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Upper Cretaceous Stratigraphy of the Central Part of Utah

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UPPER CRETACEOUS STRATIGRAPHY OF THE CENTRAL PART OF UTAH

by

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INTRODUCTION

Rocks of Late Cretaceous age in the central part of Utah are dominantly clastic. In general, the sediments in the west are of conglomerate and sandstone of continental origin; the sediments in the east are of sandstone and shale of marine origin. These rocks were deposited at or near the western shore of a sea which extended from the Arctic to the Gulf of Mexico. The strand line lay in a general northern direction through Utah with land to the west and marine water to the east.

In vertical succession rocks of Cretaceous age in Utah may be roughly divided into three divisions: (1) At the base of the Cretaceous secion is generally a thin unit of conglomerate, sandstone, and coal of continental origin, the Dakota formation or its equivalents, which represent the initial transgression of the Cretaceous sea into Utah. (2) Overlying this unit is a sequence of interbedded sandstone, coal, and shale deposits of mixed continental and marine origin which were laid down at or near the edge of the oscillating shoreline. (3) The youngest sediments of Late Cretaceous age in any given area of Utah are generally conglomerates, sandstones, and shales of continental origin deposited as the Cretaceous sea withdrew eastward.

With the exception of west-central and northwestern Utah, outcrops of rocks of Late Cretaceous age are widespread in the state. In southwestern and south-central Utah extensive exposures are found on the Kolob Terrace and the Paunsaugunt and Kaiparowits Plateaus.

Isolated outcrops occur in the vicinity of the Pine Valley Mountains. In central Utah numerous exposures of this age are in the Sanpete Valley area and on the Wasatch Plateau. To the east in the Castle Valley area and the Book Cliffs, correlative rocks form outcrops that are continuous into western Colorado. In north-central Utah exposures of Upper Cretaceous rocks are more isolated and not nearly as abundant. The most extensive occurrences are near Coalville, Utah, in the Weber River valley and in the western Uinta Basin at the southwestern flank of the Uinta Mountains.

Numerous papers have been written describing the stratigraphy of local areas throughout Utah. At the present time no regional papers have been written tying local stratigraphy into a broad, unified picture. The purpose of this study is to summarize existing knowledge and problems of local stratigraphy in the central part of Utah and to unite this information in correlation of various rock units, to draw conclusions as to the nature of the sediments and the movements of the Late Cretaceous sea. To facilitate the discussion and because of differences in terminology, the stratigraphy is discussed under three headings: the southern region, the central region, and the northern region (Figure 1). These regions are further subdivided into areas. Three correlation charts are presented to show the nomenclature and the latest age assignments and correlation of units in each of the three regions. Two diagrams correlate representative stratigraphic sections in the western areas and representative stratigraphic sections in the eastern areas. Three diagrams give stratigraphic relations in each of the three regions, and four lithofacies maps show strata deposited at various times during the Late Cretaceous.

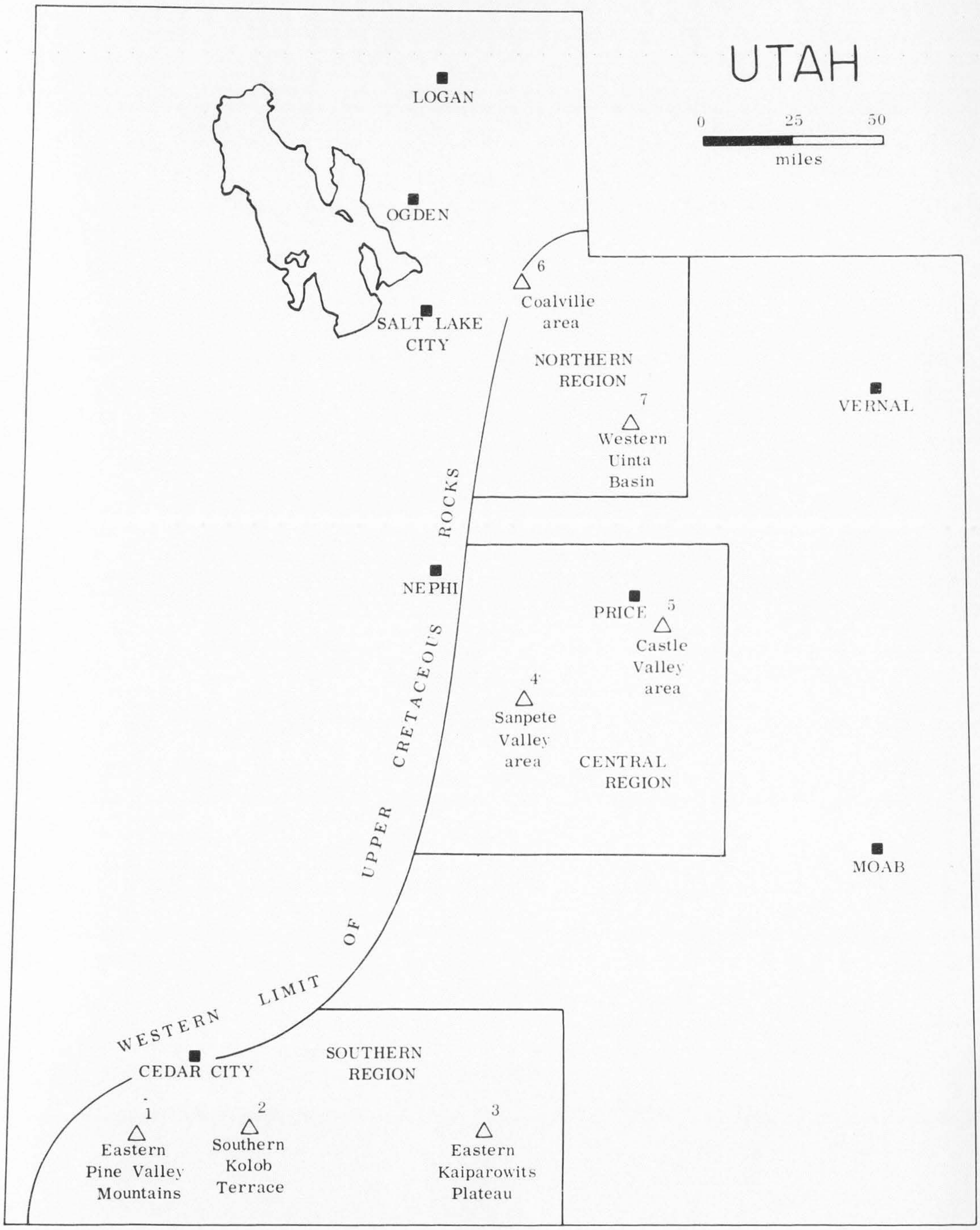

Figure 1. Index map of Utah showing locations of regions and stratigraphic columns used in Figures 5, 6, 7, 8, and 9.

STRATIGRAPHIC ANALYSIS

Southern Region

General statement

In southwestern and south-central Utah, Upper Cretaceous rocks are exposed in the vicinity of the Pine Valley Mountains, on the Kolob Terrace, and on the Paunsaugant and Kaiparowits Plateaus. The discussion of the stratigraphy of the southern region is under three headings: (1) a western area including the eastern Pine Valley Mountains and western Kolob Terrace, (2) a middle area of the southern Paunsaugunt Plateau, and (3) an eastern area of the Kaiparowits Plateau. The nomenclature used in the southern region was introduced in large part by Gregory and Moore (1931).

Western area

Cook (1957) has described the geology of the Pine Valley Mountains. In the eastern Pine Valley Mountains four rock units of Late Cretaceous age are recognized. These are, in ascending order, the Dakota formation, the Tropic formation, the Straight Cliffs and Wahweap sandstones undifferentiated, and the Kaiparowits formation. The Claron formation, which overlies the Kaiparowits formation in the vicinity of the Pine Valley Mountains, may be of Late Cretaceous age in the lower part. In the western Kolob Terrace, studied by Gregory (1950a), these same rock units are present, but the beds correlative with the Claron formation are called the Wasatch formation. Because of facies change to the west, these four Upper Cretaceous units become more coarse in texture and lithologically alike so that in the southern and western Pine Valley Mountains they are undifferentiated.

Dakota formation.--The term Dakota was first used by Meek and Hayden (1861, p. 419) for the basal Cretaceous sequence of sandstones, clays, and lignite in the Missouri Valley of northeastern Nebraska. Since that time the names Dakota group, Dakota formation, Dakota sandstone, and Dakota (?) sandstone have been applied to this widespread basal Cretaceous unit in the Western Interior. It has commonly been called Dakota sandstone or Dakota (?) sandstone in Utah. The writer prefers the term Dakota formation for this unit because of its variable lithology.

In the western area, the Dakota Formation is at the base of the Upper Cretaceous section. It unconformably overlies either the Entrada sandstone, the Winsor formation, or the Carmel formation of Jurassic age, and it grades upward into the sandstones, shales, and coals of the Tropic formation. The dominant lithology of the Dakota formation is gray to yellowish-brown conglomerate and sandstone. Pebbles of subangular chert and quartzite are found throughout this unit; pebbles of black limestone and igneous rock, fragments of petrified wood, and earthy coal are present locally. The thickness of the Dakota formation in the western area is less than 40 feet as evidenced by measured sections of Gregory (1950a) and Cook (1957).

Tropic formation.--The Tropic formation was named by Gregory and Moore (1931, p. 91) for typical exposures in the vicinity of the town of Tropic in south-central Utah where it is of nearly uniform gray marine shale. Along the western edge of the Kolob Terrace and in the eastern Pine Valley Mountains the Tropic formation is an apparent unsystematic sequence of sandstone, shale, and coal, with minor amounts of conglomerate and limestone. The coal and lignite are especially abundant in the lower 500 feet of these strata. The sandstone beds are resistant, yellowish-brown to white, fine-grained to medium-grained sandstone. The shales are silty and variegated red, gray, or brown. The formation as a whole generally weathers to slopes covered by debris and plant growth. To the west of this area in the western Pine Valley Mountains, Cook (1957, p. 36) reports that the time equivalent of the Tropic formation contains no coal and consists of medium-grained to coarse-grained sandstone with subordinate conglomerate.

The Tropic formation grades downward into the underlying Dakota formation and likewise grades upward into the overlying Straight Cliffs sandstone. In the western area the contact between the Tropic formation and the overlying Straight Cliffs sandstone has been arbitrarily set by the individual workers. This, in part, accounts for the differences in thickness given for the Tropic formation. Cook (1957, p. 36) estimates the thickness of the formation to be 800 feet on the east flank of the Pine Valley Mountains, and Gregory (1950a, p. 44) reports the thickness on the western Kolob Terrace to be between 206 and 868 feet. Bissell (1952a, p. 70) indicates the thickness of the Tropic formation on the western Kolob Terrace to be 405 feet.

Fossils from the lower coal-bearing part of the Tropic formation of the Kolob Terrace, reported by Richardson (1927, p. 467-468), are of a brackish-water species and fix the age of the Tropic formation in that area as Colorado. Gregory (1950a, p. 55) also lists brackish-water and some marine fossils of early Colorado age from the Tropic formation.

Straight Cliffs and Wahweap sandstones undifferentiated.--Gregory and Moore (1931, p. 91) named the Straight Cliffs sandstone for the Straight Cliffs south of Escalante, Utah, where the formation is typically exposed. The Wahweap sandstone received its name from Wahweap Creek in the southwestern part of the Kaiparowits Plateau (Gregory and Moore, 1931, p. 91). On the Kaiparowits Plateau the two units are similar but were distinguished by Gregory and Moore (1931, p. 104) by the absence of coal and the scarcity of fossils in the Wahweap sandstone and by a sandy shale break between the Wahweap sandstone escarpment and the Straight Cliffs escarpment. No sandy shale break or other criteria whereby the Straight Cliffs sandstone could be separated from the Wahweap sandstone were found by Cook (1957, p. 36) in the Pine Valley Mountains or Gregory (1950a, p. 46) on the Kolob Terrace although both formations are believed to be present. The Straight Cliffs and Wahweap sandstones are accordingly undifferentiated and treated as a single unit in the western area.

In the western area the Straight Cliffs and Wahweap sandstones grade downward into the sandstones and shales of the underlying Tropic formation and are disconformably overlain by the Kaiparowits formation. As a unit, the Straight Cliffs and Wahweap sandstones of the eastern Pine Valley Mountains and western Kolob Terrace is a thick sequence of sandstone with minor beds of sandy shale, limestone, conglomerate, and some lignite. The sandstone is massive, laminated or cross-bedded, yellowish-brown, and in beds ranging in thickness from 3 to 40 feet. This unit characteristically forms an escarpment. It is about

1,800 feet thick on the southeastern side of the Pine Valley Mountains (Cook, 1957, p. 36), and about 2,555 feet thick along the western edge of the Kolob Terrace (Bissell, 1949, p. 99). Fossils collected by Gregory (1950a, p. 55) indicate a Colorado age for this unit in the western area.

Kaiparowits formation.--The name Kaiparowits formation was applied by Gregory and Moore (1931, p. 91) to exposures of coarse-grained, weak grits and sandy mudstones that overlie the Wahweap sandstone on the highest part of the Kaiparowits Plateau. In the western area the Kaiparowits formation disconformably overlies the Straight Cliffs and Wahweap sandstones undifferentiated and is unconformably overlain by the Wasatch (Claron) formation. Gently inclined dark-gray sandy slopes, that resemble shale beds from a distance, generally characterize the Kaiparowits formation. The predominant rock type is thin-bedded, weakly cemented, white to dark-gray arkosic sandstone that is irregular in texture and composition. Minor rock types are sandy shale, limestone, lignite, and conglomerate. A basal conglomerate of variable thickness is locally present. Iron concretions are common throughout the formation.

The Kaiparowits formation is 1,200 feet thick in the eastern Pine Valley Mountains according to Cook (1957, p. 36). Bissell (1949, p. 99) reports 685 feet of strata along the western edge of the Kolob Terrace. Gregory (1950a, p. 79) measured 810 feet of Kaiparowits formation in Coal Canyon east of Cedar City. From fossil plants and invertebrates, Gregory (1950a, p. 55-56) concluded that the Kaiparowits formation on the western Kolob Terrace is of late Montana Age. No fossils have been found in the formation near the Pine Valley Mountains (Cook, 1957, p. 37).

Wasatch formation (Claron formation).--Unconformably overlying the Kaiparowits formation is a unit of fresh-water limestone with lesser amounts of conglomerate and calcareous sandstone and shale. Throughout southern Utah, except in the vicinity of the Pine Valley Mountains, this unit is called the Wasatch formation. The Wasatch formation was defined by Hayden (1873, p. 191) to include the strata exposed along the track of the Union Pacific Railroad Company between Carter Station, Wyoming, and Echo Canyon, Utah. Veatch (1907, p. 88-89) elevated the Wasatch formation to a group status, named formations within the Wasatch group, and defined the type locality more specifically. Later workers extended the name Wasatch into central and southern Utah to include strata of supposed Eocene age. Coeval strata exposed just north of the Pine Valley Mountains were named the Claron formation by Leith and Harder (1908, p. 41-43). Cook (1957, p. 37) chose to retain the name Claron formation rather than use the name Wasatch formation in the Pine Valley Mountains because of the uncertainty of the correlation of the southern Utah Wasatch formation with the Wasatch group of the type locality.

In both the eastern Pine Valley Mountains and the western Kolob Terrace the Claron formation or Wasatch formation can be divided into three units: (1) a basal conglomerate or sandstone, (2) a middle unit of pink limestone and calcareous shale and sandstone, and (3) an upper unit of white or gray limestone. These units are arbitrary and vary greatly in thickness. To the west of the Pine Valley Mountains, the Claron formation becomes more clastic until near Gunlock, Utah, the section is dominantly a pebble, cobble, and boulder conglomerate with sandstone lenses. This formation characteristically weathers to bold pink cliffs. In the Pine Valley Mountains the Claron formation ranges from 0 to 1,000 feet with an average of 500 feet (Cook, 1957, p. 37). On the western Kolob Terrace Gregory (1950a, p. 78) reports 1,327 feet of Wasatch formation. On the basis of correlation of the southern Utah Wasatch formation with the North Horn formation and the Flagstaff limestone of central Utah, Bissell (1949, p. 93) assigned the lower part of the Wasatch formation to a late Late Cretaceous age and the upper part to a lower Tertiary age. At the present time no paleontologic evidence has been found to prove the Wasatch formation of southern Utah is, in part, of Late Cretaceous age.

Middle area

The middle area of the southern region is the southern Kolob Terrace and the southern edge of the Paunsaugunt Plateau. Detailed work has been done in the southern Kolob Terrace by Gregory (1950b) and Cashion (1961), and in the Paunsaugunt region by Gregory (1951). The Dakota formation, the Tropic formation, the Straight Cliffs and Wahweap sandstones undifferentiated, and the Kaiparowits formation are, in ascending order, the Upper Cretaceous units. The Wasatch formation is an Upper Cretaceous (?) and Tertiary unit.

Dakota formation.--The Dakota formation is the basal Upper Cretaceous unit in the middle area. It unconformably overlies older formations, generally the Winsor formation of Jurassic age. Upward, the Dakota formation grades into the sandstones, shales, and coals of the Tropic formation. The upper limit of the Dakota formation in the southern Kolob Terrace and southern Paunsaugunt Plateau has arbitrarily been placed by Gregory (1950b, p. 102 and 1951, p. 35) just below the lowest marine fossilferous bed in the Tropic formation. In accordance with this division, the Dakota formation of the middle area ranges from 4 to 108 feet thick with an average of 30 to 40 feet.

The Dakota formation of the middle area is generally a medium-grained to coarse-grained sandstone or pebble conglomerate. Petrified wood, earthy coal, and macerated plant remains are common throughout the formation. Pebbles in the conglomerate are commonly red, brown, and gray quartzite, and chert of various colors. On outcrops the Dakota formation is often friable and does not form the resistant benches which are characteristic of this unit in other parts of the Colorado Plateau.

Tropic formation.--The Tropic formation, as defined by Gregory (1950b, p. 103 and 1951, p. 35-36) and Cashion (1961), consists of two units: a lower unit of interbedded sandstone, shale, and coal which thins eastward, and an upper unit of sandy marine shale which thickens eastward. The sandstone is generally in beds 2 to 20 feet thick and is massive, thin-bedded, or cross-bedded, white, gray, tan, or yellowish-brown, and fine-grained to coarse-grained. The shale beds are regularly-bedded, thin-bedded, or cross-bedded, gray, or grayish blue, and are arenaceous, calcareous, or carbonaceous. Measured sections in Gregory (1950b, p. 125-133 and 1951, p. 65) show the Tropic formation to vary between 389 and 1,475 feet thick in the middle area. Fossils from the Tropic formation are both brackish-water and marine types. Shale beds generally contain marine fossils while the sandy beds contain both marine and brackish-water species. Fossils reported by Gregory (1950b, p. 104 and 1951, p. 36-37), which were identified by J. B. Reeside, Jr., fix the age of the Tropic formation as early Colorado.

Straight Cliffs and Wahweap sandstones undifferentiated.--Gradationally above the Tropic shale in the middle area is a distinctive cliff-forming unit, the Straight Cliffs and Wahweap sandstones undifferentiated. In studying the Zion Park and Paunsaugunt regions, Gregory (1950b, p. 107 and 1951, p. 34) found the Straight Cliffs and Wahweap sandstones to form continuous parts of a cliff-benched regional slope. The lack of persistent physical features made it impractical for the two formations to be divided and mapped accurately as was done by Gregory and Moore (1931, p. 104) in the Kaiparowits region of south-central Utah. Contrary to this, Cashion (1961) in mapping the Orderville-Glendale area found it easier to recognize the Straight Cliffs sandstone. He did not differentiate the overlying Wahweap and Kaiparowits formations. The Straight Cliffs sandstone was restricted to the littoral marine sandstones overlying the Tropic formation. The Wahweap and Kaiparowits formations undifferentiated included sediments of inland origin.

The Straight Cliffs sandstone of the middle area is a sequence of tan, gray, or yellowish-brown sandstone that intertongues with marine shale in the lower part. Most of the sandstone beds are lenticular and vary greatly in thickness. The overlying Wahweap sandstone is composed largely of sandstone with interbedded sandy shale. It contains some carbonaceous shale, and coal and conglomerate locally.

Most of the sandstone beds are composed of poorly sorted grains and are irregularly bedded.

As in the western area, the absence of persistent horizon markers at the base of the Straight Cliffs sandstone caused Gregory (1950b, p. 107 and 1951, p. 34) to arbitrarily separate the Straight Cliffs sandstone from the underlying Tropic formation. An erosional unconformity marks the upper boundary of the Wahweap sandstone with the younger, overlying Kaiparowits formation. Measured sections in Gregory (1950b, p. 128-133 and 1951, p. 63-68) indicate a variable thickness between 746 feet and 1,406 feet for the Straight Cliffs and Wahweap sandstones undifferentiated in the middle area.

Marine, brackish-water, and fresh-water species of invertebrate fossils are found in the Straight Cliffs and Wahweap sandstones. Brackish-water and fresh-water species become more prevalent west from the Kaiparowits Plateau. Other than this difference, the fossils of the middle area in these units are generally the same as those of the Kaiparowits Plateau and indicate a Niobrara age (Gregory, 1951, p. 39).

Kaiparowits formation.--The Kaiparowits formation of the southern Kolob Terrace and the southern Paunsaugunt Plateau is essentially the same as the Kaiparowits formation found in other areas of southern Utah. It forms a distinct dark band above the gray or yellowish-brown cliffs of the Straight Cliffs and Wahweap sandstones and below the pink and white cliffs of the Wasatch formation. The formation is composed of thin-bedded arkosic sandstone with subordinate amounts of calcareous silt, limestone, and conglomerate. It readily erodes to gentle slopes that have a dark shale aspect. An erosional unconformity separates the Kaiparowits formation from the underlying Wahweap sandstone. Likewise, an easily recognized erosional unconformity lies between the Kaiparowits formation and the overlying Wasatch formation. In the middle area the formation ranges from 530 to 750 feet thick.

Fossils found in the Kaiparowits formation are of a non-marine type. Fresh-water invertebrates, land snails, turtles, dinosaurs, dicotyledons, and gymnosperms are representative. As in other areas, the Kaiparowits formation of the middle area is considered to be Montana in age. The invertebrate fossils from the Kaiparowits formation are similar to those from the Wasatch formation and the most abundant are found in both formations (Gregory, 1951, p. 43). The style of bedding, the texture, and the lithology, as well as the fossils, of the Kaiparowits formation are interpreted by Gregory (1951, p. 109) to suggest deposition by streams, rivers, and shallow ponds. Many small local unconformities support this conclusion.

Wasatch formation.--The Wasatch formation in southern Utah forms the Pink Cliffs. This escarpment, generally 100 to 400 feet high, is present along the edges of the Markagunt, Paunsaugunt, and Aquarius Plateaus and is famous for its scenic exposures at Cedar Breaks and Bryce Canyon. In describing the Wasatch formation of the Paunsaugunt Plateau Gregory (1951, p. 44-45) states:

> In a broad sense, the Wasatch of the Paunsaugunt Plateau consists of three parts: (1) a basal, generally red massive limestone with sparingly distributed exotic pebbles, or a conglomerate with calcareous cement, 20 to 100 feet thick; (2) a pink and red, irregularly bedded limestone with subordinate calcareous shales, limestone, conglomerates, and breccias, 0 to 800 feet; (3) white limestones and sandstones with much gray conglomerate and some pyroclastic sediments 0 to 300 feet.

