</td>
<td>Coal and shale- coal, bony; shale, gray to black, carbonaceous.</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Total undifferentiated coal-bearing rocks - - - - 209.6

Sego member:

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Sandstone and shale- sandstone, buff to gray, fine grained; shale, gray, sandy.</td>
<td>27.0</td>
</tr>
</tbody>
</table>
Feet

19. Coal and shale—coal, bony; shale, gray to black, carbonaceous.  — — — — — — — 12.0
18. Shale, gray, sandy, carbonaceous.  — — — — 10.0
17. Sandstone, gray to buff, coarse to medium grained, massive, cross-bedded.  — — 52.0
16. Sandstone, buff to white, coarse to medium grained, massive, marine cross-bedding, gradational into shale at base.  10.0
15. Shale, gray, sandy (Mancos tongue).  — — — 10.0
14. Sandstone, buff, fine grained, massive, marine cross-bedding, gradational into shale at base.  — — — — — — — 6.0
13. Shale, gray, sandy (Mancos tongue).  — — — 20.0
12. Sandstone, gray to white, fine to medium grained, lenticular, marine cross-bedding.  — — — — — — — 5.0
11. Sandstone, buff, massive, marine cross-bedding, gradational into shale at base.  11.0
10. Shale, gray, sandy (Mancos tongue).  — — — 3.0
9. Sandstone and shale—sandstone, gray, fine to medium grained, lenticular; shale, gray, carbonaceous.  — — — — — — — 20.0
8. Sandstone, buff, medium grained, massive, marine cross-bedding, gradational into shale at base.  — — — — — — — 35.0
7. Shale, gray, sandy (Mancos tongue).  — — — 2.0
6. Sandstone, buff to gray, fine to medium grained, calcareous, massive with marine cross-bedding, base grades into shale.  — — — — — — — — — — — — — 18.0

Total Sego member  246.0
Buck tongue of Mancos shale:

5. Shale, gray, upper part sandy, some thin lenses of calcareous concretions bearing fossils of Lewis age, whole is gypsiferous. — — — — — — — — — 350.0

Castlegate member:

4. Sandstone, buff to brown, medium to fine-grained, ferruginous, massive, marine cross-bedding, base gradational into shale. — — — — — — — — — 4.0

3. Shale, gray, calcareous, sandy (Mancos tongue). — — — — — — — — — 10.0

2. Sandstone and shale—sandstone, gray, fine grained, thin bedded, marine cross-bedding, interbedded with gray, sandy, marine shale. — — — — — — — — — 40.0

Total Castlegate member 54.0

Total Neslon facies 509.6

1. Shale, gray (Mancos tongue).
I, Robert G. Young, was born in Boulder, Colorado, on January 15, 1923. After graduation from Boulder High School, Boulder, Colorado, in 1939, I entered the University of Colorado. In December of 1942 I entered military service. Under the Pre-Cadet I studied for three months at Michigan State College. As a result of the credits thus obtained, I was graduated, in absentia, from the University of Colorado in June, 1944 with the degree Bachelor of Science (Geology). After being discharged from the Air Forces in 1945, I entered the Graduate School of the University of Colorado for one year. In 1948 I entered the Graduate School of the University of Kansas where I served as a graduate assistant. In 1949 I enrolled in the Graduate School of the Ohio State University. While at the Ohio State University, I served as a graduate assistant from 1949 to 1951. For a period of one year beginning July 1, 1951, I held the position of Research Fellow of the Ohio State University Research Foundation while completing the requirements for the degree Doctor of Philosophy.