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LATE CRETACEOUS STRATIGRAPHY OF BLACK MESA, NAVAJO AND HOPI INDIAN RESERVATIONS, ARIZONA[1]

by H. G. PAGE and C. A. REPENNING

INTRODUCTION

Cretaceous strata considered in this report form the prominent cliffs of Black Mesa. The mesa is about 60 miles in diameter and located in Navajo County, Arizona (fig. 1). Altitudes of the top of Black Mesa range from about 6000 feet above sea level along the southern edge to more than 8000 feet on the northern edge; the surrounding areas lie between 5000 and 6000 feet.

Stratigraphic correlations have been made on the basis of measured sections, two of which were adapted from a thesis by G. A. Williams (1951); drill cuttings; laboratory analyses of rock samples; and preliminary identification of fossils. Geologic mapping was done on a scale of 1:31,680, and is available from the open file of the U. S. Geological Survey.

Previous Studies and Correlation of Major Units

The first published reference to Cretaceous rocks of this area was made in 1861 by Newberry (p. 80-96), who noted strata of Cretaceous age in the vicinity of the Hopi villages. Gregory (1917) and Campbell and Gregory (1911) recognized the Dakota sandstone, the Mancos shale, and the Mesaverde formation in the Black Mesa area, and these same units have been recognized, with minor variations, by most subsequent workers in the area. The terminology of the units described in Black Mesa parallels that used in the San Juan basin, and these units are correlative with the Dakota sandstone, Tropic shale, and Straight Cliffs sandstone of the Kaiparowits Plateau in southern Utah.

LOWER BOUNDARY OF CRETACEOUS ROCKS

An unconformity marks the lower boundary of Cretaceous rocks in the Black Mesa area. The surface of this unconformity is rolling and channeled, with local relief as great as 40 feet and channels as wide as 100 yards. More commonly the channels are small, with maximum relief of about 5 feet. These channels are ordinarily filled with conglomeratic sandstone; however, in many places they are filled with finer material and even carbonaceous shale and coal. Where carbonaceous material closely or directly overlies this erosion surface, underlying Jurassic beds in most places are markedly bleached. Beds of the Dakota, on the other hand, are not bleached where overlain by coal.

Pre-Dakota structure in the Black Mesa area is so slight that the beveling of underlying formations by erosion prior to the deposition of the Dakota sandstone is of such a broad nature that no angular unconformity has been seen in any outcrop on the Navajo Indian Reservation. However, in a regional sense the unconformity is angular. This unconformity overlies progressively older formations from northeast to southwest. The Dakota sandstone overlies the Lower Cretaceous Burro Canyon formation near Ute Mountain, Colorado; the upper part of the Upper Jurassic Morrison formation at Yale Point, on the northeastern corner of Black Mesa; the Morrison and underlying Jurassic formations southwestward across Black Mesa; an equivalent of the Jurassic Carmel formation in the Hopi Buttes area; Triassic sedimentary rocks near Showlow, 60 miles south of the Navajo reservation; and Paleozoic rocks south of Showlow.

South of Showlow no Mancos shale unit is present, and the Mesaverde and Dakota strata coalesce, forming an essentially continuous sequence of sandstone and continental shale to which no formal name has been applied.

Relationships in these areas suggest that the pre-Dakota unconformity represents only a short hiatus in southwestern Colorado, where deposition was essentially continuous, and a greater time interval in the vicinity of Showlow, where the time represented involves later Permian through Early Cretaceous. However, formations deposited during this greater time interval within the Navajo reservation suggest, by their variations in thickness and lithologic character, that much of he srtatigraphic sequence missing in the Showlow area had been deposited and, thus, the pre-Dakota unconformity represents greater erosion but not necessarily greater time of erosion to the south. In the Black Mesa area the missing strata includes part of the Early Cretaceous in the northeast and increases south and southwest, where it includes Early Cretaceous and Late and possibly some Middle Jurassic.

The Mogollon highland, against which the Late Cretaceous seas encroached, had existed since Late Triassic time (Harshbarger, Repenning, and Irwin, 1957), and possibly no deposition occurred in some parts of that highland area before Late Cretaceous time. However, if such areas of nondeposition existed they must have been a considerable distance south of the Showlow area.