Although the boundaries of these major subdivisions are not clearly definable and vary considerably locally, these large features are recognizable throughout most of the Wasatch formation of southern Utah (Gregory, 1951, p. 45).

The Wasatch formation in the middle area yields fresh-water invertebrates and leaf impressions of the same type as found elsewhere in the southern Utah Wasatch formation. These fossils are not clearly diagnostic but fix the age of the formation as Eocene. The fresh-water fossils, type of bedding, and distribution of sediments suggest that the Wasatch formation is of terrestrial origin. Contrary to Dutton's (1882, p. 214-219) idea of a single large fresh-water lake, Gregory (1951, p. 51) believes the Wasatch formation of southern Utah was laid down by a group of smaller lakes in separate basins or overlapping basins of different sizes and depths. This observation is made because of the physical make-up and lateral and vertical distribution of the different types of sediments in the formation. The thinly laminated deposits of fine-grained limestone indicate deposition in quiet water, but the lenticular sandstone and conglomerates do not indicate large quiet lake conditions. The limestone, shale, sandstone, and conglomerate differ regionally in distribution and amount.

The Wasatch formation on the southern Kolob Terrace is less than 500 feet thick as reported by Gregory (1950a, p. 112), and in the Paunsaugunt region it is less than 1,180 feet thick (Gregory, 1951, p. 44). Variations in thickness may be attributed in part to deposition in different basins, but it is probably primarily due to the erosional unconformities which enclose the formation.

Eastern area

The eastern area of the southern region in this discussion has been defined as the Kaiparowits Plateau. Stratigraphic work has been done in this area by Gregory and Moore (1931). They recognized five units in the Upper Cretaceous section of the Kaiparowits Plateau, which are in ascending order, the Dakota formation, the Tropic shale, the Straight Cliffs sandstone, the Wahweap sandstone, and the Kaiparowits formation. The Wasatch formation was assigned an Eocene age by them.

Dakota formation.--As has been done in other areas, Gregory and Moore (1931, p. 94-98) referred to the Dakota formation of the Kaiparowits Plateau as the Dakota (?) sandstone. The query was used because the relationship to the Dakota group of the type locality in Nebraska was not known. The U. S. Geological Survey has since removed the query from the Dakota sandstone because Dakota has no precise meaning (Young, 1960, p. 156).

The lithology of the Dakota formation of the Kaiparowits Plateau is similar to the descriptions previously given. It is essentially a sequence of lenticular sandstone, shale, conglomerate, coal, and lignite. Locally petrified wood is very abundant. The unit forms an outcrop averaging 50 feet thick that surrounds the Kaiparowits Plateau on the western, southern, and eastern sides. In topographic expression this outcrop forms projecting ledges and hogbacks below the distinctive gentle gray slopes of the Tropic shale. Generally, in the eastern area the Morrison formation is found unconformably under the Dakota formation. Upward, the Dakota formation grades into the gray shales of the Tropic shale.

Stokes (1950, p. 91-98) applied a pedimentation concept to the origin of the Dakota formation. After widespread erosion in Early Cretaceous time an extensive gravel and sand sheet was laid down on a pediment, which is now recognized as the lenticular conglomerates and sandstones in the thin widespread Dakota formation. Inconsistent, in part, with this idea Young (1960, p. 178), who studied the Dakota of the Colorado Plateau, recognized four environments of deposition: an inland environment, a lagoonal environment, a littoral marine environment, and a marine environment.

Tropic shale.--As previously stated, the Tropic shale was named by Gregory and Moore (1931, p. 91) for exposures near the town of Tropic in south-central Utah. Throughout the Kaiparowits Plateau region the Tropic shale is a distinct unit that is conspicuous from the enclosing rock units in lithology and topographic expression. Gradationally above the Dakota formation, the base of the Tropic shale is characteristically sandy and fossiliferous. The middle of the formation is a uniform, thinly-laminated, soft, gray, clayey shale which on exposure weathers to valleys and gentle to moderately steep slopes under the protective cap of the resistant Straight Cliffs sandstone. The upper third of the Tropic shale becomes arenaceous as it grades upward into the Straight Cliffs sandstone. The formation in this area ranges between 600 and 1,400 feet thick.

As defined by Gregory and Moore (1931, p. 95) the base of the Tropic shale in the Kaiparowits Plateau is the lowest bed containing marine fossils. Strata of Cretaceous age below this lower marine-fossil bearing bed were assigned to the Dakota formation. The top of the Tropic shale is at the base of the transition zone between shale and sandstone of the overlying Straight Cliffs sandstone (Gregory and Moore, 1931, p. 100). Although everywhere observed the Tropic formation appears gradational with the overlying Straight Cliffs sandstone, Cobban and Reeside (1952a, p. 1028) infer a hiatus between the two formations on the basis that upper Carlile beds are apparently absent because the *Prionocyclus wyomingensis* fauna has not been found. Marine fossils which are abundant near the base of the formation are rare or absent in the middle and upper parts.

Straight Cliffs sandstone.--Gradationally above the Tropic shale is the Straight Cliffs sandstone which was defined by Gregory and Moore (1931, p. 91) for exposures at the Straight Cliffs, a prominent escarpment along the eastern edge of the Kaiparowits Plateau. At the type locality the Straight Cliffs sandstone is essentially massive beds of yellowish or yellowish-brown, fine-grained to medium-grained sandstone. In the eastern area coal, lignite, and carbonaceous shale are frequently found in the middle part of the formation. It is resistant to erosion and characteristically forms vertical massive cliffs above the gentle slopes of the Tropic shale. Throughout the Kaiparowits Plateau, the formation ranges between 900 and 1,200 feet thick with an average of 1,000 feet (Gregory and Moore, 1931, p. 101).

Marine and brackish-water fossils are frequently found in many parts of the Straight Cliffs sandstone. According to J. B. Reeside, Jr. (Gregory and Moore, 1931, p. 104) these fossils belong to the upper Niobrara part of the Colorado group. The Straight Cliffs sandstone was deposited at, or near, an oscillating shore line of the Late Cretaceous sea.

Wahweap sandstone.--The Wahweap sandstone, as previously discussed in this paper, was named by Gregory and Moore (1931, p. 91) for exposures near the head of Wahweap Creek on the Kaiparowits Plateau. The Wahweap sandstone is conformable above the Straight Cliffs sandstone and is distinguished from it in the eastern area by the lack of coal and scarcity of fossils in the Wahweap sandstone, and by the offset of the Wahweap sandstone cliffs behind the Straight Cliffs sandstone cliffs. The Wahweap sandstone on the Kaiparowits Plateau consists of alternating sandstone and sandy shale in the lower and middle parts. Erosion of these nonresistant beds causes the recession of the upper part of the formation which is resistant sandstone. The upper resistant sandstone beds of the Wahweap sandstone form a ledge, 100 to 200 feet thick, that is the highest escarpment on the Kaiparowits Plateau. The sandstone is yellowish to yellowish-brown and fine-grained to medium-grained with even or lenticular bedding. The average thickness of the formation as reported by Gregory and Moore (1931, p. 105) is 1,250 feet. No invertebrate fossils have been found, but a late Niobrara age is assumed because of the relationship to the underlying Straight Cliffs sandstone.

Kaiparowits formation.--The name Kaiparowits formation was applied by Gregory and Moore (1931, p. 106) to the friable arkosic sandstone that unconformably overlies the Wahweap sandstone. It is typically exposed near the top of the Kaiparowits Plateau. On outcrop, the Kaiparowits formation is markedly different than the enclosing rock units. Below it the resistant Wahweap sandstone forms a prominent yellowish cliff. The Kaiparowits formation itself appears as a dark band of rock that weathers easily to slopes. Unconformably above the formation, the Wasatch formation characteristically forms brilliant pink and white cliffs. The lithology of the Kaiparowits formation in the eastern area is similar to the arkosic sandstone that is found in the western and middle areas. Its thickness is approximately 2,000 feet.

Wasatch formation.--The Wasatch formation of southern Utah was first described geologically by Howell (1875) and Dutton (1880), who outlined three broad subdivisions in this lacustrine formation of supposed Eocene age. These were a lower conglomeratic unit, a middle pink limestone, and an upper white or gray limestone unit. According to Gregory and Moore (1931, p. 115) these divisions are very arbitrary because the Wasatch formation differs widely in composition, thickness, and arrangement of beds. In the eastern area the Wasatch formation outcrops as cliffs on the northern and western edges of the Kaiparowits Plateau on the Table Cliffs and Aquarus Plateau. In part due to erosion of this stratigraphically high unit, the thickness differs greatly from place to place. In the eastern area it ranges from 300 to 1,500 feet thick (Gregory and Moore, 1931, p. 115).

Stratigraphic relations

Dakota and Tropic formations.--Throughout the southern region the Dakota formation has been regarded as a basal sandstone and conglomerate of the Tropic formation. In his professional papers Gregory (1931, p. 95; 1950b, p. 102; and 1951, p. 35) has chosen to place the contact between the two units at the lowest horizon where marine fossils are found. Strata below the marine fossils were considered to be the Dakota formation and above the marine fossils were considered to be the Tropic formation. Following this scheme it will be noted that the Tropic formation in the middle and western areas differs greatly from the Tropic shale at the type locality. On the Kaiparowits Plateau, as previously described, the Tropic shale was in essence a more or less uniform marine shale. The sequence of carbonaceous shale, coal, and sandstone which underlie marine fossils were included in the Dakota formation. In the middle area the lower half of the Tropic formation is interbedded sandstone, shale, lignite, and coal, and the upper part of the formation is the typical drab gray, marine shale of the Kaiparowits Plateau. In the western area the Tropic formation is an apparent unsystematic sequence of sandstone, shale, lignite, and coal with the lignite and coal especially abundant in the lower 500 feet of the Tropic formation which includes almost the entire Tropic section.

Bissell (1954, p. 67-68) recognized this difficulty. He sought to solve it by restricting the Dakota formation to the basal conglomerate bed of the Cretaceous sequence, and introducing a lower Tropic shale unit and a lower Tropic sandstone unit between the Dakota formation and the Tropic shale. He justified the new divisions because the coal-bearing sequence contains fossils of Late Cretaceous age and the type Dakota group is of Early Cretaceous age. Therefore, he reasoned the coal-bearing sequence should not be included in the Dakota formation. Also the coal-bearing sequence indicates a terrestrial environment of deposition and so should not be included with the overlying marine Tropic shale.

It seems more plausible to the writer to include the coal-bearing sequence in the Dakota formation, as was done on the Kaiparowits

Plateau, and to restrict the Tropic formation to the overlying marine shale. This procedure would not further complicate the nomenclature and would keep the Dakota formation and the Tropic formation lithologically similar throughout. The Dakota formation was deposited as the Late Cretaceous sea transgressed westward. Therefore, the Dakota formation can be expected to be of a time transgressive nature with deposits in south-central and southwestern Utah not being the chronologic equivalent of the type Dakota group in Nebraska. The Tropic formation thins and wedges out to the west, while the Dakota formation rapidly increases in thickness to the west.

Straight Cliffs and Wahweap sandstones.--The Straight Cliffs sandstone and the Wahweap sandstone are found in all three areas of the southern region. In the western area they are undifferentiated, and in the middle area they are undifferentiated by Gregory (1950b, p. 107 and 1951, p. 34) but differentiated by Cashion (1961). The Straight Cliffs sandstone of the Kaiparowits Plateau has workable beds of coal which are absent in both the western and middle areas. Cashion (1961) suggests that the Straight Cliffs sandstone of the middle area was deposited before the Straight Cliffs sandstone on the Kaiparowits Plateau. The Wahweap sandstone shows a facies change from inland deposits in the west to littoral marine sandstones in the east.

On the Kaiparowits Plateau, where both the Tropic shale and the Straight Cliffs sandstone were originally defined, Gregory and Moore (1931, p. 100) placed the top of the Tropic shale and the base of the Straight Cliffs sandstone at the bottom of the transition zone between shale and sandstone. This criterion was not used by Gregory (1950b, p. 46) as he arbitrarily distinguished the Straight Cliffs sandstone from the Tropic shale in the western area. In the middle area the gray marine shale typical of the Tropic shale is found only in the upper part of the formation, and in the western area this shale is rarely as much as 100 feet thick. Sections show that it is generally very thin or absent, being replaced by interbedded sandstone and shale. If the original definition (Gregory and Moore, 1931, p. 100) of the Tropic shale and the Straight Cliffs sandstone was followed in the western area, the Tropic shale would be present only in a thin stratum or not present at all. The Straight Cliffs sandstone would be of a time transgressive nature and would be thicker due to the addition of strata previously grouped into the Tropic formation. In localities where the Tropic formation was absent there would be the new difficulty of where to place the contact between the Dakota formation and the overlying Straight Cliffs sandstone. Perhaps this boundary could be drawn at the top of the highest coal bed in the Dakota formation.

Kaiparowits formation.--The Kaiparowits formation is present in all three areas of the southern region. It varies little in lithology but the thickness differs greatly, being approximately 265 to 1,200 feet thick in the western area, 530 to 750 feet thick in the middle area, and 2,000 feet thick in the eastern area. This variation in thickness is probably, in large part, due to unconformities which enclose the formation and the mode of deposition by streams and rivers and in small fresh-water lakes and ponds.

Wasatch formation.--The Wasatch formation is represented in all of the three southern Utah areas. In the eastern and middle areas as well as the western edge of the Markagunt Plateau this unit is known as the Wasatch formation, but it is termed the Claron formation in the

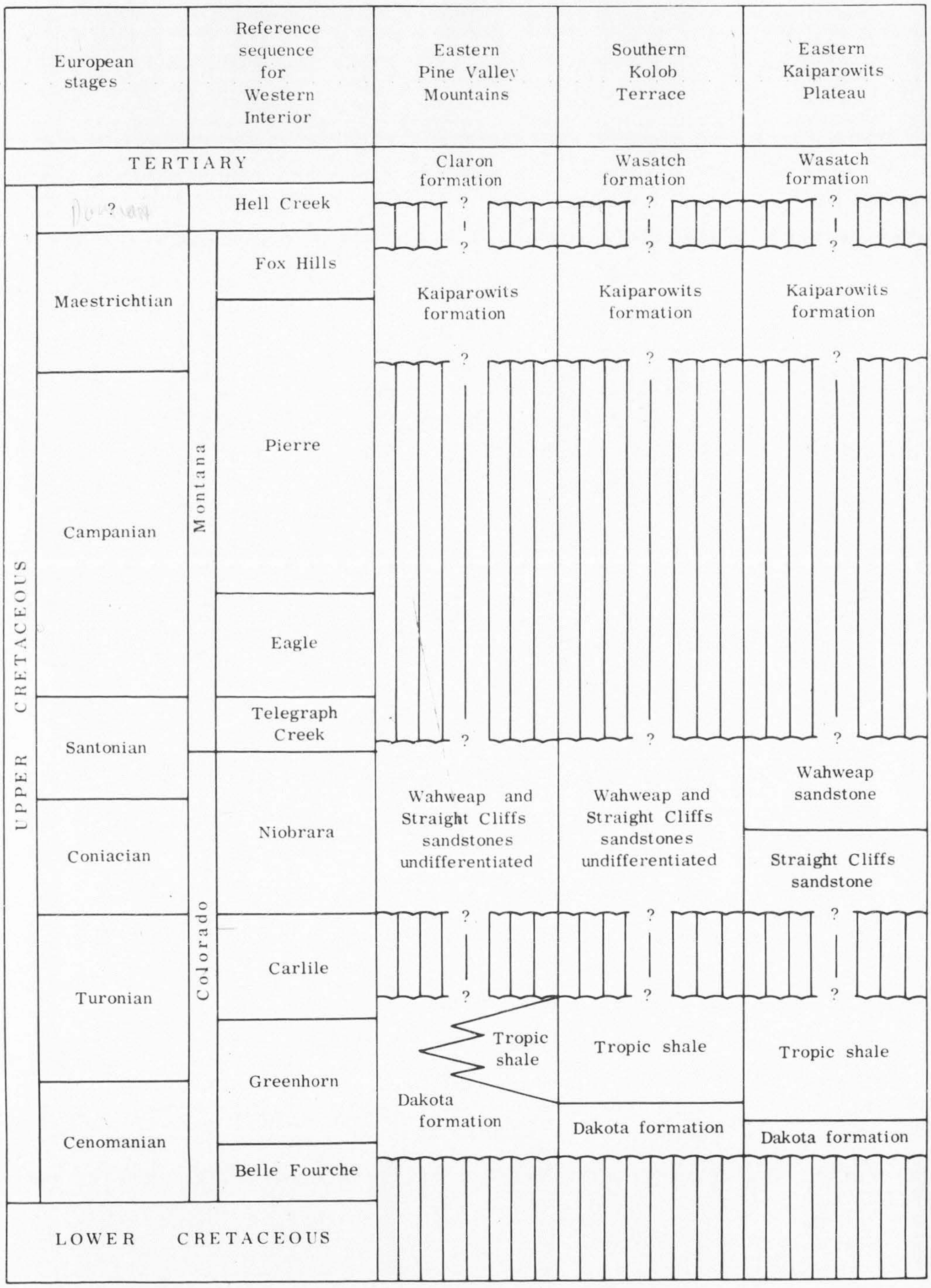

Figure 2. Correlation of Upper Cretaceous stratigraphic units of the southern region.

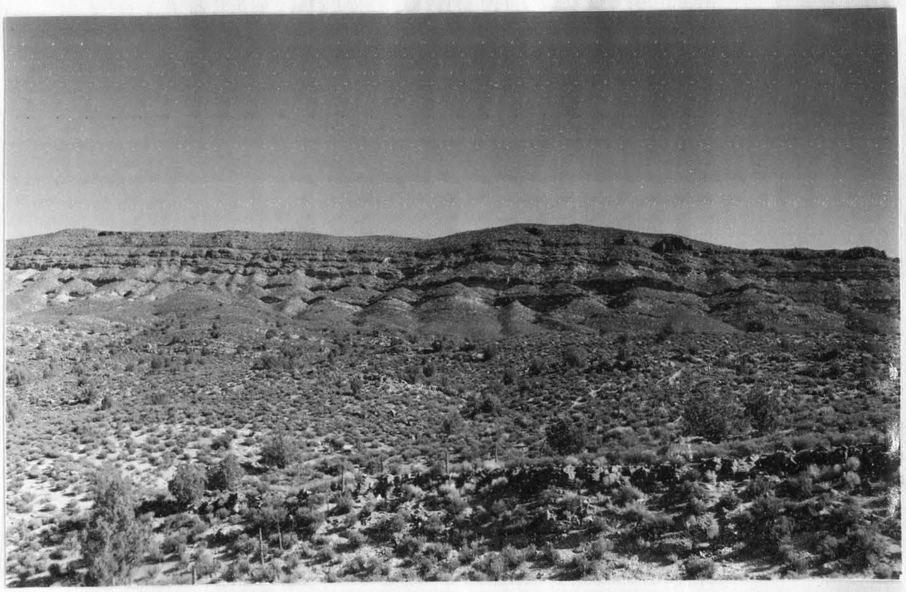

Plate 1-A. Upper part of section of Cretaceous rocks undifferentiated west of Gunlock, Utah. The Claron formation outcrops at the top of the hill in the background.

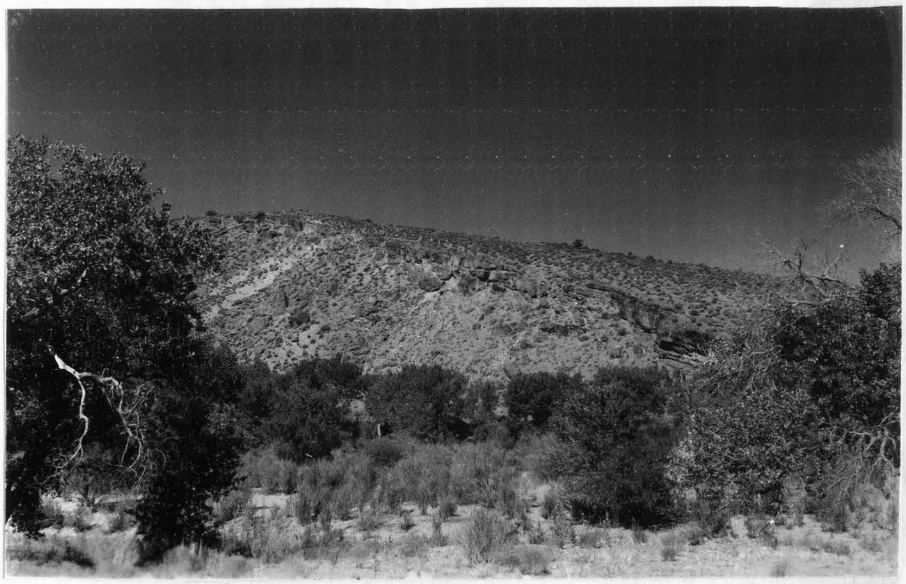

Plate 1-B. Lower part of section of Cretaceous rocks undifferentiated south of Gunlock, Utah. The ledge of resistant sandstone and conglomerate is the base of the Upper Cretaceous section. The underlying nonresistant strata is the Entrada sandstone of Jurassic age.

Plate 2. Jurassic and lower Upper Cretaceous rocks in the eastern Pine Valley Mountains west of Pintura, Utah. The Carmel formation, outcropping on the bare slope in the lower right corner, is overlain by the Entrada sandstone. The base of the Dakota formation lies approximately one-third the way up the slope on the left. The sandstone exposed in the upper left is assigned to the Tropic formation by Cook (1957).

Plate 3. Lower Upper Cretaceous and Jurassic rocks west of Orderville, Utah. Coal-bearing beds assigned to the lower part of the Tropic formation and the Dakota formation by Gregory (1950b) are exposed on the upper half of the hill in the background. The contact between the Dakota formation of Late Cretaceous age and the Winsor formation of Jurassic age is at the line of color change in the middle of the hill.

Pine Valley Mountains. The lithology is similar in the three areas and variations in thickness are attributed largely to the unconformity beneath the formation and recent erosion.

Central Region

General statement

In central Utah rocks of Late Cretaceous age are widely exposed. They crop out on the Gunnison Plateau, in the Cedar Hills, and on the Wasatch Plateau. East of the Wasatch Plateau, Upper Cretaceous rocks are continuous from Castle Valley eastward along the Book Cliffs into western Colorado. In this paper the rocks of central Utah will be discussed under two headings: the western area and the eastern area. The western area is the vicinity of the Sanpete Valley, thus including the Gunnison Plateau, the Cedar Hills, and the western Wasatch Plateau. The eastern area is defined as the northern Castle Valley vicinity which includes the northeastern Wasatch Plateau and the western Book Cliffs.