DAKOTA SANDSTONE

The Dakota outcrop encircles Black Mesa and occurs on the south and west beyond the boundaries of the mesa. Typically, it is divided into three units: a basal sandstone, a middle carbonaceous unit, and an upper sandstone, any one or all of which are absent locally on Black Mesa.

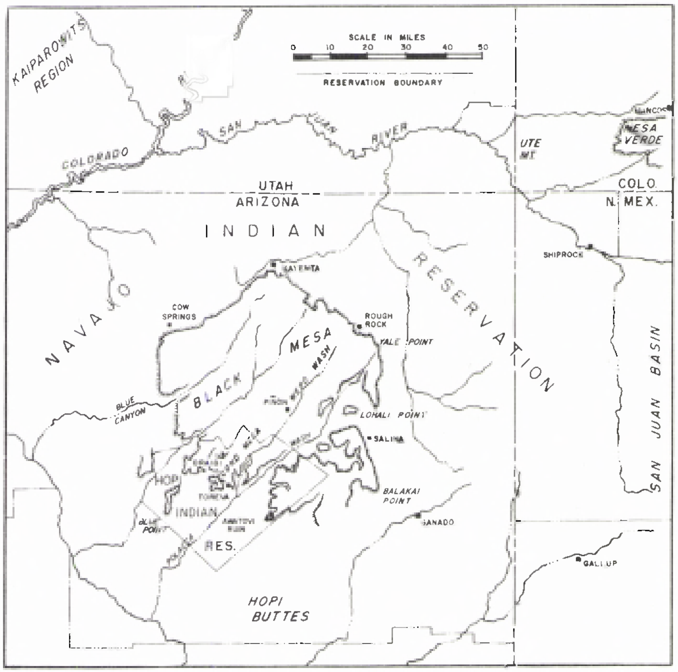

FIG. 1.—Index map of northeastern Arizona and parts of Colorado, New Mexico, and Utah.

[1] Publication authorized by the Director, U. S. Geological Survey.

General description and field relations

The lower sandstone member of the Dakota sandstone is a very pale orange and is composed of medium- to fine-grained subrounded clear and stained quartz grains intermixed with black accessory minerals. Iron-rich concretions are abundant in the unit at most localities. Typically this sandstone is very irregularly bedded and comprises a great assortment of lenticular, crossbedded sets in which the crossbedding is ordinarily of either the tabular planar or the asymmetrical trough type, according to the cross-stratification classification of McKee and Weir (1953). Cross beds are low to very low angle and small to medium scale[1]. Plant fragments and flecks and chips of coal are locally common, and a few "pebbles" of fossil resin are present. In places the unit has a basal conglomerate that is concentrated at the base of channels, and in some areas conglomeratic lenses are common throughout.

This basal sandstone is 30-60 feet thick in typical exposures, is well cemented, and forms a vertical, blocky cliff, capping the underlying sandstone of Jurassic age. The basal contact of the lower sandstone member is the pre-Dakota unconformity, and the unit grades upward into the medial carbonaceous member of the Dakota.

The middle carbonaceous member of the Dakota sandstone in the Black Mesa area consists of carbonaceous siltstone and coal in flat, very thin beds. The unit is composed of silt and clay and fine-grained subangular clear quartz, with stringers and isolated crystals of gypsum throughout the unit. Carbonized plant remains, associated with the coal, occur throughout the unit, beautifully preserved at many localities.

In most places the middle unit is 20-40 feet thick, weathers into a smooth slope back of the cliff formed by the lower member, and is capped by the ledge or ledges formed by the upper sandstone member of the Dakota. The middle carbonaceous member is variable in thickness, and in many localities thickens at the expense of either or both of the sandstone members. At a few places all the Dakota is shaly, combining with the Mancos shale to form a continuous shale sequence between the base of the Mesaverde group and the top of the Jurassic rocks. At other places the middle member of the Dakota is absent and the upper and lower members coalesce to form a single cliff of sandstone. Coal is much more abundant in the Dakota in the southwestern part of the area, where the upper sandstone member is absent in most localities.