Western area

The geology of the Gunnison Plateau has been discussed by Hardy and Zeller (1953), Hunt (1954), Hays (1960), and Thomas (1960), and the geology of the Cedar Hills has been discussed by Schoff (1951). Most of the nomenclature used in the western area was developed by Spieker (1946), who studied the geology of the Wasatch Plateau. On the western Wasatch Plateau seven formations of Late Cretaceous age and one formation of Late Cretaceous and Tertiary age are recognized. These formations are, in ascending order: the Sanpete formation, the

Allen Valley shale, the Funk Valley formation, and the Sixmile Canyon formation, all of which belong to the Indianola group, overlain by the Blackhawk formation, the Castlegate sandstone, the Price River formation, and the North Horn formation.

The Indianola group was named by Spieker (1946, p. 127) for exposures in the Indianola district, which lies between the Cedar Hills and the northern Wasatch Plateau in central Utah. Between Salina and Manti on the west flank of the Wasatch Plateau the Indianola group is subdivided into the Sanpete formation, the Allen Valley shale, the Funk Valley formation, and the Sixmile Canyon formation, in ascending order. At all other localities where the Indianola group is known, including the type locality, it is not consistently possible to differentiate it into formations. The Indianola group undifferentiated crops out in the northern Wasatch Plateau, the Cedar Hills, and the Gunnison Plateau. In these localities it is a thick assemblage of conglomerate, sandstone, shale, and minor amounts of limestone. This unit is of both marine and terrestrial origin. In the Salina area the Indianola group overlies the Morrison (?) formation. With the exception of this area, the Indianola group overlies the Arapien shale although beds of equivalent age to the Morrison (?) formation (Late Jurassic to Early Cretaceous) may be present locally at its base (Spieker, 1946, p. 125). Schoff (1951, p. 625) measured an "uncertain" 14,700 feet of Indianola group in the Cedar Hills, which is one of the thickest Cretaceous sections in the Western Interior. Just to the east of the Cedar Hills, north of Indianola, Spieker (1946, p. 129) estimates between 7,000 and 8,000 feet of Indianola group but his section may be incomplete. In the Gunnison Plateau this unit has a maximum thickness of 8,557 feet (Thomas, 1960, p. 35) although strata correlative to the Blackhawk formation of the Wasatch Plateau are probably included in the upper part of the unit.

Sanpete formation.--The Sanpete formation was named by Spieker (1946, p. 127) for outcrops just east of Sanpete Valley near Manti, Utah. This formation is the basal unit of the Indianola group and, as such, it is the oldest formation of Late Cretaceous age in the western area. Possibly beds of Early Cretaceous age are also present, since the age of the lower Sanpete formation has not been precisely determined (Cobban and Reeside, 1952a, p. 1028). The contact of the Sanpete formation with the underlying Morrison (?) formation is indefinite and appears gradational. This caused Spieker (1946, p. 125) to arbitrarily place the contact between the two formations at the point of greatest color change from the colored rocks of the Morrison (?) formation to the buff and gray rocks of the Sanpete formation. Upward, the Sanpete formation grades into the Allen Valley shale. Outcrops of the resistant Sanpete formation are found just south of Manti. Equivalent beds are found where the Indianola group is undifferentiated. The dominant lithology of the Sanpete formation is brown, yellowish-brown, and gray sandstones and shales, with gray conglomerate in the lower part. It was deposited in an inland environment. At Salina Canyon, the only place where this unit can be completely measured, it is approximately 1,350 feet thick (Spieker, 1946, p. 127).

Allen Valley shale.--The type locality of the Allen Valley shale is at Allen Valley, which is located just southwest of Manti, Utah. There Spieker (1946, p. 127) assigned the name Allen Valley shale to 620 feet of evenly bedded gray shale with subordinate interbedded bentonite, siltstone, fine-grained sandstone, and gray limestone. The only other place this formation is recognizable as a unit, other than the type locality, is in Salina Canyon where it is 850 feet thick. Although the Allen Valley shale appears conformable with the overlying Funk Valley formation, Cobban and Reeside (1952a, p. 1028) infer a hiatus between the two formations on the basis of faunal evidence. The lower contact of the Allen Valley shale with the Sanpete formation is gradational. The fossil Collignoniceras woolgari of early Carlile age is present in the Allen Valley shale according to Katich (1953, p. 858). Green (1959, p. 37), who studied the microfauna of the Allen Valley shale, reports that at the type locality the lower two-thirds of the formation are of Greenhorn age and the upper one-third is of early Carlile age.

Funk Valley formation.--The name and type locality of the Funk Valley formation were designated by Spieker (1946, p. 128) for outcrops surrounding Funk Valley, which is 3 to 4 miles southwest of Manti, Utah. The lithology there is described by Spieker (1946, p. 128) as follows:

> At the type locality the formation consists of three clearly separable members: (1) a basal series of sandstones with thin interbedded shale, about 900 feet thick; (2) a middle unit of gray marine shale, 650 feet thick; and (3) an upper sandstone 700 feet thick. The sandstones range in color from white through cream and buff to brown.

The middle shale unit is dated as early Niobrara age by the presence of Inoceramus deformis (Katich, 1953, p. 858). The microfauna support this age assignment according to Glissmeyer (1959, p. 25). The Funk Valley formation is probably more widespread than other formations of the Indianola group. Rocks equivalent to the Funk Valley formation make up a large part of the Indianola group undifferentiated.

Sixmile Canyon formation.--The youngest formation of the Indianola group was named the Sixmile Canyon formation by Spieker (1946, p. 128). Although equivalent strata are probably present in the Indianola group undifferentiated, the only place the Sixmile Canyon formation has been recognized is at the type locality in Sixmile Canyon just southwest of Manti, Utah. There this unit is approximately 2,725 feet thick. At Sixmile Canyon Spieker (1946, p. 128) recognized three members in this formation: (1) a lower gray conglomeratic sandstone; (2) a middle sequence of gray to white, fine-grained sandstone, carbonaceous shale and coal; and (3) an upper conglomerate and conglomeratic sandstone. The Sixmile Canyon formation conformably overlies the Funk Valley formation. Spieker (1946, p. 128) regards this unit as Colorado in age on the basis of fossil plants and mollusks. By stratigraphic position this unit is of middle and late Niobrara age.

Blackhawk formation.--The Blackhawk formation received its name from exposures near the Blackhawk (King No. 1) mine on the eastern edge of the Wasatch Plateau near Hiawatha, Utah (Spieker and Reeside, 1925, p. 442-443). It is partially exposed on the western Wasatch Plateau east of Mount Pleasant, south of Manti, and in Salina Canyon (Spieker, 1946, p. 130). In each case the base is not exposed and relationships with underlying units are uncertain. Pashley (1956, p. 12) gives the thickness of the Blackhawk formation on the western Wasatch Plateau as 1,953 feet by combining well and surface data. The Blackhawk formation is apparently absent in the Cedar Hills, probably due to pre-Castlegate erosion, but coeval strata likely are present in the upper part of the Indianola group on the northern Gunnison Plateau

(Hays, 1960, p. 98). Spieker (1949a, p. 23) describes the Blackhawk formation of the western Wasatch Plateau as being very similar to the Blackhawk formation of the Castle Valley area. As such, it is a sequence of fine-grained to medium-grained sandstone with interbedded shale and coal. It is probably of Eagle age (Hale, 1960a, p. 133-134).

Castlegate and Price River formations undifferentiated.--Spieker and Reeside (1925, p. 445) defined the Price River formation for exposures in Price River Canyon above Castlegate, Utah. It was divided into two members at the type locality by Clark (1928, p. 20 and 119), who named the lower member the Castlegate sandstone. The Castlegate sandstone has since been treated as a formation in the Book Cliffs of Utah by Fisher, Erdmann, and Reeside (1960, p. 13-14). Although the Castlegate sandstone is discernible from the overlying Price River formation in the eastern area, it is not consistently possible to differentiate the two units in the western area. Accordingly, the two units are discussed under a single heading in the western area. The Castlegate and Price River formations undifferentiated crop out on the Gunnison Plateau, the Cedar Hills, and the western Wasatch Plateau. Only on the western Wasatch Plateau has the Castlegate sandstone been definitely distinguished. However, the South Flat formation as defined by Thomas (1960, p. 47) on the northern Gunnison Plateau is probably correlative to the Castlegate sandstone.

The lithology of the Castlegate and Price River formations undifferentiated are variable. In general the tendency is to progress from coarser clastics in the west to finer clastics in the east. They consist of medium-grained to coarse-grained sandstone with minor conglomerate and shale at the type locality, but on the northwestern

Wasatch Plateau, Spieker (1946, p. 132) reports these units are red to gray conglomerate. In the Cedar Hills, according to Schoff (1951, p. 627), the Castlegate and Price River formations undifferentiated are essentially a massive red conglomerate with a red and gray matrix, and on the Gunnison Plateau, Hardy and Zeller (1953, p. 1267) found these units to be dominantly a gray conglomerate with subordinate medium-grained to coarse-grained sandstone lenses.

In the western area the Castlegate sandstone has an angular unconformity at its base and thus overlies different older formations. On the Wasatch Plateau the Price River formation grades upward and intertongues with the overlying North Horn formation (Spieker, 1946, p. 130). Schoff (1951, p. 629-630) reports a similar contact in the Cedar Hills. However, on the west-central part of the Gunnison Plateau, Hardy and Zeller (1953, p. 1268) have found angular discordance between the two formations.

Thicknesses given for the Castlegate and Price River formations in the western area have a great range. On the western slope of the Wasatch Plateau Pashley (1956, p. 12) reports 583 feet for the Castlegate sandstone and 248 feet for the Price River formation. In the northwestern Wasatch Plateau Spieker (1946, p. 132) estimated 1,000 to 2,000 feet for the thickness of the undifferentiated units. In the Cedar Hills these formations range from 134 to 1,000 feet thick according to Schoff (1951, p. 628), and in the west-central Gunnison Plateau Hardy and Zeller (1953, p. 1268) assigned a maximum of 1,800 feet of strata to these formations.

The age of the Castlegate and Price River formations undifferentiated is probably late Montana. In the western area these units were deposited in an inland environment. The conglomerates reflect the early Laramide orogeny during Montana time (Schoff, 1951, p. 628).

North Horn formation.--Strata formerly classified as the lower member of the Wasatch formation in central Utah have been designated the North Horn formation by Spieker (1946, p. 132). The type locality for this formation is at North Horn Mountain on the east-central part of the Wasatch Plateau. The North Horn formation extends throughout the western area and into the western Book Cliffs. Variegated shale and sandstone, conglomerate, and fresh-water limestone are the lithology of this unit. The shales are red, gray, or black with interbedded buff or gray sandstone and minor amounts of limestone and conglomerate. Thick beds of conglomerate are found in the Cedar Hills and the Gunnison Plateau. Spieker (1946, p. 133) divided this formation into four units which are present throughout the central part of the Wasatch Plateau, but which are not identifiable, or identifiable only in part, at other localities.

At all places where the North Horn and Price River formations are present, except the Gunnison Plateau, the North Horn formation grades downward into the Price River formation. It likewise grades upward into the Tertiary Flagstaff limestone except locally on the western Wasatch Plateau. The North Horn formation generally thickens north and east from the Wasatch Plateau and thins to the west. In the western area it is highly variable in thickness. It is 1,650 feet thick at the type locality, between 1,650 feet and 6,700 feet thick in the Cedar Hills (Schoff, 1951, p. 629), and from 0 to 500 feet thick on the Gunnison Plateau (Hardy and Zeller, 1953, p. 1270).

Plant leaves, fresh-water invertebrates, dinosaur and mammal bones are found in the North Horn formation. Spieker (1946, p. 135) reports dinosaur bones from the lower 500 feet of the formation. On this basis, he concludes that the Cretaceous-Tertiary boundary lies within the North Horn formation, and that this formation is of latest Cretaceous and earliest Tertiary age. Previous to this time, strata now assigned to the North Horn formation were grouped with the Wasatch formation and were considered to be of early Tertiary age. North Horn strata were deposited during rapidly shifting fluviatile and lacustrine conditions. Flood-plain, channel, and fresh-water lake deposits are recognized in this unit (Spieker, 1946, p. 133).

Eastern area

Rocks of Late Cretaceous age in the vicinity of Castle Valley have received much attention from geologists. Numerous coal beds caused much early economic interest, and in more recent years, scientific interest has been caused by the intertonguing relationships demonstrated there and throughout the Book Cliffs. Local nomenclature was largely developed by Spieker and Reeside (1925) and Clark (1928). Additional geologic information is found in Lupton (1916), Spieker (1931, 1946, 1949a, and 1949b), Katich (1953 and 1954), Davis (1954), Young (1955), Hale (1959), and Fisher, Erdmann, and Reeside (1960). In the Castle Valley area the Mancos shale with a small thickness of Dakota formation at its base forms valleys, and the overlying resistant Mesaverde group and North Horn formation, predominantly sandstone, form steep escarpments.

In Castle Valley the Mancos shale is exposed along most of the valley bottom. Spieker (1931, p. 18) estimates its thickness as greater than 5,000 feet. The Mancos shale gradationally overlies the Dakota formation and underlies and intertongues to the west with the sandstones of the Mesaverde group. It is divided into five members, which are in ascending order, the Tununk shale, the Ferron sandstone, the Blue Gate shale, the Emery sandstone, and the Masuk shale. The Ferron sandstone and the Emery sandstone are sandstone tongues, probably of the Indianola group of the western Wasatch Plateau, that project and thin eastward into the main body of Mancos shale.

The Mesaverde group of the eastern Wasatch Plateau and the western Book Cliffs form the prominent escarpment that partly surrounds northern Castle Valley. It is composed of four formations: the Star Point sandstone, the Blackhawk formation, the Castlegate sandstone, and the Price River formation, in ascending order. Young (1955, p. 182) did not use the term Mesaverde group, but used the formation names in his paper on the Book Cliffs. However, later workers, including Hale (1959, p. 58) and Fisher, Erdmann, and Reeside (1960, p. 9-11), chose to retain the term Mesaverde group in their classification of strata in the Book Cliffs.

Dakota formation.--As previously stated in the discussion of the southern region, the Dakota group was named by Meek and Hayden (1861, p. 419) for the basal Cretaceous sequence of sandstones, clays, and lignite in the Missouri Valley of northeastern Nebraska. In the eastern area the Dakota formation is exposed at the Farnham anticline and southwestward along the west flank of the San Rafael Swell. There the Dakota formation consists of lenticular sandstone and conglomerate with interbedded shale and coal. The dominant sandstone is light gray to yellowish brown, medium grained to coarse grained and often cross bedded. The outcrop is generally resistant and ranges between 0 to 60 feet thick with most exposures being less than 30 feet thick. The Dakota formation in this locality overlies the Cedar Mountain formation of Early Cretaceous age. The contact is probably unconformable. Equivocal evidence shows the Dakota formation to be of Early Cretaceous and Late Cretaceous age. Katich (1951, p. 2093-2094) reports an Early Cretaceous fossil, *Inoceramus comancheanus* Cragin, from the Dakota formation. Fisher, Erdmann, and Reeside (1960, p. 25-26) present floral and faunal evidence that indicates a Late Cretaceous age. The writer tentatively assigns the Dakota formation of the Castle Valley area to an Early Cretaceous age on the basis of correlation with the Dakota formation of the western Uinta Basin.

Tununk shale.--The Tununk shale was defined by Gilbert (1877, p. 4) for exposures on the Tununk Plateau northwest of the Henry Mountains. This unit is the oldest member of the Mancos shale in Castle Valley and was called the lower Mancos shale member until Spieker (1949a, p. 59) introduced the term Tununk shale from the Henry Mountains. The Tununk shale is a soft, dark blue-gray to gray, silty shale that is sandy at the bottom and top. It outcrops along the eastern edge of Castle Valley, near the west flank of the San Rafael Swell, where it thickens from 400 feet at the Farnham anticline to 650 feet near the south end of the valley (Katich, 1954, p. 46). It forms gentle slopes above the Dakota formation and below the resistant Ferron sandstone. The age of the Tununk shale is early Greenhorn in the lower part and early Carlile in the upper part according to Hale (1960a, p. 134) who cites Katich (personal communication) as a reference.

Ferron sandstone.--Lupton (1916, p. 31) first used the name Ferron sandstone for well-developed exposures in the vicinity of Ferron, Utah. Katich (1953) and Davis (1954) have made detailed studies of the unit. The resistant Ferron sandstone forms a continuous southwest trending escarpment from the Farnham anticline to the south end of Castle Valley. It thickens along this outcrop from about 75 feet at the north end to near 800 feet at the south end.

The Ferron sandstone is composed of gray to brown, fine-grained to medium-grained, massive sandstone with interbedded gray shale, thin bentonite beds, and locally carbonaceous shale and coal. Coal of economic value is found in the outcrop south of Emery, Utah. North of this point, coal beds become scarce and are lacking at the Farnham anticline. Sandstone of a typical white color is found beneath the coal beds in the Ferron sandstone, as it is found beneath most of the Upper Cretaceous coal beds in Utah. The Ferron sandstone has a gradational bottom with the overlying Blue Gate shale that is conformable but sharp.

The Ferron sandstone was deposited in a variety of different environments. Strata at the Farnham anticline indicate deposition in a littoral marine environment; to the southwest and west a lagoonal, paludal, and inland environment. Katich (1951, p. 2093-2094) reports the fossils Collignoniceras hyatti Stanton and Prionocyclus wyomingensis from the Ferron sandstone that indicate an early and middle Carlile age.

Blue Gate shale.--The Blue Gate shale was defined by Gilbert (1877, p. 4) for exposures on the Blue Gate Plateau northwest of the Henry Mountains. In Castle Valley, where erosion of this soft unit has formed most of the valley bottom, it is sometimes called the middle shale member of the Mancos shale. It is a west and southwest projecting shale tongue which separates the Ferron and Emery sandstones. Thickness ranges from 1,650 feet at the southwest end of Castle Valley to 2,400 feet at the north end (Spieker, 1931, p. 20). Although it is a lighter color and more arenaceous, the Blue Gate shale has a similar lithology to the older Tununk shale. It is a light blue-gray, soft, marine shale with many thin sandy beds. In northern Castle Valley it contains a thicker sandstone bed, the Garley Canyon sandstone, which is lenticular at the outcrop. The Blue Gate shale contains the index fossil *Inoceramus deformis* of Niobrara age according to Katich (1953, p. 858).

Emery sandstone.--The Emery sandstone was named by Spieker and Reeside (1925, p. 439) for exposures near Emery, Utah, where this member of the Mancos shale is best developed. It is exposed as a step-like cliff below the main cliffs of the eastern Wasatch Plateau. At the type locality it is 800 feet thick and along the outcrop it thickens to the south and thins and breaks into two sandstone tongues to the north (Spieker and Reeside, 1925, p. 439). An isopachous map of the Emery sandstone by Hale (1959, p. 59) shows this unit thickens rapidly westward. Hale (1959, p. 58) also reports a change from paludal to offshore sandstone deposits that corresponds to the thickness change from west to east. He indicates a Telegraph Creek and early Eagle age for this member.

Masuk shale.--This uppermost member of the Mancos shale in Castle Valley was named by Gilbert (1877, p. 4) for exposures on the Masuk Plateau of the Henry Mountains. It erodes to a slope at the base of the east edge of the Wasatch Plateau. Spieker (1931, p. 20) reports a thickness of 1,000 feet on the northern front of the eastern Wasatch Plateau, 1,100 feet on the central front, and 300 feet at the extreme south end. According to Hale (1959, p. 58), evidence from wells shows this member to wedge out rapidly to the west to a zero point in the central part of the Wasatch Plateau. This shale tongue separates and is gradational with the underlying Emery sandstone and the overlying Star Point sandstone. The Masuk shale, which is a blue-gray, soft, marine shale with some sandy beds, is similar in lithology to the Blue Gate and Tununk shale tongues. Hale (1960a, p. 133) indicates this unit to be of Eagle age.

Star Point sandstone.--This formation was defined by Spieker and Reeside (1925, p. 442-443) as the basal formation of the Mesaverde group in the eastern Wasatch Plateau where its thickness ranges from 200 to 450 feet. At the type locality at Star Point southwest of Price, Utah, this unit encompasses three prominent sandstone beds which thicken rapidly to the west. To the east in the western Book Cliffs, these sandstone beds split to form three sandstone tongues that extend and wedge out into the Mancos shale. Clark (1928, p. 17) has named these sandstone tongues the Panther tongue, the Storrs tongue, and the Spring Canyon tongue, in ascending order. The sandstone tongues are separated by intertonguing masses of Mancos shale that wedge out to the west. Each sandstone tongue characteristically has a sharply defined top and a bottom that grades into the underlying shale. The Star Point sandstone as a unit consists of brown, buff, gray, or white, fine-grained to medium-grained, massive, cross-bedded, or thin-bedded sandstone. Hale (1960a, p. 133) regards the Star Point sandstone as Eagle age.

Blackhawk formation.--This formation of the Mesaverde group was defined by Spieker and Reeside (1925, p. 442-443) for exposures near the Blackhawk (King No. 1) mine on the eastern edge of the Wasatch Plateau near Hiawatha, Utah. In the eastern area the Blackhawk formation forms slopes that are distinguishable from the steep escarpments of the underlying Star Point sandstone and the overlying Castlegate sandstone. Gray or buff, fine-grained to medium-grained sandstone with interbedded shale, arenaceous and carbonaceous shale, and coal characterize the Blackhawk formation at this locality. White-capped sandstone beds with sharply defined tops generally underlie coal beds. The Blackhawk formation is gradational with the underlying Star Point sandstone and the contact between the two formations at the type locality was defined by Spieker and Reeside (1925, p. 444) as the lowest coal bed in the Blackhawk formation. They report a thickness for this unit of 750 to 900 feet, but Spieker (1949b, p. 59) increased this range from 700 to 1,500 feet.

In general, near the type locality the lower part of this formation contains carbonaceous beds, and in the upper part these beds are scarce or lacking. This coupled with fresh-water and brackish-water invertebrates and fossil plants suggests a lagoonal and paludal type of deposition for the lower part of the formation and an inland, flood plain type of deposition for the upper part. To the east in the Book Cliffs, the Blackhawk formation undergoes a facies change to littoral marine sandstone tongues, similar to those of the underlying Star Point sandstone, that intertongue and wedge out into the Mancos shale.

In the western Book Cliffs the most prominent tongue is the basal tongue which is 100 to 200 feet thick. It was named the Aberdeen sandstone member of the Blackhawk formation by Clark (1928, p. 18). Farther to the east in the Book Cliffs, Young (1955, p. 183) recognized four additional younger littoral marine sandstone tongues in the Blackhawk formation and also reclassified the Spring Canyon tongue of the Star Point sandstone to the basal member of the Blackhawk formation. This classification is not feasible in the eastern Wasatch Plateau because there the Spring Canyon tongue merges with the Storrs and Panther tongues of the Star Point sandstone. Hale (1960a, p. 133-134) suggests an Eagle age for the Blackhawk formation on the basis of correlation with stratigraphic units in western Colorado.

Castlegate sandstone.--The Castlegate sandstone was defined by Clark (1928, p. 20 and 119) as the lower of two members of the Price River formation. It was treated as a formation by Fisher, Erdmann, and Reeside (1960, p. 13-14), who restricted the Price River formation to the overlying upper member. In the eastern area the Castlegate sandstone ranges from 150 to 500 feet thick. At the type locality in Price River Canyon it is 400 feet thick (Clark, 1928, p. 119). It is composed of massive, medium-grained to coarse-grained sandstone that characteristically forms a cliff. Lenses of conglomerate are common. At the contact between the Castlegate sandstone and the underlying Blackhawk formation, a distinct lithologic change occurs from coarse sediments in the upper unit to fine sediments in the lower unit. Spieker (1946, p. 130) interpreted this contact to be disconformable. The upper contact of the Castlegate sandstone is gradational. The type of sediments suggest a fluviatile origin for the Castlegate sandstone at the type locality. To the east it forms a single littoral marine sandstone tongue that extends into the Mancos shale. The few fossils that have been collected from this unit do not give an exact age assignment according to Fisher, Erdmann, and Reeside (1960, p. 31). Hale (1960, p. 133-134) dates it as early Pierre on the basis of correlation with stratigraphic units in western Colorado.

Price River formation.--As previously stated in the discussion of west-central Utah, Spieker and Reeside (1925, p. 445) defined the Price River formation for exposures in Price River Canyon above Castlegate, Utah. The Price River formation has since been divided into two formations by Fisher, Erdmann, and Reeside (1960, p. 13-14); the older Castlegate sandstone and the younger Price River formation. The two separate units are used in this paper.

The Price River formation is the uppermost formation of the Mesaverde group. It intertongues with and grades into the overlying North Horn formation. Spieker (1946, p. 131) chose to place the contact at the horizon of greatest change between the sandstones and conglomerates of the Price River formation and the variegated beds of the North Horn formation. The Price River formation does not form cliffs as does the underlying Castlegate sandstone. It is composed of massive, medium-grained to coarse-grained sandstone with interbedded shale and sandy shale. This formation ranges in thickness from 600 to 800 feet thick in the eastern area. To the east it passes through a coal-bearing facies and then to littoral marine sandstone tongues. Few fossils have been found in the Price River formation. However, its age is fixed as Pierre by correlation with strata to the east according to Fisher, Erdmann, and Reeside (1960, p. 32).

North Horn formation.--As previously stated in the discussion of west-central Utah, Spieker (1946, p. 132) defined the North Horn formation for exposures on North Horn Mountain on the east-central part of the Wasatch Plateau. There he divided the formation into four units of alternating fluviatile and lacustrine origin. The formation is composed of red, gray, or black shale with interbedded gray to buff, fine-grained to medium-grained sandstone and minor amounts of fresh-water limestone and conglomerate. The formation is 2,200 to 2,500 feet thick in Price Canyon (Spieker, 1946, p. 133) and thins to the east in the Book Cliffs. It is gradational with both the underlying Price River formation and the overlying Flagstaff limestone. Spieker (1946, p. 133) found it impossible to define a contact between the North Horn formation and the Tertiary Flagstaff limestone in much of the eastern Wasatch Plateau.

Stratigraphic relations

Indianola group and Mancos shale.--In the vicinity of Sanpete Valley the Indianola group is of probable late Early Cretaceous age and Colorado age. Coeval strata to the east in the vicinity of Castle Valley are the Dakota formation, and the Tununk shale, the Ferron sandstone, and the Blue Gate shale members of the Mancos shale. From the Gunnison Plateau, east across the Wasatch Plateau to Castle Valley this section undergoes a rapid facies change from coarse clastics to fine clastics. Spieker (1946, p. 122) correlated the Sanpete formation with the Tununk shale, the Allen Valley shale with the Ferron sandstone, and the Funk Valley and Sixmile Canyon formations with the Blue Gate shale. Katich (1953, p. 858) presented paleontologic evidence that the Allen Valley shale should be correlated with the Tununk shale of Castle Valley and not the Ferron sandstone. On the basis of stratigraphic position he concluded that the Sanpete formation is the time equivalent of the Dakota formation and the lower Tununk shale, and that the lower sandstone beds of the Funk Valley formation are equivalent to the Ferron sandstone. By paleontologic correlation, the shales of the middle Funk Valley formation are equivalent to the lower part of the Blue Gate shale (Katich, 1953, p. 858). The Sixmile Canyon formation is the correlative of the upper part of the Blue Gate shale.

The writer agrees with Katich's (1953) correlation with one exception. Cobban and Reeside (1952a, p. 1028) infer a hiatus between the Allen Valley shale and the Funk Valley formation because the *Prionocyclus wyomingensis* fauna has not been found. Strata equivalent to the Ferron sandstone are apparently absent. A proposed correlation by the author to the Coalville area supports Cobban and Reeside (1952a) and will be discussed later.

The upper members of the Mancos shale in Castle Valley, the Emery sandstone and the Masuk shale, are of early Montana age. Spieker (1946, p. 130) reports that no rocks of this age have been definitely identified on the west side of the Wasatch Plateau. If these strata are absent, it is probably due to erosion rather than non-deposition.

Star Point sandstone.--In the Castle Valley area the Star Point sandstone conformably lies between the Masuk shale and the Blackhawk formation. The relationship of the Star Point sandstone, if present, to enclosing units in the Sanpete Valley area is poorly understood. According to Spieker (1946, p. 130) no coeval strata have been identified on the western side of the Wasatch Plateau. However, deposits correlative to the Star Point sandstone may be present but not exposed. On the northern Gunnison Plateau Hays (1960, p. 43) and Thomas (1960, p. 68) have shown strata correlative to the Blackhawk formation are present in the upper part of the Indianola group. Possibly conformable underlying strata are equivalent to the Star Point sandstone.

Blackhawk formation.--The Blackhawk formation of medial Montana age extends through the Wasatch Plateau and is exposed on the east side and locally on the west side. The lithology is similar in both areas (Spieker, 1946, p. 130). Strata equivalent to the Blackhawk formation appear to be present on the northern Gunnison Plateau. There Hunt (1954, p. 121) defined a new formation, the South Flat formation, as the strata separating the Indianola group and the Price River formation. He correlated the South Flat formation with the Blackhawk formation of the Wasatch Plateau on the basis of stratigraphic position and fragmentary plant fossils from the South Flat formation. A later worker, Thomas (1960, p. 47), redefined Hunt's (1954) South Flat formation to include less strata. Deposits on the northern Gunnison Plateau coeval to the Blackhawk formation should be included as an upper unit of the Indianola group according to Thomas (1960, p. 43) and Hays (1960, p. 68). The redefined South Flat formation is correlated with the Castlegate sandstone.

In the Castle Valley area the Blackhawk formation is conformable with the underlying Star Point sandstone and probably disconformable with the overlying Castlegate sandstone. On the western Wasatch Plateau the base of the Blackhawk formation is not exposed and the relation to underlying units is uncertain, however, it is unconformable with the overlying Price River formation. Strata on the northern

Wasatch Plateau correlative to the Blackhawk formation appear to be conformable with underlying deposits and in angular unconformity with the overlying South Flat formation (Thomas, 1960, p. 20).

Castlegate sandstone and Price River formation.--The relationship of the Castlegate sandstone to the overlying Price River formation has been discussed under both the western and eastern area headings. In the eastern area Fisher, Erdmann, and Reeside (1960, p. 13-14) raised the Castlegate sandstone from a member to a formation status and restricted the Price River formation. In much of the western area the Castlegate sandstone has not been differentiated from the Price River formation.

The Castlegate sandstone and the Price River formation are recognized over a comparatively large area. They extend from the Gunnison Plateau and the Cedar Hills, through the Wasatch Plateau, and east in the Book Cliffs to the Utah-Colorado state line. A facies change occurs from a dominantly conglomerate section in the western outcrops to a medium-grained to coarse-grained sandstone in Price Canyon.

On the northern Gunnison Plateau the South Flat formation of Thomas (1960, p. 47) is probably the westward extension of the Castlegate sandstone. There the South Flat formation is unconformable with the overlying Price River formation (Thomas, 1960, p. 20). An unconformity between the Castlegate sandstone and the Price River formation has not been identified in other areas to the author's knowledge.

North Horn formation.--Although it does not extend as far to the east in the Book Cliffs, the North Horn formation is found over practically the same area as the Price River formation. The North Horn formation differs from the other Upper Cretaceous rocks in central

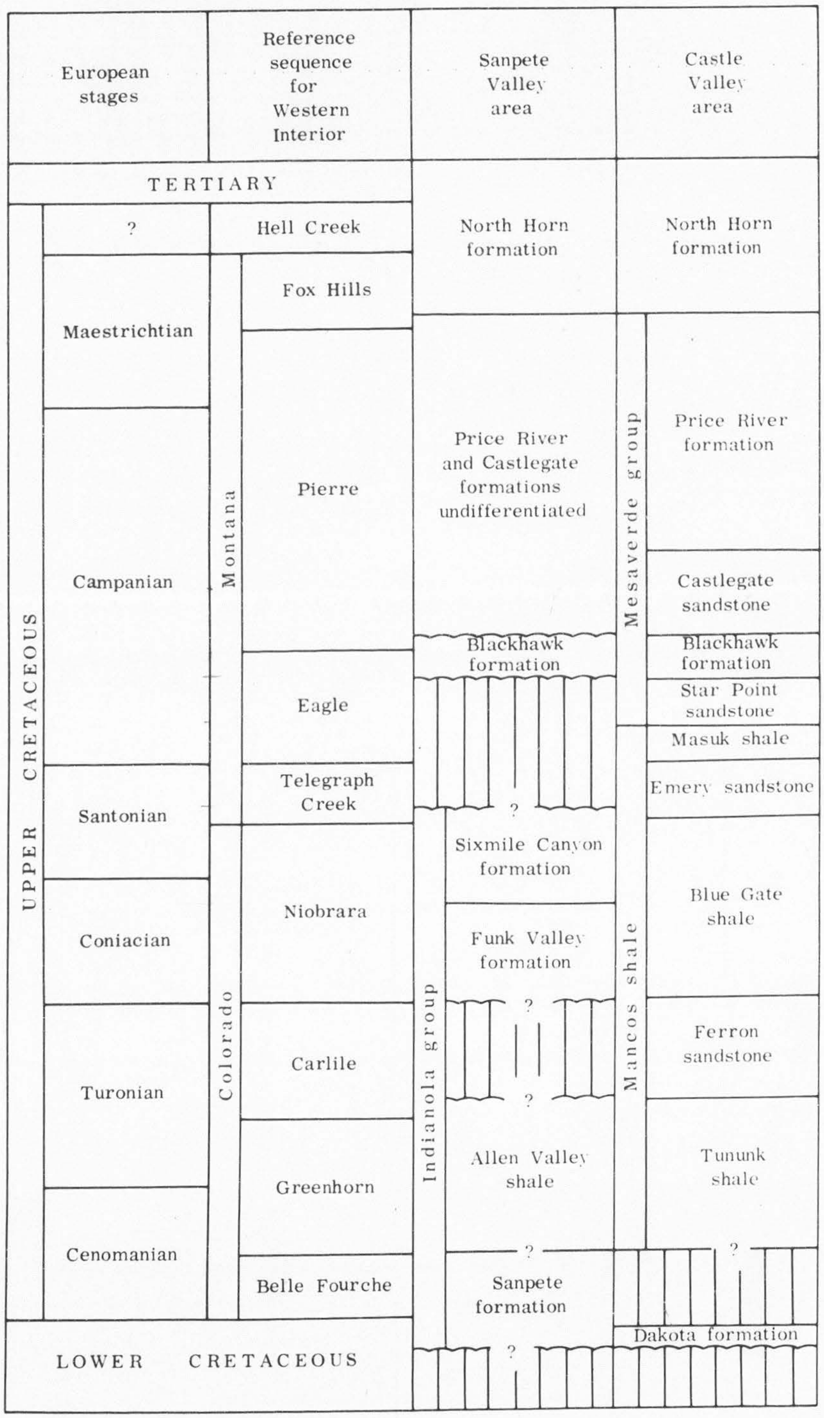

Figure 3. Correlation of Upper Cretaceous stratigraphic units of the central region.

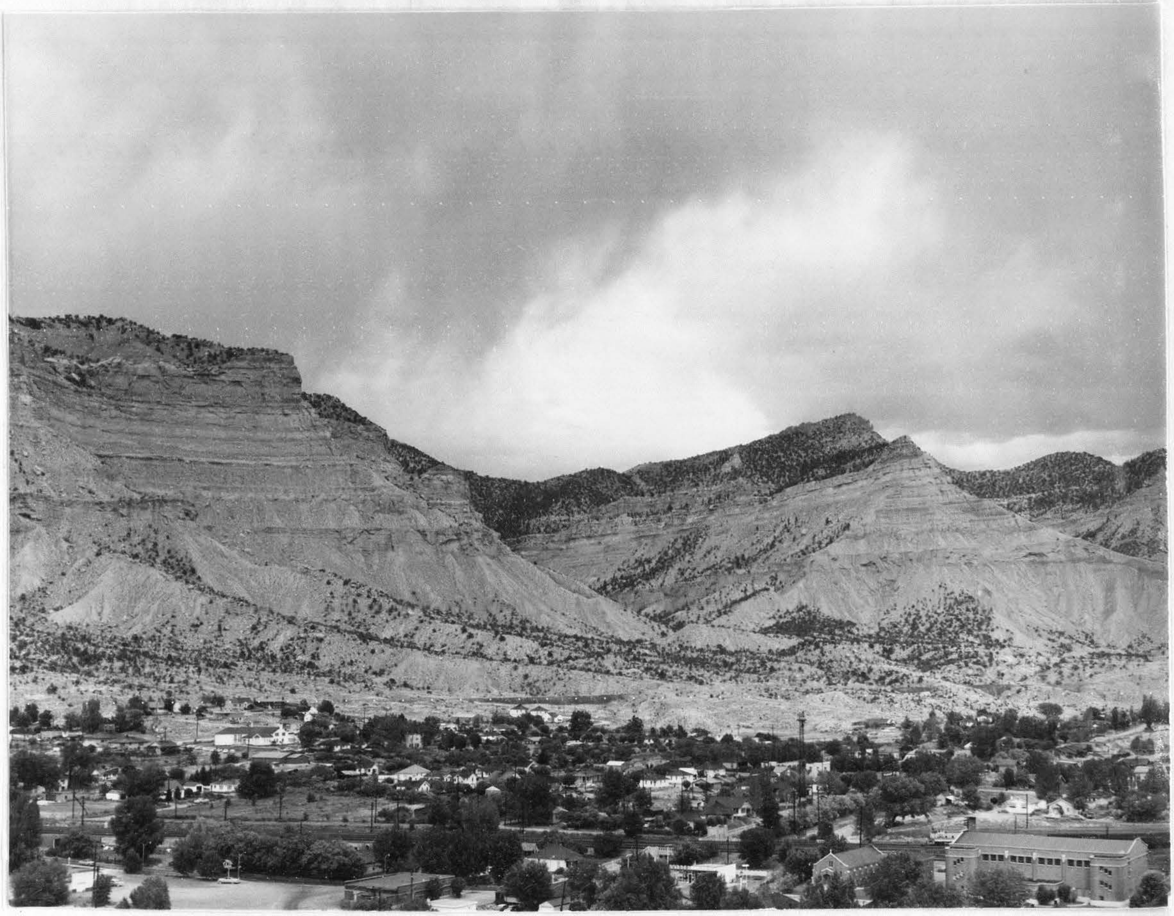

Plate 4. The Masuk shale member of the Mancos shale, Star Point sandstone, and Blackhawk formation northeast of Helper, Utah. The slope forming Masuk shale gradationally underlies the Star Point sandstone. The Blackhawk formation caps the cliffs. Members of the Star Point sandstone are the Panther tongue, lower prominent escarpment, the Storrs tongue, middle escarpment, and the Spring Canyon tongue, upper cliff.

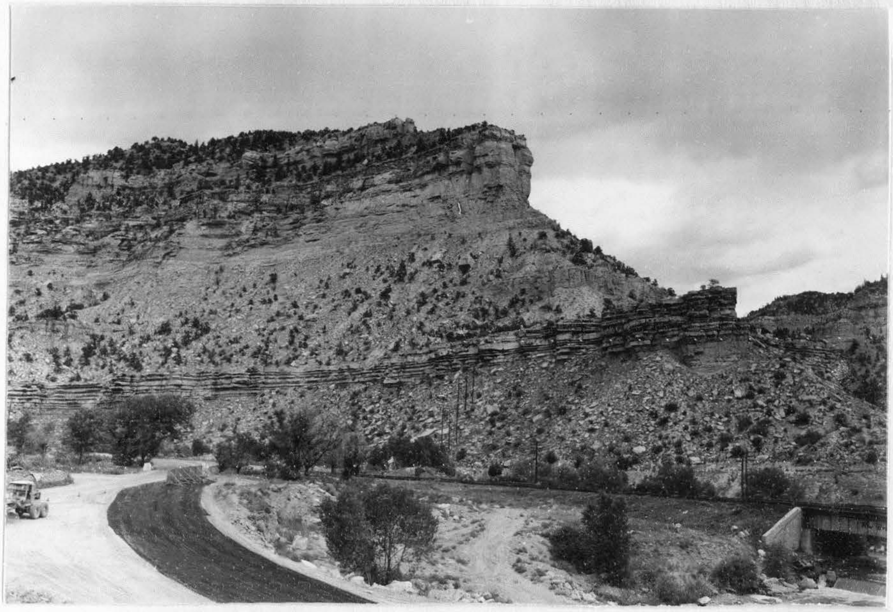

Plate 5-A. The Star Point sandstone in Price River Canyon north of Helper, Utah. The lower prominent sandstone, which wedges out in a northern direction, is the Panther tongue. The middle less-prominent sandstone is the Storrs tongue, and the upper prominent sandstone is the Spring Canyon tongue.

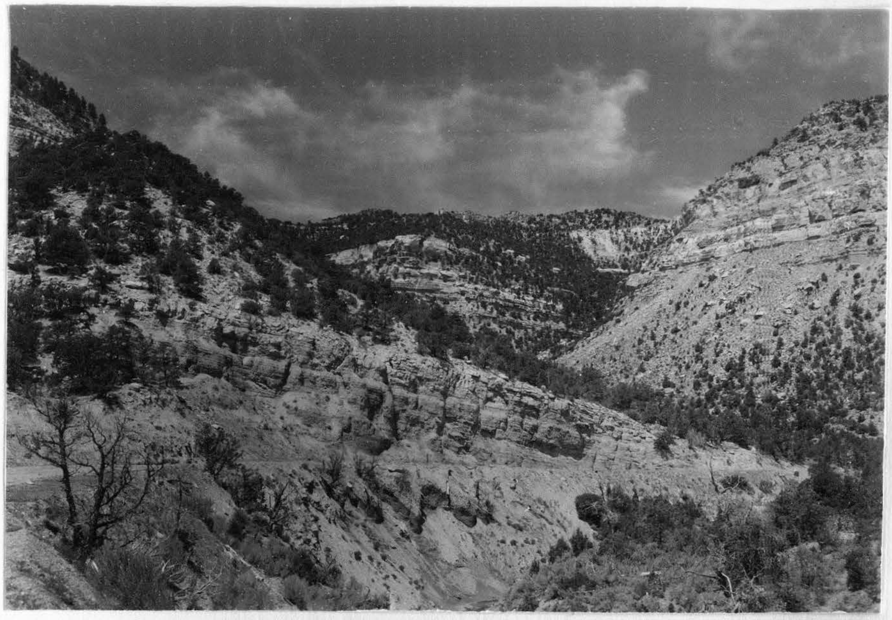

Plate 5-B. The Star Point sandstone and Blackhawk formation near Wellington, Utah. The upper member of the Star Point sandstone, the Spring Canyon tongue, crops out in the foreground. The Blackhawk formation is exposed on the hills in the background.

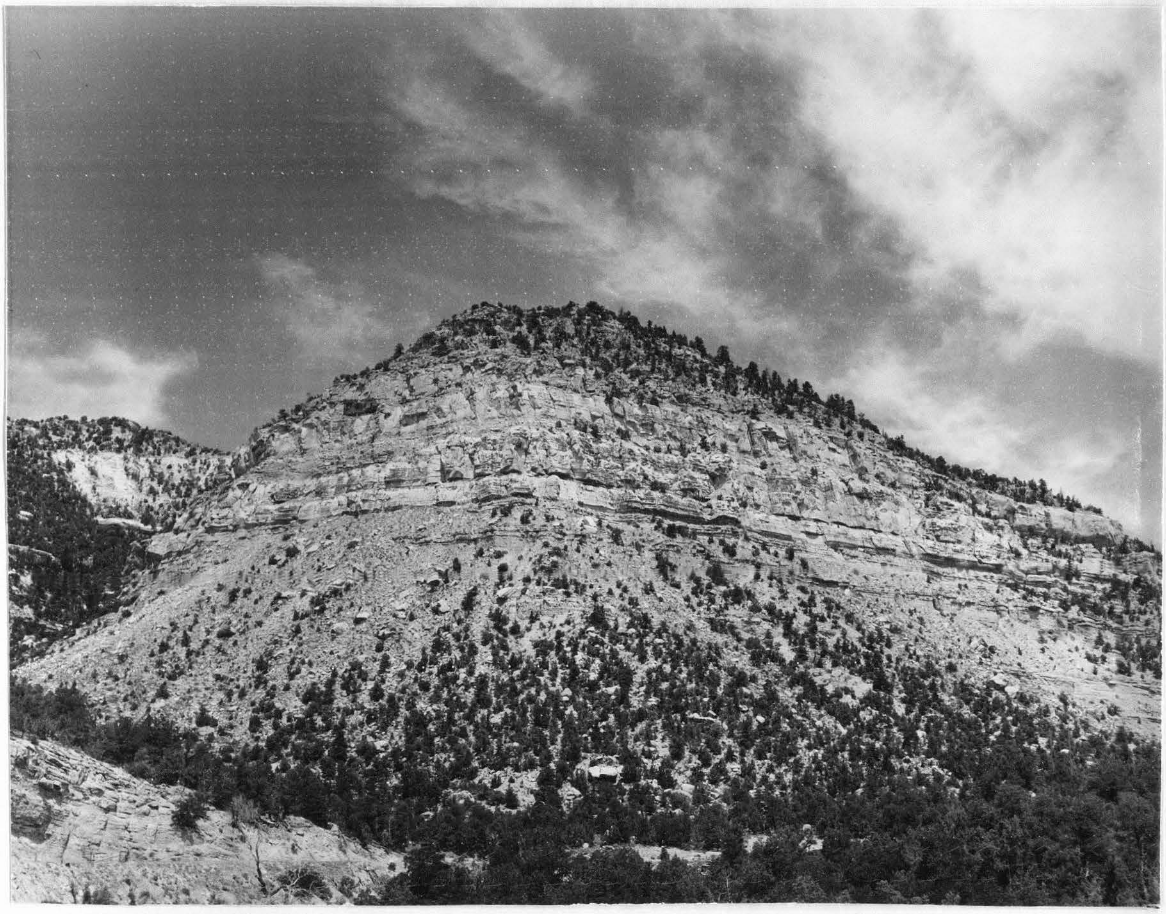

Plate 6. The Blackhawk formation in Coal Canyon near Wellington, Utah. White-capped sandstone beds generally underlie coal. Sand bar, as described by Young (1955), is seen near center of cliff.