The upper sandstone member differs to some extent from the lower. Its color and general composition are approximately the same; however, the upper member contains a greater amount of very fine sand and silt and in many localities it consists of a series of thin ledges and intercalated shaly beds. It is composed of a series of flat, thin to thick beds which individually are commonly crossbedded at a very low angle and on a medium to large scale. This unit is ripple cross laminated (McKee, 1939, p. 74) in many localities and grades upward into the Mancos shale. The base of the upper sandstone member, in contact with the middle carbonaceous member, is a sharp and somewhat irregular surface of erosion. The upper member of the Dakota is prominent in most of the northern half of the Black Mesa area, but is absent in most of the area south of a line between Balakai Point and Blue Canyon.

As a formation, the Dakota sandstone ranges in thickness throughout the Black Mesa area from a maximum observed of 119 feet to a minimum of about 50 feet, averaging about 80 feet.

Age assignment and correlation

Although critical dating fossils are unknown from the lowest part of the formation, the relations of the Dakota to fossils of a known age higher in the section are such that the formation is believed to be entirely of Late Cretaceous age in the Black Mesa area. Throughout this area the Dakota sandstone is directly overlain by fossil-bearing beds in the base of the Mancos shale that are of an age similar to that of the Greenhorn limestone of the Colorado Front Range. At Blue Point, in the southwestern part of Black Mesa, a thin marine shale in the medial carbonaceous member of the Dakota contains an abudance of Gryphaea newberryi Stanton 37 feet above the base of the Cretaceous, the lowest known occurrence of marine invertebrates in the formation. It is believed that the Dakota sandstone of Black Mesa represents deposition over a time interval that is roughly equal to the time of deposition of the Graneros shale of the Front Range.

The belief that the Dakota represents only Late Cretaceous time is suggested also by the stratigraphic rise of the Dakota southwestward across Black Mesa without a parallel increase in thickness. Projection of this trend northeastward from Black Mesa suggests that the Dakota gradually becomes older until it is entirely Early Cretaceous in age — which appears to be the fact.

The Dakota sandstone of Black Mesa is considered correlative with the Dakota of the Kaiparowits Plateau and in part correlative with the Dakota of the San Juan basin; all three seem unquestionably to be a genetic unit. South of Showlow a brackish-water fauna is recognized near the base of an undifferentiated sequence of Cretaceous rocks. This fauna is probably Greenhorn in age and is correlative with the Dakota sandstone of Black Mesa. East of the Showlow area, near Springerville, Arizona, the Dakota may be older, because Young (1957) describes ammonites that are of an age comparable to the Dakota of Black Mesa but are reportedly from the base of the Mesaverde group of the Springerville area. A middle Carlile fauna also is recognized in the rocks of the Showlow area (Darton, 1925, p. 150).

MANCOS SHALE

The marine shale of the Mancos intertongues south and west of the type locality, Mancos, Colorado, with sandstone units of the overlying Mesaverde group, the top of the Mancos thereby lowering in age in those directions. Evidence on Black Mesa suggests also that the base of the Mancos rises in age in those directions from the type locality, although the rate of change in age is not nearly as great. The ultimate result is the pinch-out of the Mancos

[1] As used in this report, "high-angle" applies to crossbeds dipping at angles greater than 30° from horizontal; "medium-angle" to beds dipping between 30° and 20°; "low-angle" to beds dipping between 20° and 10°; and "very low-angle" to beds dipping less than 10° from horizontal.
"Small-scale" crossbeds are less than 1 foot in length; "medium" between 1 and 10 feet long; and "large-scale" more than 10 feet long.
Grain-size description follows the classification used by Wentworth (1926) and rocks are named accordingly. A "shale" is any fine-grained rock showing shaly weathering, and a "mudstone" is a mixture of grains which wall into two or more size groups between clay and fine sand, unless more specifically described.