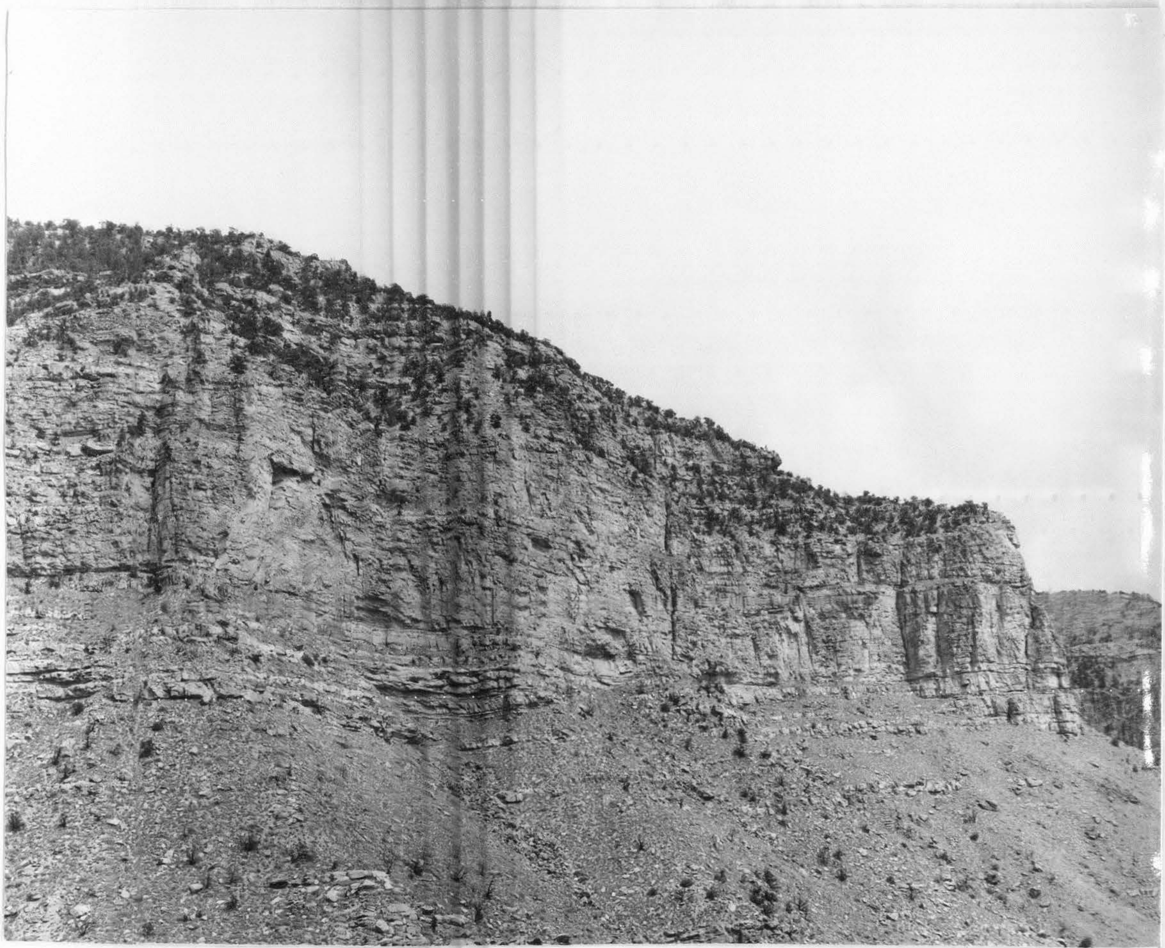

Plate 7. The Blackhawk formation and Castlegate sandstone in Price River Canyon. The Blackhawk formation forms the slope; the overlying Castlegate sandstone forms the massive cliff.

Utah by having been deposited, in part, in a lacustrine environment. It has an increased amount of sandstone in the southwestern, east-central, and northern Wasatch Plateau (Katich, 1954, p. 51). Thick beds of conglomerate occur in the formation in the Gunnison Plateau and the Cedar Hills.

Northern Region

General statement

In north-central Utah rocks of Late Cretaceous age are not exposed over large areas as in southern and central Utah. Isolated outcrops occur in the Weber River valley in the vicinity of Coalville, Utah, and others occur in the western Uinta Basin near Tabiona, Utah. The Coalville vicinity is defined as the western area of the northern region and the western Uinta Basin as the eastern area.

Western area

Rocks of Late Cretaceous age outcrop in Echo Canyon, at Coalville, Utah, and between Wanship and Peoa, Utah. Stanton (1893) did early work in this area. Although he did not introduce unit names, he originally measured two well-known sections, the Coalville section and the Rockport section between Wanship and Peoa (Stanton, 1893, p. 38-44). Veatch (1907, p. 103-105) discussed these sections and introduced nomenclature from southwest Wyoming. Other references that contribute to the knowledge and nomenclature of this area are Wegemann (1915), Eardley (1944 and 1952), Cobban and Reeside (1952b), Jones et al. (1953), Trexler (1955 and 1957), Williams and Madsen (1959), and Hale (1960b).

The nomenclature of the Upper Cretaceous stratigraphy in the Coalville area has been continually rearranged because of insufficient data and conflicting ideas. Hale (1960b), the latest publication, divided the Upper Cretaceous section into three formations, which are in ascending order: the Frontier formation, the Henefer formation, and the Echo Canyon conglomerate. He further defined ten members within the Frontier formation. The author concurs with this classification with some reservation and modification. The new member names, first published by Hale (1960b), have not been cleared with the Geologic Names Committee of the United States Geological Survey and can only tentatively be accepted. For reasons discussed later the Frontier formation is reclassified as a group and the Henefer formation omitted.

The term Frontier was first used by Knight (1902, p. 721) for exposures at Frontier, Wyoming, a small coal mining town, 2 miles north of Kemmerer, Wyoming. The name Frontier is applied throughout most of Wyoming, and in southwest Montana, eastern Idaho, northeast Utah, and northwest Colorado. Over most of this extent it is recognized as a formation, but in some areas, such as the western Uinta Basin, it is recognized as a member of the Mancos shale. The term was extended to the vicinity of Coalville from the type locality by Veatch (1907, p. 103).

In the vicinity of Coalville, Trexler (1957, p. 1874) divided the Frontier into four units according to origin. These are in descending order:

(4) 2,440 feet of marine sandstone and shale with a 635-foot nonmarine sequence in the lower half; an early Niobrara (Coniacian) fauna;

(3) 800 feet of nonmarine sandstone and claystone with a 75-foot bed of conglomerate 200 feet from the base;
(2) 795 feet of marine sandstone and shale dated as early Carlile (Turonian) and late Greenhorn (Turonian) ages; coal is associated with sandstones near the base;
(1) 400 feet of dominantly nonmarine sands and clays (probably Cenomanian).

An angular unconformity at the base of the widespread conglomerate in unit three of Texler's section was first reported by Williams and Madsen (1959, p. 122). They believe this unconformity may identify the Carlile-Niobrara time boundary in this area. They divided the strata formerly assigned to the Frontier formation into two formations. The name Frontier formation was retained for the strata below the angular unconformity, and a new name, the Wanship formation, was suggested for the strata above the angular unconformity. Although the name Wanship formation was used, it has not been formally proposed (Williams and Madsen, 1959, p. 122).

Hale (1960b) rejected the division of the Frontier formation into two formations. He postulates that lithology should be of major importance in stratigraphic nomenclature and time lines and local hiatuses of minor importance. He further pointed out that these criteria in order of importance have been the basis for the division of the Cretaceous rocks in the Rocky Mountain Region. On the basis of differing lithology Hale (1960b) first published ten member names within the Frontier, some of which had been named by Trexler (1955). According to the Code of Stratigraphic nomenclature (American Commission on Stratigraphic Nomenclature, 1961, p. 650, Article 6):

> The formation is the fundamental unit in rock stratigraphic classification. . . . A formation should possess some degree of internal lithologic homogeneity or distinctive lithologic features. It may contain between its upper and lower limits (i) rock of one lithologic type, (ii) extreme heterogeneity

> of constitution which in itself may constitute a form of unity compared to the adjacent rock units.

It can be seen from the preceding and following discussions that in the Coalville area Hale's (1960b) members within the Frontier formation are the fundamental lithologic units and should be treated as formations. It follows that the Frontier formation should be reclassified as a group. The new formation names within the Frontier group are in ascending order: the Longwall sandstone, the Spring Canyon formation, the Chalk Creek formation, the Coalville formation, the Allan Hollow shale, the Oyster Ridge sandstone, the Dry Hollow formation, the Grass Creek formation, the Judd shale, and the Upton sandstone.

Longwall sandstone.--The Longwall sandstone was named by Hale (1960b, p. 138). It is the basal formation of the Frontier group, overlies the Aspen shale, and underlies the Spring Canyon formation. The lower contact of the Longwall sandstone and the Frontier group is placed at the highest occurrence of the fish scales of the Aspen shale or the point of transition from shale to sandstone (Jones et al., 1953, p. 10). The Longwall is a light gray to white, medium-grained to coarse-grained resistant sandstone. Hale (1960b, p. 138) reports a thickness of 70 to 100 feet and a probable late Early Cretaceous age for this marine sandstone.

Spring Canyon formation.--The Spring Canyon formation was named by Hale (1960b, p. 139) for exposures southeast of Coalville in Spring Canyon. It is approximately 350 feet thick and is of paludal origin. Lithologically this formation consists of thin coal beds interbedded with carbonaceous shale and sandstone. The coal units have been called the Spring Canyon bed locally for some time (Wegemann, 1915, p. 180). Hale (1960b, p. 138) indicates the Spring Canyon formation to be of late Early Cretaceous and Belle Fourche age.

Chalk Creek formation.--Gradationally lying above the Spring Canyon formation is a sequence of reddish shale and medium-grained to conglomeratic sandstone. Hale (1960b, p. 139) named this sequence the Chalk Creek formation from Chalk Creek valley east of Coalville where the upper portion of this unit is exposed. Near Coalville the Chalk Creek formation is about 3,150 feet thick of which the lower 2,300 feet has been obscured by a thrust fault. Because of this, workers previous to Hale's (1960b) study failed to recognize the unit's full thickness. The Chalk Creek formation is of fluviatile origin and is of probable Belle Fourche and Greenhorn age according to Hale (1960b, p. 139).

Coalville formation.--Hale (1960b, p. 139) defined the Coalville formation for 75 to 223 feet of marine sandstone and overlying coal beds and sandstone typically exposed immediately northeast of Coalville. The coal beds in the upper part of the formation are commonly called the Wasatch coal (Wegemann, 1915, p. 163). The Coalville formation is gradational with both the subjacent Chalk Creek formation and the superjacent Allan Hollow shale. Cobban and Reeside (1952b, p. 1936) reports the occurrence of a distinctive late Greenhorn fossil, *Inoceramus labiatus*, from the lower marine part of the formation.

Allan Hollow shale.--The Allan Hollow shale was defined by Hale (1960b, p. 139) for typical exposures at Allan Hollow northeast of Coalville. There this non-resistant formation forms a strike valley between the underlying Coalville formation and the overlying Oyster

Ridge sandstone. Hale (1960b, p. 139) reports a thickness of 780 feet for the Allan Hollow shale at this locality. The formation is a dark gray marine shale which contains a distinctive early Carlile ammonite, Collignoniceras woolgari.

Oyster Ridge sandstone.--The Name Oyster Ridge sandstone was first used by Hayden (1872, p. 149) for a distinctive sandstone member within the Frontier formation of southwestern Wyoming. Wegemann (1915, p. 163) first recognized this unit in the Coalville area. The Oyster Ridge sandstone is composed of yellow to gray, medium-grained to coarse-grained, massive sandstone. It contains interbedded shale in the upper part and typically forms a ridge or hogback on outcrop. Hale (1960b, p. 140) gives the thickness of the Oyster Ridge sandstone as 200 to 280 feet thick. The early Carlile fossil Collignoniceras woolgari has been found in this unit (Cobban and Reeside, 1952b, p. 1936).

Dry Hollow formation.--The name Dry Hollow was first used by Trexler (1955, p. 64) for approximately 200 feet of interbedded sandstone and shale overlying the prominent conglomerate bed in the Coalville area. Hale (1960b, p. 141) redefined this unit to include the conglomerate at the base and additional overlying strata. According to Hale's (1960b, p. 141) definition, the Dry Hollow formation ranges from 1,000 to 1,220 feet thick and includes a basal conglomerate, a middle sequence of nonmarine sandstone and shale, a coal-bearing zone, and an upper resistant sandstone bed. The coal-bearing zone is commonly called the Dry Hollow bed (Wegemann, 1915, p. 165). The Dry Hollow formation unconformably overlies the Oyster Ridge sandstone of early Carlile age and grades upward into the Grass Creek formation.

The early Niobrara guide fossil *Inoceramus deformis* has been found in this unit (Cobban and Reeside, 1952b, p. 1937).

Grass Creek formation.--The Grass Creek formation was named by Hale (1960b, p. 141) for strata exposed in Grass Creek valley near the Echo Reservoir. The lower part consists of interbedded coarse-grained sandstone and red shale of fluviatile origin; the upper part consists of thin-bedded sandstone and gray shale of mixed marine and nonmarine origin. Its thickness, reported by Hale (1960b, p. 138), ranges from 1,025 feet in the west to 875 feet in the east. By stratigraphic position this unit is of early Niobrara age.

Judd shale.--The Judd shale was defined by Trexler (1955, p. 70) for exposures near the mouth of Judd Canyon six miles east of Coalville. There this unit is 690 to 760 feet thick and is composed of gray, calcareous marine shale. According to Trexler (1955, p. 70) it thins rapidly westward to 300 feet thick west of the Weber River. No diagnostic fossils have been collected from the Judd shale, but an early Niobrara age is indicated by enclosing units.

Upton sandstone.--This unit was named by Trexler (1955, p. 72) from exposures near Upton, Utah, about 7 miles east of Coalville, Utah. There the Upton sandstone is 450 feet thick and is composed of light yellowish-gray to bluish-gray, fine-grained sandstone. Trexler (1955, p. 77) indicates the Upton sandstone is of shallow-water marine origin on the basis of lithology and fossils. He reports the early Niobrara fossils *Inoceramus deformis* and *Cardium curtum* from this unit.

Echo Canyon conglomerate.--The Echo Canyon conglomerate was defined by Williams and Madsen (1959, p. 125) for exposures in the lower part of Echo Canyon near Echo, Utah. It includes strata between the

Frontier group of Colorado age and the Knight formation of Eocene age. In the Weber River valley the strata of Late Cretaceous and supposed early Tertiary age were classified by Eardley (1944, p. 840-845) as, in ascending order, the Henefer formation, the Almy conglomerate, the Fowkes formation, and the Knight formation. The Henefer formation was believed to be Montana or Paleocene age and was believed to unconformably overlie the Frontier group and unconformably underlie the lower part of the Almy conglomerate of supposed Paleocene age. In Echo Canyon the Almy formation was divided into a lower unit, the Pulpit conglomerate, and an upper unit, the Saw Mill conglomerate. The contact between these two units of the Almy conglomerate was placed at the conspicuous angular unconformity about 5 miles east of Echo Junction in Echo Canyon. The Fowkes formation is absent there, and the Knight formation was believed to be unconformable on the Saw Mill conglomerate member of the Almy formation.

Eardley (1952, p. 54-55) changed this classification. The name Henefer formation was dropped because these strata were thought to represent the lower part of the Almy conglomerate. The contact between the Almy conglomerate and the Knight formation was redefined as the conspicuous angular unconformity about 5 miles east of Echo Junction. This obliterated the name Saw Mill conglomerate. The Almy conglomerate included all the strata between the Frontier group and the Knight formation in the vicinity of Coalville and was thought to be of Paleocene age.

Williams and Madsen (1959, p. 123-125) have renamed Eardley's (1952) Almy conglomerate the Echo Canyon conglomerate. This revision is justified by them because of structural and paleontological evidence which shows these strata to be of Late Cretaceous age and not Paleocene age as previously supposed. An unconformity was believed to be present at the base of strata included in the Echo Canyon conglomerate by Eardley (1944, p. 841). However, Williams and Madsen (1959, p. 123) found the conglomerate sequence to be concordant with the underlying Frontier group although local diastems are present.

The Echo Canyon conglomerate is a sequence of red conglomerates, sandstones, and shaly sandstones. It forms massive red conglomerate cliffs in lower Echo Canyon. Because erosion has removed much of the formation before the deposition of the Eocene Knight formation, its thickness has a wide range. Williams and Madsen (1959, p. 125) report a minimum of 3,100 feet in Echo Canyon, but the original thickness was probably much more. Fossils from the formation are interpreted to be of late Niobrara age by Williams and Madsen (1959, p. 125). They suppose that the upper part is of Montana age with no supporting evidence.

<u>Eastern area</u>

Geologic information of the Upper Cretaceous section of the western Uinta Basin is found in Lupton (1910), Walton (1944), Huddle and McCann (1947), and Bissell (1952b). There the Mancos shale is of late Early Cretaceous and early Late Cretaceous age. The underlying Dakota formation is of Early Cretaceous age and is not discussed in detail. Above the Mancos shale, the other units of Late Cretaceous age are the Mesaverde formation and the overlying Currant Creek formation.

The Mancos shale of the western Uinta Basin is gradational with the underlying Dakota formation and intertongues with the overlying

Mesaverde formation. It ranges in thickness from 2,631 to 3,700 feet thick. At Red Creek, west of Tabiona, Utah, Walton (1944, p. 101) identified five members in the Mancos shale, which are, in ascending order: a lower shale member, the Aspen shale member, a middle shale member, the Frontier sandstone member, and an upper shale member. At Red Creek the lower shale member is gray and is 310 feet thick; the Aspen shale member is silver-gray, siliceous, contains fish scales, and is 15 feet thick; the middle shale member is a gray sandy or clay shale, and is 100 feet thick. Because of mapping difficulties, Huddle and McCann (1947) grouped these lower three members together as the lower shale member of the Mancos shale. Cobban and Reeside (1951, p. 1892-1893) report ammonites found in the Aspen shale or its equivalent, the Mowry shale, which date this unit as late Early Cretaceous age. The shale strata below the Aspen shale, and the Dakota formation are therefore of Early Cretaceous age, and Walton's middle shale member is of early Late Cretaceous age.

Middle shale member of Mancos shale.--This member is gradational with both the underlying Aspen shale and the overlying Frontier sandstone. The marine middle shale member is a lithologically distinct unit. It is more sandy and argillaceous than the siliceous, silver-gray Aspen shale. Bissell (1952b, p. 608) reports fossils from the middle shale member which suggest a Greenhorn age. It is unlikely that only 100 feet of shale represent continuous deposition through Belle Fourche and part of Greenhorn time. For this reason, Cobban and Reeside (1952a, col. 33) indicate probable hiatuses within the middle shale member.

Frontier sandstone.--The Frontier sandstone member of the Mancos shale forms a prominent ledge or hogback where it is exposed. The underlying shale members and the overlying upper shale member erode easily to valleys and slopes that add relief to this resistant unit. The Frontier sandstone consists of white, buff, or brown sandstone beds with interbedded sandy shale and shale. The sandstone is fine to coarse grained and is cross bedded, lenticular, and massive. Coal beds are present locally in the upper part of the member. It ranges from about 400 to 756 feet thick in the western Uinta Basin and thins eastward by intertonguing and by facies change to sandy shale. Walton (1944, p. 104) reports a brackish-water fauna from the Frontier sandstone that indicate a Greenhorn age. Bissell (1952b, p. 609) found additional faunal evidence that suggests a Greenhorn to Carlile age. At this locality the Frontier sandstone was deposited on or near the shore of the Late Cretaceous sea.

Upper shale member of Mancos shale.--The upper shale member of the Mancos shale overlies the Frontier sandstone and grades upward into the Mesaverde formation. It is of marine origin and is composed of calcareous gray shale that is sandy in the upper part of the unit. It typically forms valleys and gentle slopes that make exposures poor. The upper shale member thins westward and ranges from 1,450 to 2,600 feet thick in the western Uinta Basin. Bissell (1952b, p. 610) collected fossils from this unit that indicate only a Colorado age. By stratigraphic position and proposed correlations with shale units in other areas, the author believes this member is of early Carlile age.

Mesaverde formation.--In the western Uinta Basin, Walton (1947, p. 106), Huddle and McCann (1947), and Bissell (1952b, p. 610) chose to call the Mesaverde a group but treated it as a single unit or formation. The formation is divided into two general units by Lupton (1910, p. 608), a lower sandstone unit of marine origin, and an upper sandstone, sandy and carbonaceous shale, and coal unit of nonmarine origin. The sandstone beds are fine to coarse grained and are lenticular, cross-bedded, and massive. The Mesaverde formation differs locally in thickness due to an erosional unconformity which separates it from the overlying Currant Creek formation, but as a whole it thins eastward. At Red Creek where the formation is best exposed, it is 3,001 feet thick. The lower 869 feet are assigned to the lower marine unit and the remaining 2,132 feet are assigned to the upper nonmarine unit (Walton, 1944, p. 106). The Mesaverde formation gradationally rests on, and intertongues to the east with the Mancos shale. Walton (1944, p. 108) reports marine and brackish-water pelecypods and gastropods and some fresh-water gastropods from this unit. From these fossils he concludes that the Mesaverde formation is of Niobrara age. Fossils from the Mesaverde formation, collected by Bissell (1952b, p. 613), indicate a Carlile and Niobrara age.

Currant Creek formation.--The Currant Creek formation was defined by Walton (1944, p. 117) to include the strata between the late Colorado Mesaverde formation and the Eocene Uinta (?) formation in the western Uinta Basin. The Currant Creek formation was deposited on the eroded surface of the Mesaverde formation with no apparent discordance. It has apparent concordance with the overlying Uinta (?) formation, and though no evidence for an unconformity has been found, Walton (1944, p. 119) believes an unconformity is present. He defined the boundary between the two formations at the point of color change from the gray of the Currant Creek formation to the red beds of the Uinta (?) formation.

The Currant Creek formation is known only in the western Uinta Basin. It is about 5,000 feet thick at Red Creek and thins rapidly eastward to 3,000 feet thick at the Duchesne River (Huddle and McCann, 1947). It appears to wedge out under the Uinta (?) formation just east of the Duchesne River. The formation is a sequence of conglomerates, sandstones, and variegated shales that, as a unit, are gray or yellowish. The sandstones in the lower part of the formation are very similar in composition and appearance to those of the underlying Mesaverde formation and were probably formed by reworking. In the western outcrops thick beds of conglomerate are abundant in the basal part, but toward the east these beds become thinner and less common.

Walton (1944, p. 120) suggests that the Currant Creek formation was deposited in alluvial fans and river plains by eastward flowing rivers. No fossils have been found in the formation so its age is subject to doubt. On the basis of lithology and stratigraphic position, Walton (1944, p. 119-120) correlates it with the Price River and North Horn formations of central Utah, which would imply a late Montana and possible early Tertiary age. More recently a unit of similar lithology and stratigraphic position to the Currant Creek formation has been re-evaluated in the nearby Coalville area. Williams and Madsen (1959, p. 125) defined the Echo Canyon conglomerate of late Niobrara age for strata that were previously considered to be Tertiary age. It is possible that the Currant Creek formation is correlative to the Echo Canyon conglomerate and is of late Niobrara age.