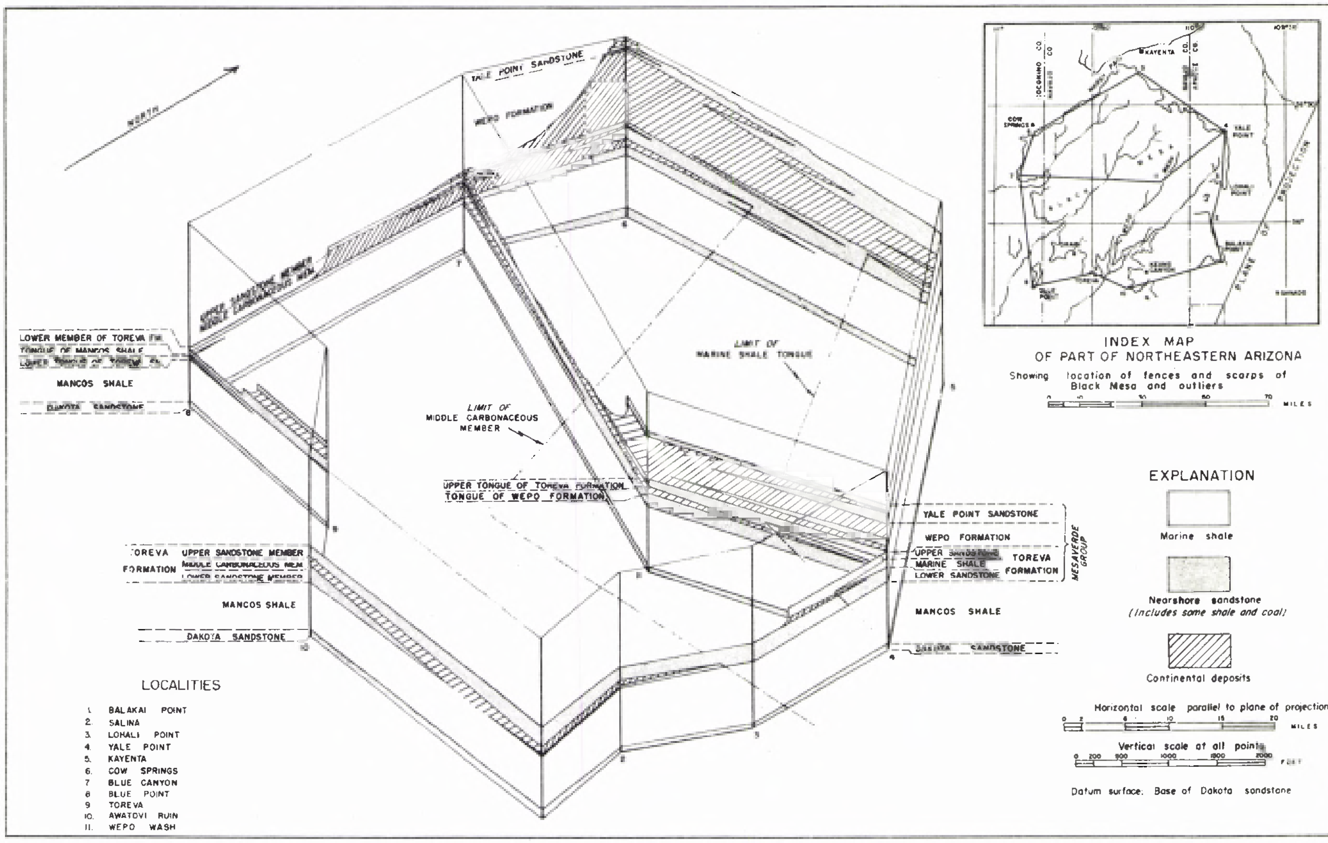

FIG. 2.—Fence diagram showing correlation of Cretaceous rocks of Black Mesa area, Arizona. Localities 6 and 7 adapted from Williams (1951).

shale to the southwest; a situation apparent in the vicinity of Showlow.

In a regional sense the Mancos shale of Black Mesa is a southwestward-extending tongue of the Mancos of the type locality and could be referred to as such; however, long accepted usage applies the formational name to the partial representative on Black Mesa.

General description and field relations

In the Black Mesa area the Mancos shale is banded by thick zones of light gray and medium dark gray and is yellowish gray in the sandier parts. Upon weathering the dark gray materials assume a bluish cast. In many other exposures debris from sandy, yellowish gray zones cover the outcrop enough to impart a yellowish cast to the entire Mancos section.

The Mancos is composed of silt and clay and very fine-grained sand. Thinly bedded fine-grained sandstones occur in several zones and are particularly prominent about midway up the unit in a lithologic zone that is conspicuous throughout the area, nearly all exposures of which contain the ammonite Collignoniceras wollgari (Mantell), diagnostic of the basal member of the Carlile shale of the Front Range in north-central Colorado.