Stratigraphic relations

Longwall sandstone, Spring Canyon formation, Chalk Creek formation, Coalville formation, and middle shale member and Frontier sandstone member of the Mancos shale.--Pre-Carlile and post-Aspen shale strata in the Coalville area are divided into four formations which are in ascending order, the Longwall sandstone, the Spring Canyon formation, the Chalk Creek formation, and the Coalville formation. Rocks of equivalent age in the western Uinta Basin comprise only the middle shale member and most of the lower part of the Frontier sandstone member of the Mancos shale. It is probable that the Longwall sandstone, the Spring Canyon formation, and the lower part of the Chalk Creek formation of the Coalville area do not have complete lithic equivalents in the middle shale member of the Mancos shale which is only 100 feet thick. The lower part of the Frontier sandstone is likely coeval to the upper part of the Chalk Creek formation and the upper coal-bearing part of the Frontier sandstone coeval to the coal-bearing Coalville formation in the Coalville area (See Figure 4).

Allan Hollow shale and upper shale member of the Mancos shale.--The Allan Hollow shale of the Coalville area has been dated as early Carlile age by the presence of the ammonite *Collignoniceras woolgari* (Hale, 1960, p. 139). In the western Uinta Basin the upper shale member of the Mancos shale occupies a similar stratigraphic position but has not been dated as precisely as the Allan Hollow shale. It is probable that the Allan Hollow shale is a northwestern extension of the upper shale member. If such is the case, the marine shale unit thins in a northwest direction from 1,450 feet thick in the western Uinta Basin to 789 feet thick at Coalville.

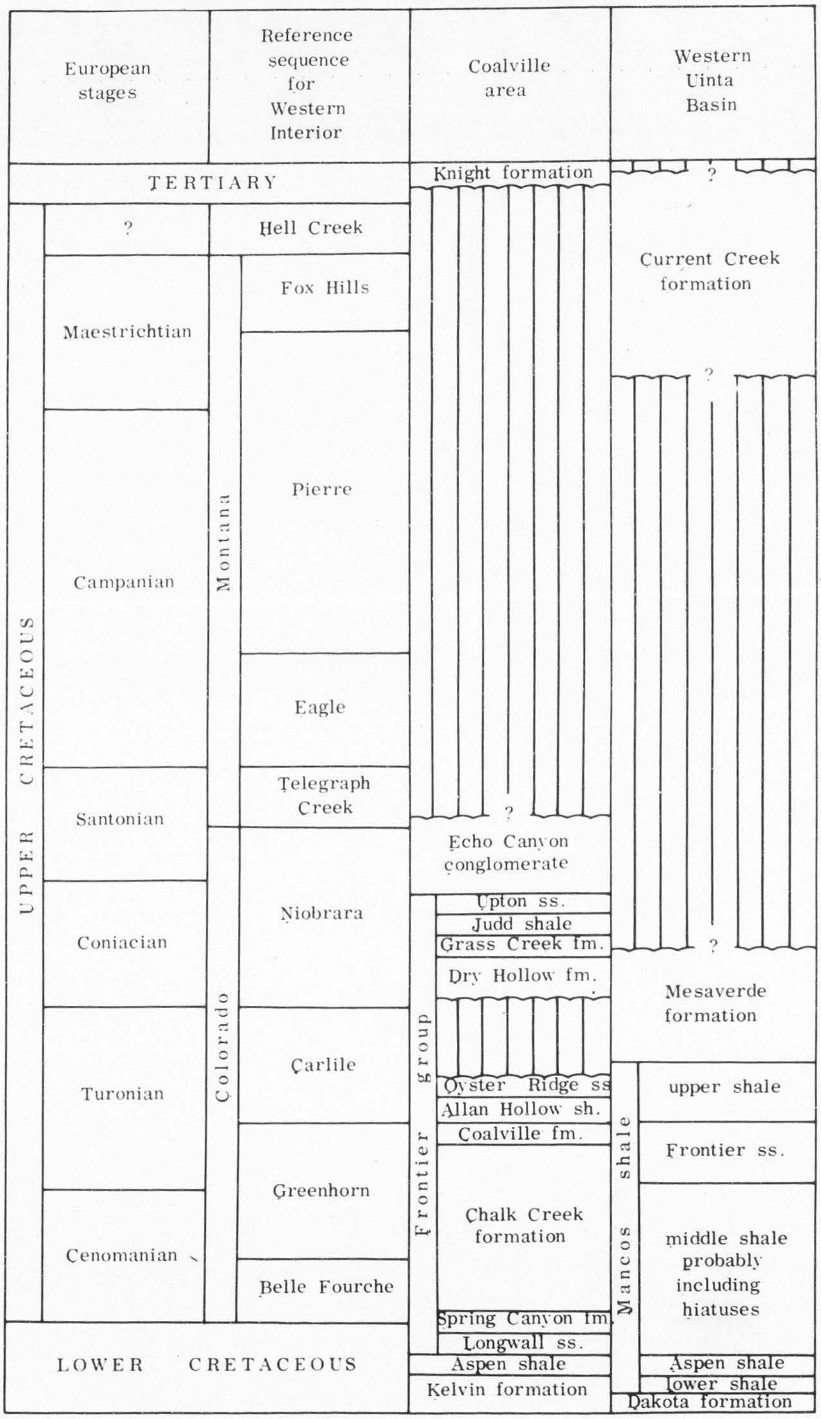

Figure 4. Correlation of Upper Cretaceous stratigraphic units of the northern region.

Oyster Ridge sandstone, Dry Hollow formation, and Mesaverde formation.--The Oyster Ridge sandstone and the Dry Hollow formation of the Coalville area are separated by an unconformity that probably spans middle and late Carlile time (Williams and Madsen, 1959, p. 122). The Oyster Ridge sandstone has been dated as early Carlile by the presence of the fossil *Collignoniceras woolgari*, and the Dry Hollow has been dated as early Niobrara by the fossil *Inoceramus deformis*. In the western Uinta Basin the Mesaverde formation is of Carlile and Niobrara age. No unconformity has yet been identified within the formation and deposition seems to have been continuous during middle and late Carlile time. The coal-bearing strata in the upper part of the Dry Hollow formation may be coeval to the coal-bearing strata in the upper part of the Mesaverde formation.

Grass Creek formation, Judd shale, and Upton sandstone.--The three upper formations of the Frontier group in the Coalville area are of early Niobrara age. The author believes that no coeval strata to these formations are present in the western Uinta Basin on the basis of a proposed correlation of the underlying upper Dry Hollow formation and the upper Mesaverde formation of the western Uinta Basin (See Figure 4).

Echo Canyon conglomerate and Currant Creek formation.--The relationship of the recently defined Echo Canyon conglomerate of the Coalville area to the Currant Creek formation of the western Uinta Basin has previously been discussed. The two formations have a similar lithology and stratigraphic position. The Echo Canyon conglomerate has been shown to be of late Niobrara age in part by Williams and Madsen (1959, p. 125). To the knowledge of the writer no fossils have been found in the Currant Creek formation. Walton (1944, p. 120) correlated the Currant Creek formation with the Price River and North Horn formations of central Utah, which would imply an age younger than Niobrara.

STRATIGRAPHIC SYNTHESIS

Correlation

Different nomenclature is used for rocks of Late Cretaceous age in the southern, central, and northern regions with few exceptions. However, there are many similarities in lithology. Refer to Figures 2, 3, and 4 for nomenclature and age of stratigraphic units and Figures 5 and 6 for correlation of representative sections.

Southern-central regions

The Dakota formation in both the southern region and the eastern area of the central region is at the base of the Cretaceous section. It appears to be younger in the southern region being of Belle Fourche to Greenhorn age. In east-central Utah this unit is thought to be of latest Early Cretaceous age. In west-central Utah, an equivalent and lithologically similar unit is called the Sanpete formation. It is of questionable age in the lower part and of Belle Fourche and Greenhorn age in the upper part.

Overlying the Dakota formation and equivalent strata is a distinctive marine shale unit. This shale bed thins and wedges out to the west. It is called the Tropic shale in the southern region, the Allen Valley shale in the western area of the central region, and the Tununk shale in the eastern area of the central region. In all cases it is of late Greenhorn to early Carlile age.

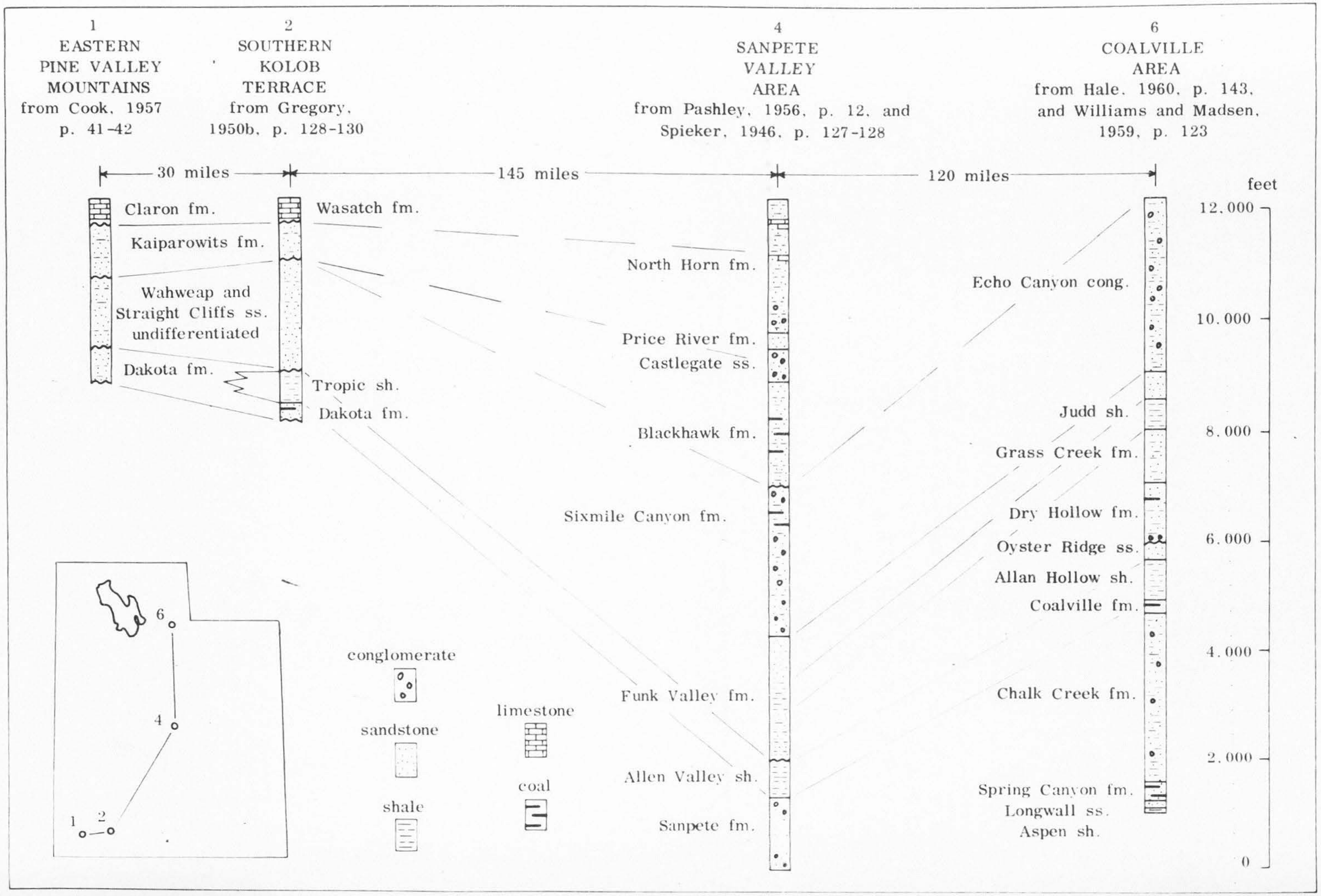

Figure 5. Correlation of western stratigraphic sections.

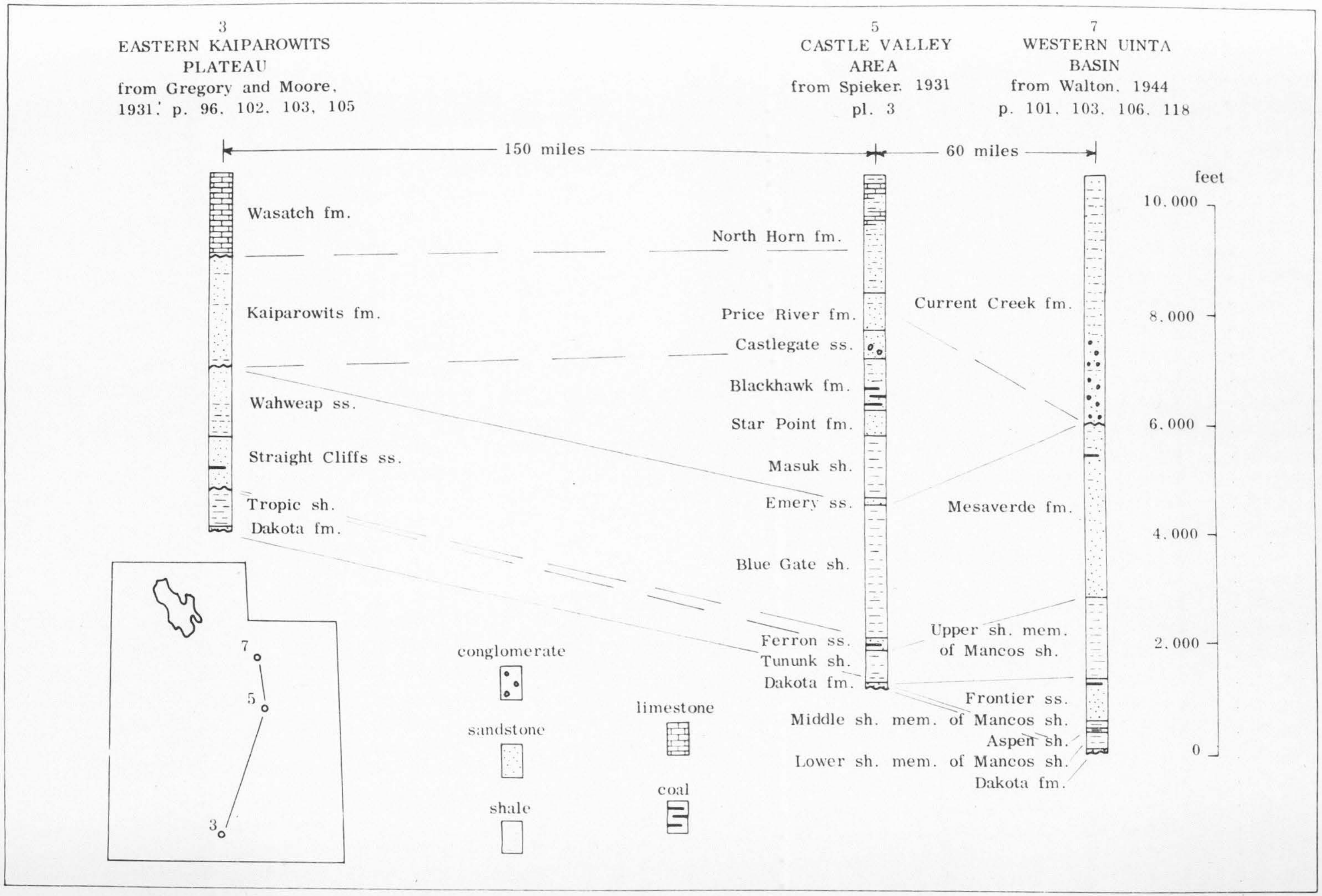

Figure 6. Correlation of eastern stratigraphic sections.

The overlying Straight Cliffs sandstone of the southern region is a sequence of sandstone with some shale and coal. A Niobrara age is reported by Gregory and Moore (1931, p. 104). The Straight Cliffs sandstone is correlated with the Funk Valley formation of west-central Utah and the lower part of the Blue Gate shale in east-central Utah. If middle and late Carlile strata are found within the Straight Cliffs sandstone, they would be correlative to the Ferron sandstone of east-central Utah.

The Wahweap sandstone of the southern region is dominantly interbedded sandy shale and sandstone. Because of scarcity of fossils, its precise age is not known. Based on its relation to the underlying Straight Cliffs sandstone, it is of probable late Niobrara age. The upper part may be of earliest Montana age. The Wahweap sandstone is correlated with the Sixmile Canyon formation of west-central Utah, which has a similar lithology although more conglomeratic, and the upper part of the Blue Gate shale of east-central Utah. The upper part of the Wahweap sandstone may also be equivalent to the Emery sandstone of earliest Montana age in east-central Utah.

Deposition was continuous throughout Montana time in east-central Utah. In west-central Utah and the southern region there were periods of non-deposition or erosion. The Kaiparowits formation is the only unit of known Montana age in the southern region. It is of fresh-water origin. It may be equivalent in part to either, or both, the Price River formation or the lower part of the North Horn formation of the central region.

The correlation of the southern Utah Wasatch formation is difficult because of questionable age. If it is of Late Cretaceous age in the lower part, it could be correlated with the North Horn formation of the central region. If it is entirely of Tertiary age it may be correlated with the upper part of the North Horn formation and/or younger Tertiary strata.

Central-northern regions

The oldest strata of Late Cretaceous age in the central region are the fluviatile Sanpete formation and the marine Allen Valley shale in the vicinity of Sanpete Valley and the marine Tununk shale in the vicinity of Castle Valley. These strata range in age from Belle Fourche, through Greenhorn, to early Carlile. Lithologic correlation of these units with units in the northern region is difficult. Probably the correlation is nearly perpendicular to the facies strike of these rocks. In the Coalville area the coal-bearing Spring Canyon formation, the fluviatile Chalk Creek formation, the coal-bearing Coalville formation, the marine Allan Hollow shale, and the littoral marine Oyster Ridge sandstone in ascending order range from Belle Fourche to early Carlile age. In the western Uinta Basin this time interval is occupied by the marine middle shale, the littoral marine and paludal Frontier sandstone, and the marine upper shale member of the Mancos shale. It is apparent that the dominant marine section of central Utah passes north or northwest to the Coalville area to fluviatile deposits grading upward to coal-bearing, marine, and finally littoral marine deposits and to the western Uinta Basin to marine deposits grading upward through littoral marine to paludal back to marine deposits. The Allan Hollow shale of the Coalville area and the upper shale member of the Mancos shale of the western Uinta Basin are the lithic equivalents of the Greenhorn and early Carlile marine shale of central Utah but appear to be only time equivalent to the upper early Carlile part.

The Ferron sandstone of east-central Utah is of Carlile age. Equivalent strata are absent in west-central Utah according to Cobban and Reeside (1952a, p. 1028), and an unconformity marks middle and late Carlile time in the Coalville area. The lower littoral marine part of the Mesaverde formation in the western Uinta Basin is coeval to the Ferron sandstone.

In east-central Utah Niobrara time is represented by a single marine shale unit, the Blue Gate shale, which contains the early Niobrara fossil Inoceramus deformis. As previously discussed, the Funk Valley formation of west-central Utah is coeval to the lower part of the Blue Gate shale and encompasses three members: (1) a basal series of sandstone with thin interbedded shale, about 900 feet thick; (2) a middle unit of gray marine shale, 650 feet thick and containing Inoceramus deformis; and (3) an upper white, buff to brown sandstone, 700 feet thick. Member 2 correlates lithologically with the marine Judd shale of the Coalville area, which is about 725 feet thick. Member 3 correlates lithologically with the Upton sandstone, which overlies the Judd shale at Coalville, is 450 feet thick and contains Inoceramus deformis. By stratigraphic position member 1 of the Funk Valley formation correlates with the Dry Hollow formation and the Grass Creek formation that underlie the Judd shale at Coalville. The Dry Hollow formation contains Inoceramus deformis. In the western Uinta Basin the upper part of the Mesaverde formation is of probable early Niobrara age.

The Sixmile Canyon formation of west-central Utah is of late Niobrara age and is the time equivalent of the upper Blue Gate shale. The Sixmile Canyon formation correlates with the Echo Canyon conglomerate of the Coalville area, which is also of late Niobrara age. The Currant Creek formation of the western Uinta Basin is of uncertain Late Cretaceous age and could possibly be correlated with the Echo Canyon conglomerate and the Sixmile Canyon formation.

The post-Niobrara sediments of central Utah probably have no correlative in the Coalville area. In the western Uinta Basin the Currant Creek formation could possibly be coeval to the Price River or North Horn formations as suggested by Walton (1944, p. 119-120).

Facies

Environments of deposition and their resulting lithofacies in the Cretaceous strata of Utah are discussed by Spieker (1949a, p. 60-62) and Young (1955, p. 193; 1957, p. 1764; and 1960, p. 178-180). In general, rocks grade from coarse clastics in the west to fine clastics in the east. According to these authors, the sediments were deposited in different environments which paralleled the edge of the sea. The environments of deposition, in sequence from land to sea, are piedmont, inland, lagoonal, littoral marine, and offshore marine. Piedmont deposits are dominantly conglomerate with subordinate red sandstone, sandy shale, and fresh-water limestone. They are found in the extreme western part of the area under discussion. Inland deposits, also common in the western part, are conglomeratic sandstone, variegated shale, fresh-water limestone and sandstone, and buff sandstone and gray shale. They were deposited by streams and small fresh-water lakes and ponds. Sediments of lagoonal origin are generally coal-bearing sequences of buff to gray sandstone and shale. They were deposited near the edge of the sea. Littoral marine deposits are of fine-grained to medium-grained, white, gray, or buff sandstone that were laid down as beach sands. Gray shale and siltstone, common in eastern Utah, were deposited in an offshore marine environment.

In Utah the facies change in Upper Cretaceous rocks is not as simple as previously described. The writer believes it is possible to discern two different sequences of facies. In the first sequence the environmental change from west to east is piedmont, inland, littoral marine, to offshore marine. The lagoonal sediments are not present. This facies change is exemplified by the Castlegate sandstone. The second sequence begins with inland sediments in the west and passes eastward to lagoonal, littoral marine, and offshore marine sediments. In this case piedmont sediments have not been found to be present. The Ferron sandstone of east-central Utah is coal bearing. To the west, southwest, and northwest, it is probable no coeval strata now exist. A similar example is the coal-bearing Emery sandstone of east-central Utah, which probably has no coeval strata west, southwest, or northwest. It could be argued that rather than nondeposition, conglomerate equivalent to these coal-bearing units was deposited and subsequently eroded. However, evidence reported by Young (1955, p. 193-200) indicates little erosion occurred in source areas during the development of a coal swamp. First, the great purity of coal beds in east-central Utah, and second, calcareous concretions, probably indicative of long periods of little deposition, are found at the tips of sandstone tongues overlain by coal. These two facies sequences seem to relate that vigorous erosion in source areas and lagoonal deposition did not occur simultaneously.

Thickness

Rocks of Late Cretaceous age in Utah have a great range in thickness. The Upper Cretaceous section is nearly complete only in east-central Utah where sediments aggregate approximately 9,400 feet. In all other parts of the state nondeposition or erosion have left many hiatuses. The greatest thicknesses of sediments are in the Cedar Hills and the Coalville area. In the Cedar Hills the maximum thickness of Lower and Upper Cretaceous strata is 17,350 feet according to Schoff (1951, p. 625, 628, and 629). In the Coalville area the maximum thickness of Upper Cretaceous strata is approximately 11,300 feet with deposits of Montana age apparently absent. Much of these thick sections are of piedmont conglomerate and were probably deposited very near to the source area. Burger (1959, p. 10) in his study of the Mesaverde group found the thickness of a given unit to be largest at the point of transition from marine to continental deposits. However, his study did not include the piedmont conglomerates which seem to have the greatest thickness of Upper Cretaceous rocks in Utah. Southern Utah appears to have been farther away from the source area. No large masses of piedmont conglomerate are found there and the thickness of Upper Cretaceous sediments averages a comparatively thin 4,000 feet.

It could be argued that weight of sediment causes subsidence. This seems to be at least partially true in Utah. Areas where the great thicknesses of piedmont conglomerate are found would have to subside much more rapidly to receive sediments than areas which might only receive shale deposition. The areas of conglomerate deposition would be nearer to the source and might not be expected to subside more rapidly than other areas nearer to the center of the sedimentary basin.

Intertonguing

The Cretaceous sea transgressed westward into central Utah during latest Early Cretaceous and earliest Late Cretaceous. From early Colorado to late Montana time, the tendency of the sea was to regress eastward. The regression was interrupted by transgressions which caused an intertonguing relationship in rocks of Late Cretaceous age.

Five facies, classified according to environment of deposition, are present in the Upper Cretaceous strata of Utah and have been discussed previously. If a time line were traced eastward from the westernmost exposures, it would pass from terrestrial deposits to marine deposits. Transgressions and regressions of the sea caused a corresponding horizontal shift in environments of deposition through time. By intertonguing, the facies are present, in part, in vertical succession as well as in lateral succession. If these facies progress in ascending order in a complete vertical succession from terrestrial deposits to marine deposits, a transgression of the sea is indicated. Conversely, ascending order in a complete vertical succession from marine to terrestrial deposits indicates a regression of the sea. The intertonguing relationship of facies in vertical succession and the inferred transgressions and regressions of the sea can be seen in Figures 7, 8, and 9 for the southern, central, and northern regions, respectively.

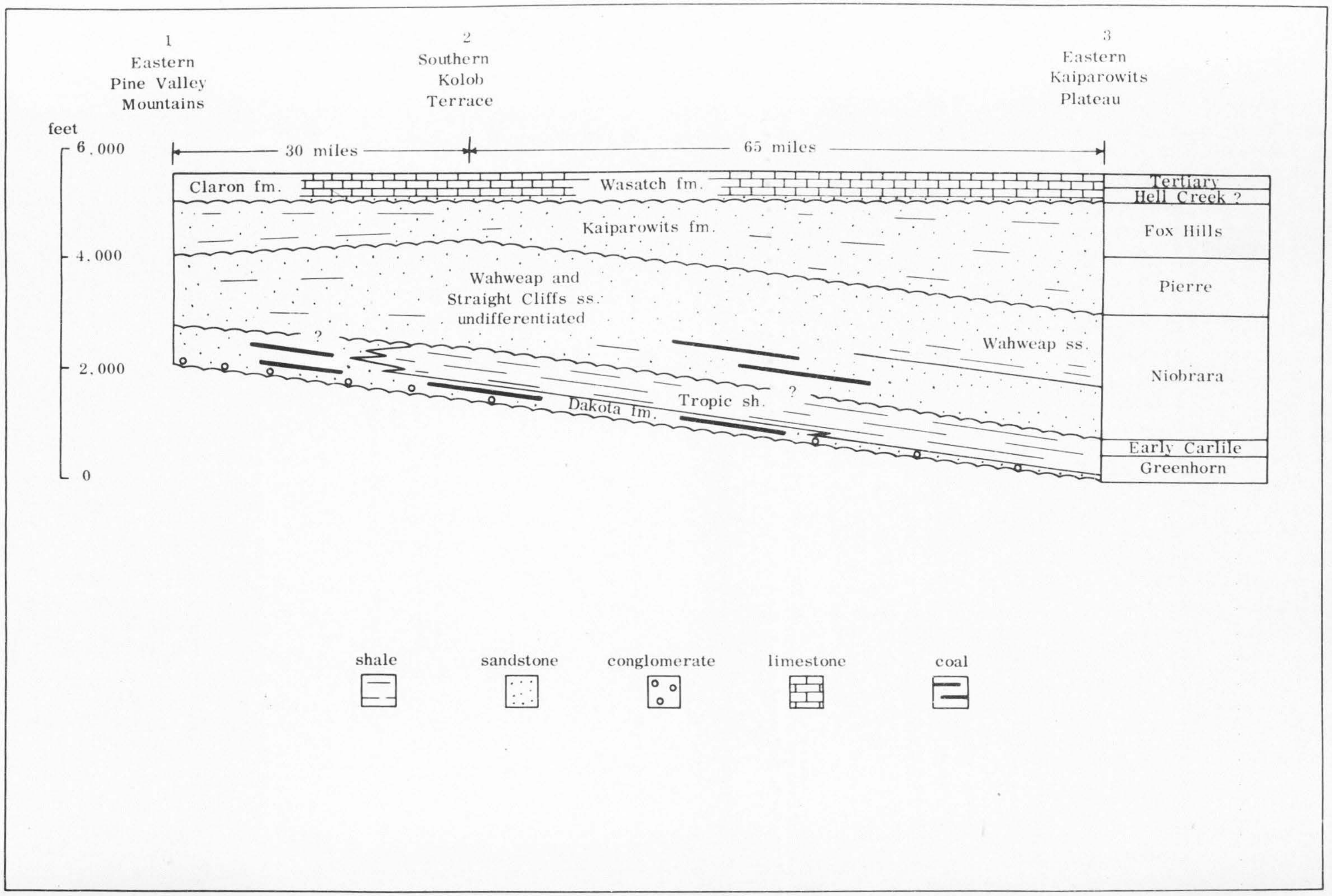

Figure 7. Stratigraphic relations of the southern region.

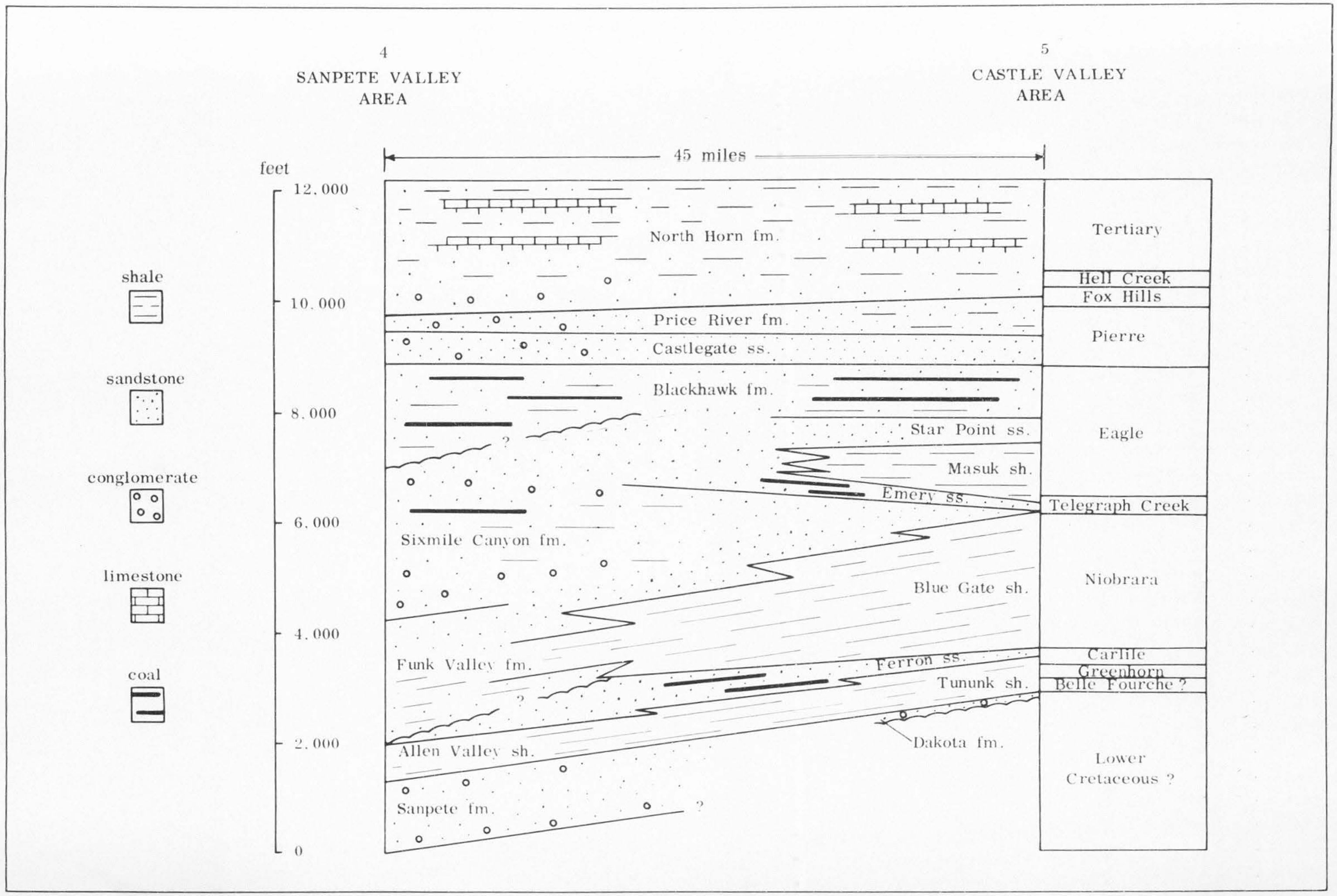

Figure 8. Stratigraphic relations of the central region.

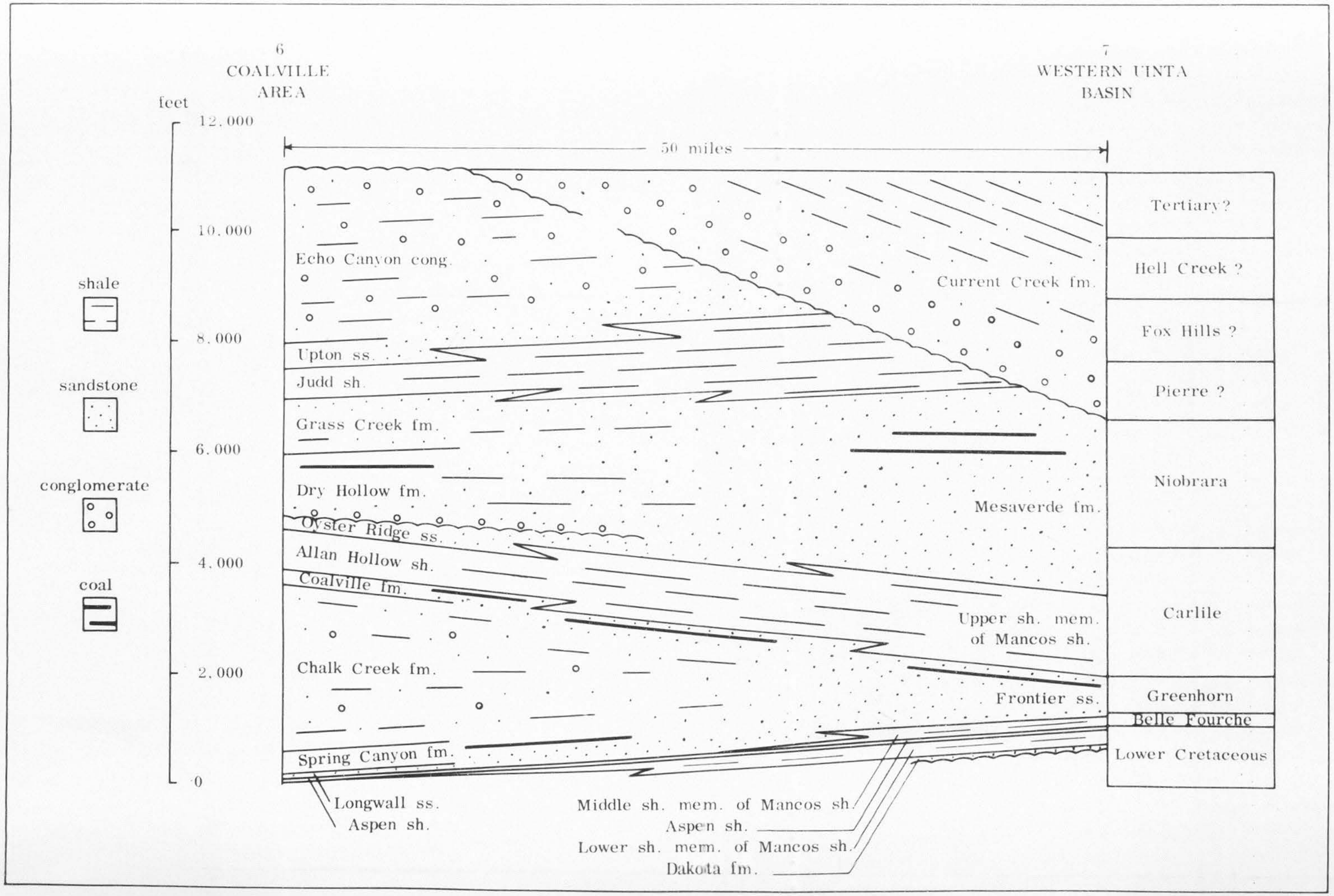

Figure 9. Stratigraphic relations of the northern region.

Characteristics and causes of transgressive and regressive relations in rocks of Cretaceous age have been discussed by Sears, Hunt, and Hendricks (1941, p. 102-105), Pike (1947, p. 1), Spieker (1949a, p. 65-66), Bergstrom (1955, p. 79-89), Young (1955, p. 193-200; 1957, p. 1764-1767; and 1960, p. 189-190), Burger (1959, p. 137-146), and Weimer (1960, p. 3). In general, two conflicting theories have been advanced to explain the transgression and regression of the Cretaceous sea and the resulting intertonguing of sediments. The first theory, advocated by Spieker, Bergstrom, Young, and Weimer, depends on repeated, sharp, sudden drops of the sedimentary basin to produce rapid transgressions of the sea between slow uniform regressions. Influx of sediments is a secondary cause of intertonguing. The second theory, backed by Sears, Hunt, and Hendricks (1941) and Burger (1959), allows for a sedimentary basin that subsides slowly and more regularly as it receives sediments. The cause of the intertonguing is found primarily in a repeated supply of sediments. In the discussion that follows, the applicability of each theory to observable data in Upper Cretaceous strata of Utah is evaluated.

In central Utah, where Spieker has done much work, transgressive deposits of Late Cretaceous age seem scarce or absent. Sandstone tongues, projecting eastward into shale, have gradational bottoms which are taken as indicative of regression. Furthermore, they have sharply defined tops which are taken as indicative of rapid transgression without deposition. Spieker (1949a, p. 65) theorizes, that as the sandstone tongue extended seaward, the local basement remained stable with little or no diastrophic movement. A sudden subsidence followed with reinvasion of the sea allowing deposition of shale in sharp contact with sandstone.

Young (1955, p. 193-200) agrees with Spieker's ideas with some modification. Young attributes the formation of sandstone tongues to periods of slow regular subsidence in a shallow basin in which supply of sediment was greatly dominant over space available. A sharp pulse of subsidence of small magnitude gave rise to an offshore bar behind which a coal swamp developed. During the life of the coal swamp, little sediment was deposited in the sea as attested to by two sources of evidence. First, the great purity of coals in the Castle Valley area infers minor sediment transport through the coal swamp; second, calcareous concretions at the ends of the sandstone tongues probably indicate fairly long periods of little deposition. A sharp pulse of subsidence of large magnitude allowed the sea to inundate the coal swamp. The sea transgressed so rapidly that the only recognizable transgressive deposits are the few inches of reworked material at the base of each marine shale tongue (Young, 1957, p. 1764).

From the preceding discussion some critical observations can be made. First, the influx of sediment into the sedimentary basin is cyclic. Sedimentation varies from a large amount during the deposition of a sandstone tongue to a very minor amount during the deposition of a coal bed and to a small amount during the deposition of a shale tongue. Second, the amount and type of subsidence is cyclic. Subsidence is slight and regular during the deposition of a sandstone tongue; it occurs in sharp small pulses during the formation of a coal bed; and it occurs in a sharp large pulse preceding the deposition of a shale tongue. Third, the cycle of influx of sediment is in phase with the cycle of subsidence. A sandstone tongue is deposited during a period of great influx of sediment and little, regular subsidence. A coal bed is deposited during very minor influx of sediment and sharp small pulses of subsidence. A shale tongue is deposited during little influx of sediment and following a sharp large pulse of subsidence. It seems that the amount of sediment entering the basin is dependent upon the rate and type of subsidence, or that the rate and type of subsidence are dependent upon the amount of sediment entering the basin. Logically, influx of sediment and rate and type of subsidence do not depend upon each other. The amount of sediment reaching a sedimentary basin at a given time reflects conditions at the source area.

An alternate theory, proposed by Burger (1959, p. 143-144), attributes the transgression and regression of the sea and the resulting intertonguing to intermittent delivery of sediment to a more uniformly subsiding sedimentary basin. If this theory were true a cyclic supply of sediment would not depend upon corresponding cyclic movements of the basin. Sand extends seaward when influx of sediment is greater than space available. As sediment entering the basin becomes less, waves and currents build an offshore bar which supports a lagoon and finally a coal swamp. Transgressive sand in the littoral zone is removed and redistributed as bars are built causing a distinct top on the littoral sand. As subsidence continues mud is deposited in sharp contact with littoral sand and the sea gradually inundates the coal swamp. When sediment reaches the sea in abundance, sand will again extend seaward.

Young (1957, p. 1764) observed that at the base of each marine shale tongue is a few inches of reworked material. A question naturally follows as to whether a sea slowly transgressing with an apparent lack of incoming sediments would rework a greater amount of material in the littoral zone and possibly cause a transgressive sand deposit to form, or if a rapid transgression is necessary to account for the small amount of reworked material. The writer feels, that until more evidence is available, a slow transgression without consequential transgressive sand deposits is tenable.

In the northern part of the Gunnison Plateau, slightly farther to the west of the Book Cliffs where Young (1955) worked, Thomas (1960, p. 44) noted a rough depositional cycle in the Indianola group and the South Flat, Price River, and North Horn formations. Thomas (1960, p. 44) found:

> One typical cycle of deposition would contain coarse, limestone and/or dolomite bearing conglomerate, all of which would indicate a piedmont or highland environment. Following this stratigraphically upward would be a zone of conglomeratic sandstone, sandstone, shale, and fresh-water limestone, indicating an inland floodplain, channel, or lake environment respectively (Spieker, 1949a, p. 60). Finally, the cycle would come to a climax with coal-bearing units and sandstone which represent a lowland floodplain or swamp (Spieker, 1949a, p. 60). The entire cycle would indicate the gradual lowering and/or migration of a highland source.

It appears, that in the northern Gunnison Plateau, there is direct evidence that cyclic deposition of rocks of Late Cretaceous age in Utah is caused primarily by repeated supply of sediments and not by repeated, sharp sudden drops of the sedimentary basin.

Weimer (1960, p. 1-20) presents diagrammatic sections across Montana, Wyoming, Utah, Colorado, and New Mexico in his study of Upper Cretaceous rocks of the Rocky Mountains. Across this large area, he correlates major transgressions and regressions to prove that sharp subsidences of a single sedimentary basin caused the intertonguing of Upper Cretaceous sediments. Weimer (1960, p. 19) states, "The movements of strandline seem to have been largely tectonically controlled rather than controlled by excess of supply or lack of supply of sediment as postulated by many authors." For his idea to be valid, all major transgressions and regressions of the Cretaceous sea must be time equivalent. This may not be entirely true in Utah.

The Dakota formation is of early Late Cretaceous age in the southern region and of late Early Cretaceous age in both the central and northern regions. The initial transgression of the Cretaceous sea into Utah did not occur instantaneously as if by a sharp subsidence of the entire sedimentary basin.

In the southern region, the marine Tropic shale overlies the Dakota formation of inland and littoral marine origin and underlies the littoral marine beds of the Straight Cliffs sandstone. The Tropic shale is of Greenhorn to early Carlile age and implies a major transgression. In the central region, the Allen Valley shale and the Tununk shale of Greenhorn to early Carlile age reflect this same major transgression. In the Coalville area, the Chalk Creek formation of Belle Fourche and Greenhorn age is of fluviatile origin and implies a major regression. It overlies marine and littoral marine rocks and underlies littoral marine and marine rocks. The lithic correlative of the Allen Valley shale and the Tununk shale is the Allan Hollow shale in the Coalville area, but it is only of early Carlile age and does not include Greenhorn strata. In the western Uinta Basin the Frontier sandstone reflects the same Greenhorn regression of the Coalville area.

Thus, strata in southern and central Utah demonstrate a major transgression through Greenhorn and early Carlile time. But, in northern Utah a regression marked Greenhorn time and a transgression occurred in early Carlile time.

In east-central Utah the Blue Gate shale of Niobrara age rests on the Ferron sandstone of Carlile age implying a major transgression in early Niobrara time. However, this transgression was not rapid. In the Coalville area to the northwest, approximately 2,000 feet of sediments of fluviatile, paludal, and littoral marine origin and of early Niobrara age lie under the early Niobrara Judd shale, which is the lithic equivalent of the Blue Gate shale.

Sedimentation patterns in Upper Cretaceous rocks of Utah seem to indicate that subsidence on a local basis had more effect on deposition than subsidence on a regional basis. Furthermore, the evidence seems to favor gradual and continued subsidence of the sedimentary basin rather than sudden subsidences. It is believed that intertonguing is primarily caused by an irregular supply of sediments coupled with slow subsidence of the sedimentary basin.

Stratigraphic History

Transgression

Transgressions, or westward movements, of the Late Cretaceous sea are represented by a shift of facies westward. In east-central Utah, where the Upper Cretaceous section is most complete in Utah, three major transgressions of the sea can be discerned. In most other areas of Utah, because of incomplete sections, a lesser number of transgressions are obvious. As previously discussed, the writer visualizes these transgressions as slow in comparison to the rapid transgressions envisioned by many other authors.

The subsidence of the sedimentary basin began to the east of Utah during late Early Cretaceous time. The Dakota formation of east-central and northeastern Utah was deposited as the transgressing sea slowly envaded. It was not a simple westward transgression for the Dakota formation of southern Utah is younger than the Dakota formation in both central and northeastern Utah. The Late Cretaceous sea continued to transgress westward or remain stationary in southern and central Utah throughout Belle Fourche, Greenhorn, and into early Carlile time as affirmed by the Tropic shale, the Tununk shale, and the Allen Valley shale. In northern Utah a regression disturbed the pattern during Greenhorn time as attested by the fluviatile Chalk Creek formation and the littoral marine and paludal Coalville formation of the Coalville area and the littoral marine and paludal Frontier sandstone of the western Uinta Basin (Figure 10). In the Coalville area, the Allan Hollow shale, and in the western Uinta Basin, the upper shale member of the Mancos shale, indicate that the trend of the sea was to again transgress in early Carlile time (Figure 11). In southern and central Utah a transgression is obvious during late Early Cretaceous, Belle Fourche, Greenhorn, and early Carlile time. In northern Utah two transgressions occurred; the first in late Early Cretaceous time, the second in early Carlile time.