Gypsum occurs in veinlets and as isolated crystals and is locally abundant in several zones. Marl is common near the base, in a faunal zone which is equivalent in age to part of the Greenhorn, and also beneath the thin sandstone beds that contain Collignoniceras. This upper marl zone beneath the sandstone commonly contains cone-in-cone structures, and, because of this, is conspicuous in most exposures. Beds of bentonitic clay, locally as much as 3 feet thick, are present at several horizons. All the sediments in the Mancos shale of Black Mesa are well sorted, weakly cemented, and have flat, very thin bedding. The formation weathers into a smooth slope, with the exception of the Collignoniceras-bearing beds which form a cliff or a series of thin ledges at most localities. The slope formed by the Mancos is commonly covered by talus from the cliffs of the overlying sandstone beds of the Mesaverde group.

The upper and lower contacts of the Mancos shale are gradational. Although gradational, the basal contact with the upper sandstone member of the Dakota is easily selected in most localities. However, the contact with the Mesaverde is gradational through a fairly thick sequence of transitional beds, and the selection of a formational boundary is quite arbitrary. In the Black Mesa area it is placed at the base of the zone of transition, because in most places the zone occurs in a cliff that is continuous with the cliff formed by the overlying Toreva formation of the Mesaverde group and that is in physiographic contrast to the slope of the Mancos.

The Mancos-Mesaverde contact in the Black Mesa area is complicated by intertonguing between the units (fig. 2). Throughout much of the area these intertonguing relations are in contrast to the general trend of northeastward tonguing of Mesaverde units into the top of the Mancos. Although in contrast to the regional trends, the relations are not of regional significance; they are the result of deposition in a large bay of early Mesaverde-late Mancos time in the southern part of the Black Mesa area. This bay was bounded on the offshore side at the northeast by a large peninsula (spit?) of sand which became the northern phase of the lower sandstone member of the Toreva formation. As a result of the presence of this bay, and its confining peninsula, a prominent tongue of the Mancos shale extends from the southeast into the basal part of the Toreva formation. Because of its distinctly lagoonal and paludal nature, this tongue is not considered a part of the Mancos shale, but is referred to as the middle carbonaceous member of the Toreva formation.

From Blue Point, in the extreme southwestern part of the Black Mesa area, the Mancos is progressively thicker toward the northeast and is 669 feet thick near Rough Rock, on the northeastern corner of Black Mesa. This thickness is the maximum for the area. Variations in the general trend of thickness are believed to be due primarily to variations in thickness, or local absence, of the upper sandstone member of the Dakota, but partly to intertonguing with the Mesaverde.

Age assignment and correlation

The Mancos shale of this area appears to include equivalents of most of the Greenhorn limestone and the Carlile shale of the Colorado Front Range, although oldest Greenhorn faunal zones and youngest Carlile zones have not been recognized.

Because of the occurrence of the Dakota-Mancos contact higher in the faunal section and the Mancos-Mesaverde contact lower in the faunal section on the southwest, a specific breakdown in terms of feet of Mancos section is not possible for many faunal zones across the Black Mesa area. With only an approximation of average thickness, therefore, the Mancos shale of the Black Mesa area contains the following faunal zones, as set up by Cobban and Reeside (1952, p. 1015 et seq.) (fig. 3):

1. Lower zones of Greenhorn limestone and equivalents — averages approximately 50 feet thick in the basal Mancos, and extends into the Dakota sandstone in the southwestern part of the Black Mesa area. It has not been possible to say with any assurance how many of the faunal zones of the lower part of the Greenhorn are present in this area, but it is believed that the thickness of the zone is not great enough to include much more than the youngest part of the Gryphaea newberryi Stanton and Exogyra columbella range, both fossils being common throughout the area.

2. Sciponoceras gracile (Shumard), middle Greenhorn zone — averages very roughly about 40 feet thick in the Black Mesa area, but its upper limit has not been ascertained with accuracy. This is the most conspicuous fossil horizon in the Cretaceous of this area, and has many other forms associated with the index baculitid.

3. Inoceramus labiatus Schlotheim, highest Greenhorn zone — averages about 235 feet thick in this area. Fragments of the index species are common in fresh material beneath the surface. The top of this zone is placed at the lowest occurrence of Collignoniceras woollgari (Mantell) in the Black Mesa area and is arbitrary at most localities because of the sporadic occurrence of the ammonite in the basal part of its zone.

4. Collignoniceras woollgari (Mantell), lowermost Carlile zone — averages 159 feet thick in the Black Mesa area. The ammonite-bearing cliff-forming sandstone unit contained approximately midway in this zone is traceable throughout the area and is one of the most prominent marker beds in the Cretaceous sequence. These sandstone beds contain impressions of the type ammonite in every exposure that has been examined carefully.

5. Higher zones of Carlile shale and equivalents — essentially absent in the southern part and up to 150 feet thick in the northern part of Black Mesa. This zone is not clearly marked by faunal representatives; however, presence of Inoceramus dimidius White in the Mancos-Toreva transition beds would indicate inclusion of the zone of Scaphites warreni Meek and Hayden in these beds and imply that the zone of Collignoniceras hyatti (Stanton) is represented in the usually barren upper part of the Mancos shale in the northern part of Black Mesa.

Paleontologic and stratigraphic evidence presented in other reports (Reeside and Baker, 1929, p. 35; and Gregory and Moore, 1931, p. 100-110) suggests that the Mancos shale of Black Mesa is identical, as nearly as can be determined, with the Tropic shale of the Kaiparowits Plateau area in southern Utah.

Relationships from the northwestern part of the San Juan basin (near Shiprock) to the southwestern part (near Gallup) are similar, although not identical, to those across Black Mesa from northeast to southwest. The section at Shiprock, however, includes in the Mancos shale all rock units equivalent in age to the Mesaverde group of Black Mesa, and rock units of an age comparable with the Mesaverde group of the Shiprock area are not present in the Black Mesa area. Equivalents of the Mancos shale of Black Mesa occur entirely in the lower part of the Mancos of the Shiprock area, between the Dakota and the Juana Lopez sandstone member (of Rankin, 1944, p. 12) of the Mancos.

No marine shales assignable to the Mancos have been recognized south of the Black Mesa area, although several workers (Veatch, 1911; Lee, 1915; Darton, 1925; and Pike, 1947) discuss areas near Showlow where sandstone associated with coal deposits contains a marine fauna comparable with that in the zone of Collignoniceras hyatti in the Carlile shale.

MESAVERDE GROUP

The Mesaverde group of Black Mesa, in its entirety, is older than any part of the Mesaverde at the type locality in southwestern Colorado. Continued usage of the name in the Black Mesa area parallels the extension of the name to rocks older than those of the type locality in the expanded section along the southern edge of the San Juan basin, New Mexico. As discussed by Reeside and Baker (1929), the Mesaverde group of Black Mesa is correlative also with the Straight Cliffs sandstone of southern Utah, and it coalesces south of the Navajo reservation with the Dakota sandstone.

Three distinct formations have been recognized and mapped in the Mesaverde group of Black Mesa (Repenning and Page, 1956). The lowest of these has been subdivided into three members, which have been mapped in a wide belt across the southern part of the Black Mesa area. The three formations are named the Toreva formation at the base, the Wepo formation, and the Yale Point sandstone, which is the youngest Cretaceous unit in the area. The Toreva formation is further subdivided into a lower sandstone member, a middle carbonaceous member, and an upper sandstone member. The Mesaverde was first treated as a group in the Black Mesa area by Williams (1951), and present treatment as such is in keeping with its treatment by Allen and Balk (1954, p. 90) in the San Juan basin and vicinity.

TOREVA FORMATION

At the type locality, 1.3 miles northwest of the settlement of Toreva in the Hopi Indian Reservation, the lower

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it consists of an alternation of ... edded carbonaceous mudstone, varicolored siltstone units with coal, and thick lenses of yellowish gray fine- to coarse-grained poorly sorted quartz sandstone that is trough crossbedded at a medium angle, with medium-scale crossbeds. Mica is common in sandstone and siltstone units. In some places, as in Keams Canyon, the unit consists almost entirely of sandstone with shale and coal in the lower part only. In other places this member contains very few sandstone units, especially in the southeastern part of the area where the unit coalesces with the Mancos shale because of the eastward pinch out of the underlying lower sandstone member. The middle member pinches out toward the north.