During early Niobrara time another transgression of the sea is recorded by the Blue Gate shale in east-central Utah and the middle marine shale member of the Funk Valley formation of west-central Utah. In the Kaiparowits area of southern Utah this transgression might be

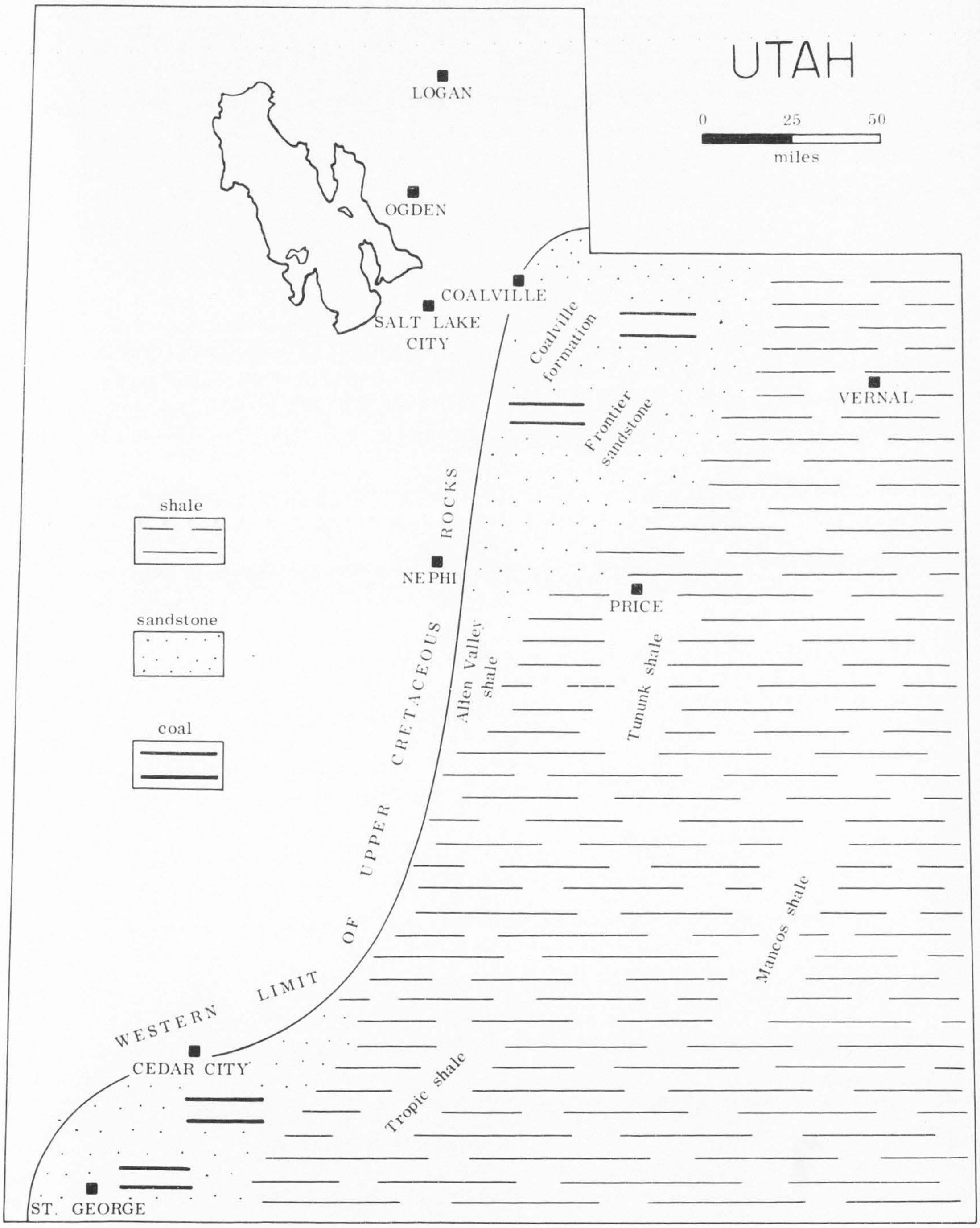

Figure 10. Lithofacies of middle Greenhorn strata.

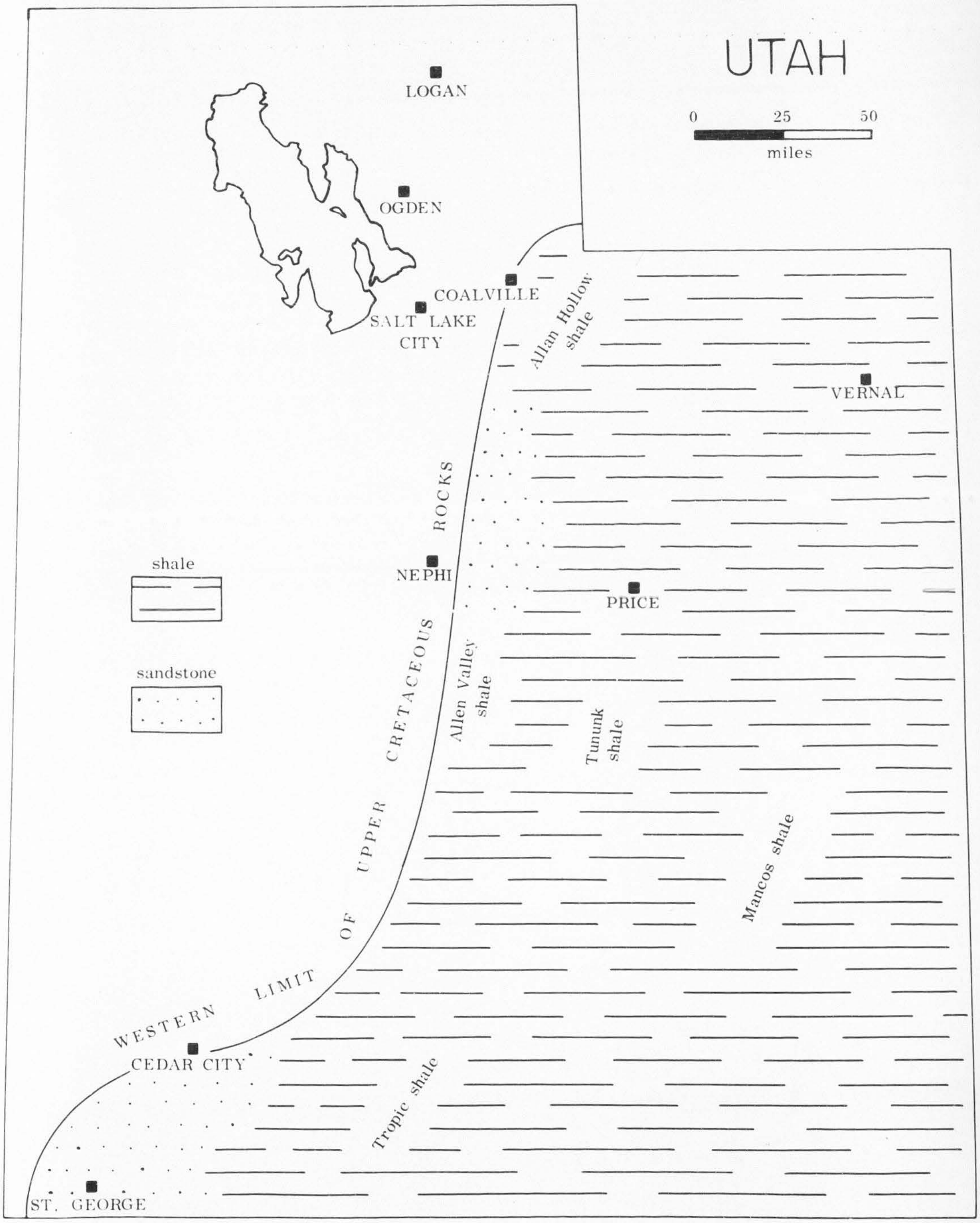

Figure 11. Lithofacies of lower Carlile strata.

represented by the shale break between the Straight Cliffs and Wahweap sandstones. Strata deposited during this transgression are apparently absent in the western Uinta Basin, but the Judd shale of the Coalville area is illustrative of this early Niobrara advance of the sea.

The youngest major transgression of the Late Cretaceous sea in the central part of Utah occurred during Eagle time. Marine shale of this age, the Masuk shale, is found only in east-central Utah. Rocks of equivalent age are probably not present in any of the other areas discussed.

Regression

Regression, or eastward movement of the sea, was the dominant pattern after early Carlile time. Four major regressions are recognizable in the Upper Cretaceous rocks of the central part of Utah.

The oldest major regression of the Late Cretaceous sea is only discernible in northern Utah and occurred during Greenhorn time. The fluviatile Chalk Creek formation of the Coalville area and the littoral marine and paludal Frontier sandstone of the western Uinta Basin record this regression (Figure 10).

The second major regression of the sea occurred during middle and late Carlile time (Figure 12). This is evidenced by eastward projecting sandstone strata into the Mancos shale. These units are the Ferron sandstone of east-central Utah and the Mesaverde formation of the western Uinta Basin. In parts of southern Utah, in west-central Utah, and in the Coalville area it is probable that middle and late Carlile time was a period of nondeposition and/or erosion.

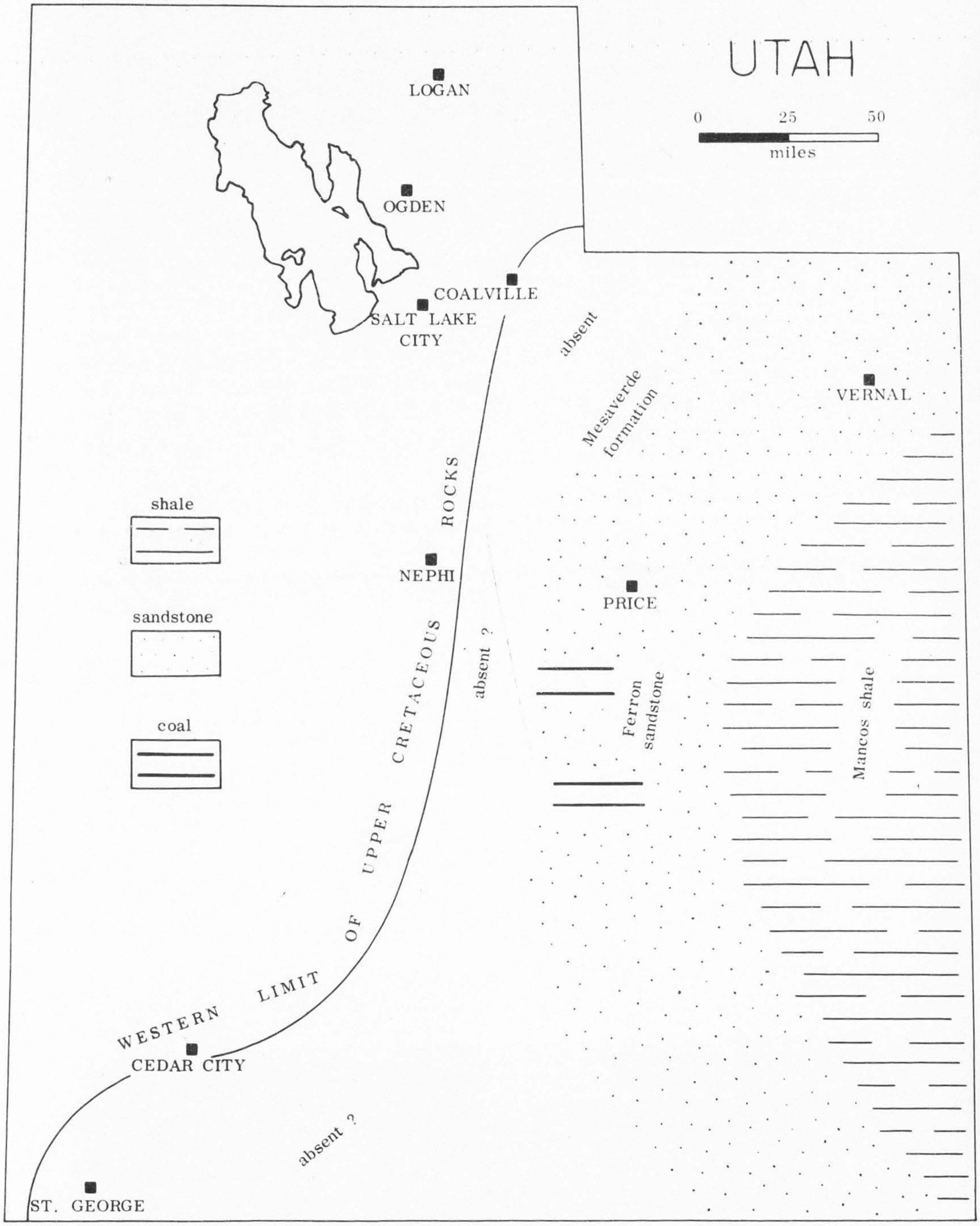

Figure 12. Lithofacies of middle Carlile strata.

A third major regression started during late Niobrara time and continued until the end of Telegraph Creek time (Figure 13), when it was terminated by a transgression. In the southern region the Wahweap sandstone of late Niobrara age and hiatus (?) during Telegraph Creek time represent this interval of time. In west-central Utah the Sixmile Canyon formation is of terrestrial origin and there is a similar hiatus (?) during Telegraph Creek time. This regression is evidenced in east-central Utah by the regressive Emery sandstone which separates the transgressive Blue Gate shale and Masuk shale tongues of the Mancos shale. In the Coalville area the late Niobrara Echo Canyon conglomerate of fluviatile origin overlies marine sediments of the Upton formation showing an eastward shift of environments of deposition. Strata of late Niobrara age may or may not be present in the western Uinta Basin in the presence of the fluviatile Currant Creek formation.

The final regression of the Late Cretaceous sea recognizable in the area of discussion started during Eagle time. Eagle time to the end of the Cretaceous period is represented by nonmarine sediments or hiatus in southern and northern Utah and in west-central Utah. In east-central Utah littoral marine sandstone tongues of the Star Point sandstone of Eagle age overlie the marine Masuk shale. The Star Point sandstone is overlain by near-shore and lagoonal deposits of the Blackhawk formation, which in turn, is overlain by fluviatile sediments of the Price River formation. The ascending order of marine to terrestrial deposits indicates regression of the sea. By early Fox Hills time the Late Cretaceous sea had regressed east and marine deposition in Utah had ceased.

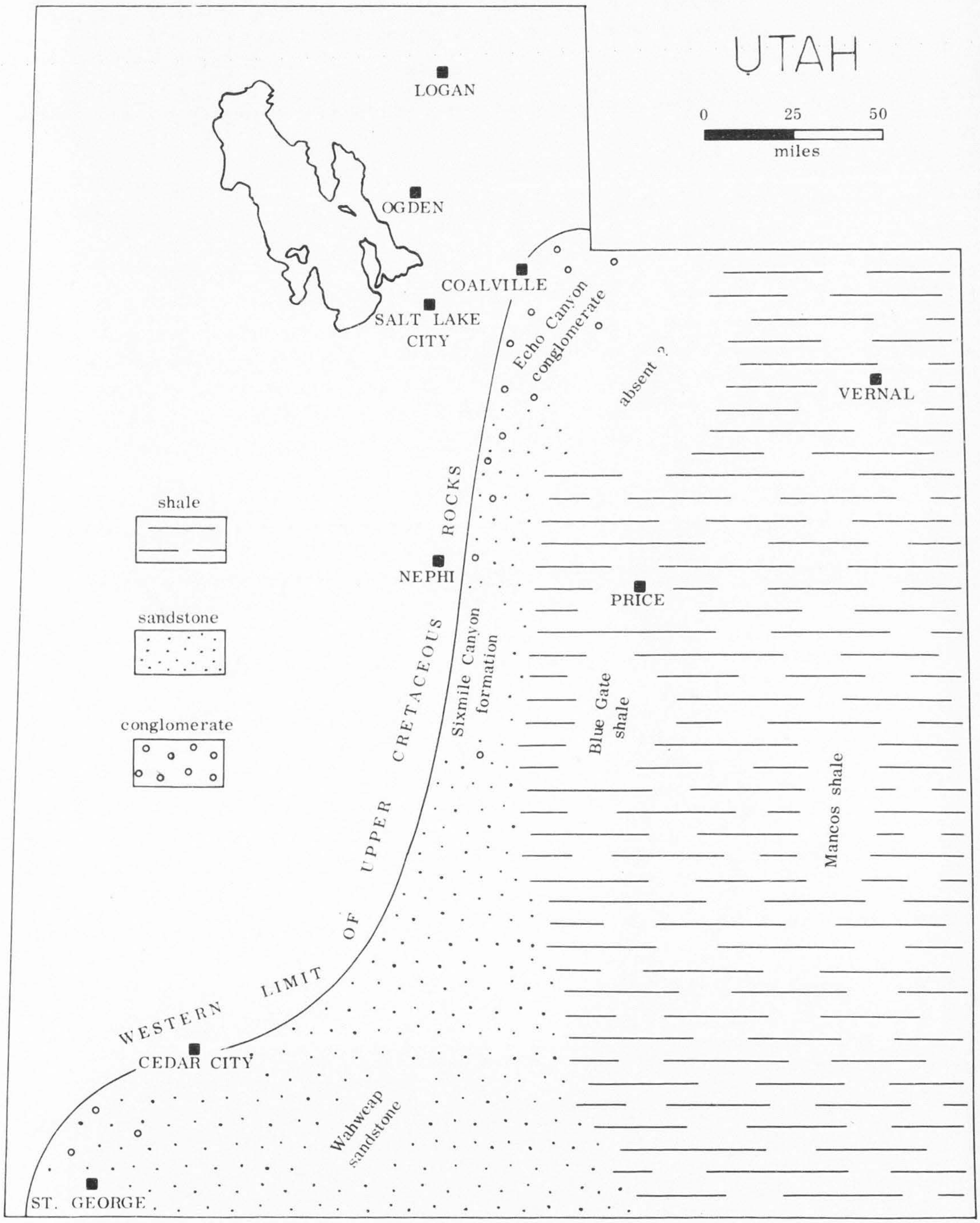

Figure 13. Lithofacies of upper Niobrara strata.

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APPENDIX

INDEX OF PUBLISHED STRATIGRAPHIC SECTIONS

Southern Region

Cretaceous rocks undifferentiated

(Cook, E. F., 1957, p. 43-45), (Reeside, J. B., Jr., and H. Bassler, 1922, p. 77).

Dakota formation

(Cook, E. F., 1957, p. 41), (Gregory, H. E., 1950a, p. 78-88), (Gregory, H. E., 1950b, p. 125, 128-133), (Gregory, H. E., 1951, p. 66-68), (Gregory, H. E., and R. C. Moore, 1931, p. 93-99, 109, 111).

Tropic formation

(Cook, E. F., 1957, p. 41-42, 47), (Gregory, H. E., 1950a, p. 73-80, 83-88), (Gregory, H. E., 1950b, p. 125, 128-133), (Gregory, H. E., 1951, p. 62-65), (Gregory, H. E., and R. C. Moore, 1931, p. 99, 109, 111), (Thomas, H. E., and G. H. Taylor, 1946, p. 26-27).

Straight Cliffs and Wahweap sandstones undifferentiated

(Cook, E. F., 1957, p. 41-42), (Gregory, H. E., 1950a, p. 78-80, 85-86, 91-92), (Gregory, H. E., 1950b, p. 128-133), (Gregory, H. E., 1951, p. 61-66), (Thomas, H. E., and G. H. Taylor, 1946, p. 26-27).

Straight Cliffs sandstone

(Gregory, H. E., and R. C. Moore, 1931, p. 102-103, 109, 111).

Wahweap sandstone

(Gregory, H. E., and R. C. Moore, 1931, p. 105).

Kaiparowits formation

(Cook, E. F., 1957, p. 41-42), (Gregory, H. E., 1950a, p. 78-80, 85-86, 90-92), (Gregory, H. E., 1950b, p. 128-133), (Gregory, H. E., 1951, p. 61-68), (Gregory, H. E., and R. C. Moore, 1931, p. 107).

Claron formation

(Cook, E. F., 1957, p. 41-45).

Wasatch formation

(Gregory, H. E., 1950a, p. 78-80), (Gregory, H. E., 1950b, p. 130-133), (Gregory, H. E., 1951, p. 62-65, 66-68).

Central Region

Indianola group undifferentiated

(Hardy, C. T., and H. D. Zeller, 1953, p. 1266-1267), (Schoff, S. L., 1951, p. 624), (Spieker, E. M., 1946, p. 130).

Dakota formation

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 45, 47-49, 51, 56-57, 59, 61, 63, 64), (Lupton, C. T., 1916, p. 27-29).

Mancos shale

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 47, 49, 52, 58, 61), (Spieker, E. M., 1931, p. 18-19).

Ferron sandstone

(Lupton, C. T., 1916, p. 32-33).

Star Point sandstone

(Spieker, E. M., 1931, p. 22-24).

Blackhawk formation

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 45-52, 54, 56-59, 61), (Spieker, E. M., 1931, p. 30-35), (Spieker, E. M., and A. A. Baker, 1928, p. 138).

Castlegate and Price River formations undifferentiated

(Hardy, C. R., and H. D. Zeller, 1953, p. 1268), (Schoff, S. L., 1951, p. 627-628), (Spieker, E. M., 1946, p. 132).

Castlegate sandstone

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 45, 47-49, 51, 56-57, 59, 61, 63-64), (Spieker, E. M., 1931, p. 40-41), (Spieker, E. M., 1946, p. 140), (Spieker, E. M., and A. A. Baker, 1928, p. 141).

Price River formation

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 43-45, 47-49), (Spieker, E. M., 1931, p. 40), (Spieker, E. M., 1946, p. 140).

North Horn formation

(Fisher, D. J., C. E. Erdmann, and J. B. Reeside, Jr., 1960, p. 41-43, 50), (Hardy, C. T., and H. D. Zeller, 1953, p. 1271), (Spieker, E. M., 1946, p. 133, 140).

Northern Region

Frontier group

(Veatch, A. C., 1907, p. 103-104), (Wegemann, C. H., 1915, p. 163).

Mancos shale

(Bissell, H. J., 1952b, p. 606), (Lupton, C. T., 1910, p. 611), (Walton, P. T., 1944, p. 101).

Frontier sandstone

(Bissell, H. J., 1952b, p. 609), (Walton, P. T., 1944, p. 103).

Upper shale member of Mancos shale

(Walton, P. T., 1944, p. 105).

Mesaverde formation

(Bissell, H. J., 1952b, p. 611-612), (Lupton, C. T., 1910, p. 609-610), (Walton, P. T., 1944, p. 101, 106-107).

Currant Creek formation

(Walton, P. T., 1944, p. 118).