The upper sandstone member is yellowish gray to grayish orange-pink sandstone composed of fine- to very coarse-grained, subrounded to subangular, poorly sorted quartz sand. Mica is present as an accessory mineral, as in other members of the Toreva formation, but the upper member contains also a large amount of altered feldspar, especially in its higher parts. The upper part of the upper sandstone member is commonly conglomeratic in the southern part of Black Mesa, especially so in the southwestern part of the area, where the uppermost part of the member contains cobbles up to 3 inches in diameter composed of silicified limestone in which Paleozoic fossils are common.

The upper sandstone member consists of a series of irregular and lenticular sets, 6 inches to 4 feet thick, that contain trough crossbedding at a medium to low angle, with crossbeds of medium scale. Within and between these sandstone sets, especially toward the top, are found mudstone pellets and lenses up to 3 feet thick. A few units within the upper member are slumped and folded in some localities.

Beyond the point of disappearance of the middle member toward the north, the upper and lower members retain their lithologic characters with little variation, but they are not separable, without more detailed study than has been made, because of their similarity and the absence of an intervening unit. This undivided unit contains, toward the north, an additional unit of coal, carbonaceous shale, and sandstone, and is capped by a ledge of medium- to fine-grained sandstone. The conglomeratic nature of the uppermost part of the upper member diminishes toward the north, and also the Toreva formation is complicated in the northeastern part of Black Mesa by the presence of a tongue of marine shale in its higher part. This marine tongue is stratigraphically higher than most of the Toreva formation in the area extending southwest toward the type locality. However, because the sandstone unit overlying the shale tongue coalesces toward the south with a sandstone unit beneath the shale tongue which, in turn, coalesces with the uppermost part of the Toreva formation and is inseparable from it (fig. 2), these sandstone units, and the included marine shale in the northeastern part of the area, are defined as part of the Toreva formation.

At Rough Rock the Toreva formation is 278 feet thick, the upper sandstone being 56 feet thick, the middle marine shale 78 feet thick, and the lower sandstone 144 feet thick. Southwest of this area the marine shale pinches out, and the upper sandstone and the upper part of the lower sandstone coalesce. In the same area the upper part of the lower sandstone is separated from the lower part of the unit by a tongue of the overlying Wepo formation. Thus separated from the main part of the Toreva formation, the sandstone units adjacent to the marine shale form an upper tongue which extends southward above the main body of the Toreva (fig. 2). The uppermost part of the main body, underlying this upper tongue and the tongue of the Wepo formation, is the host rock for considerable uranium mineralization in the particular area where these stratigraphic relations are developed.

The upper tongue of the Toreva formation is recognized over a fairly wide area in the northeastern part of Black Mesa. It becomes conglomeratic southwest of the point of pinch-out of the marine shale, and has medium angle, medium scale, prominent trough-type crossbedding. Fragmental marine vertebrates have been found in it, but no invertebrates; however, its age is reasonably well indicated by the invertebrates in the marine shale.

One other prominent tongue of the Toreva formation is present in the southwesternmost exposure of the Cretaceous rocks of Black Mesa. It represents the oldest deposition of Mesaverde type in the Black Mesa area; at Blue Point it is 111 feet above the cliff-forming *Collignoniceras*-bearing sandstone zone in the Mancos shale, and the base of the Toreva formation lies 15 feet above this cliff. Northeastward this interval between the base of the Toreva and the cliff formed by the Mancos is progressively greater, and at Rough Rock it is 285 feet.

Although thicknesses of the members of the Toreva formation vary considerably in different localities across the southwestern half of Black Mesa, the overall thickness of the formation is approximately constant throughout this area (fig. 2). It is roughly 300 feet thick in southern Black Mesa, thinning to 140-240 feet along the pinch-out line of the middle carbonaceous member, and thickening to 235-325 feet where it is coalesced with the upper tongue on the northeast side of the area.

Age assignment and correlation

Fossil evidence and intertonguing relationships suggest that the Toreva formation at its type locality in southwestern Black Mesa is equivalent in age to all but the basal part of the Carlile shale; and in the northeastern

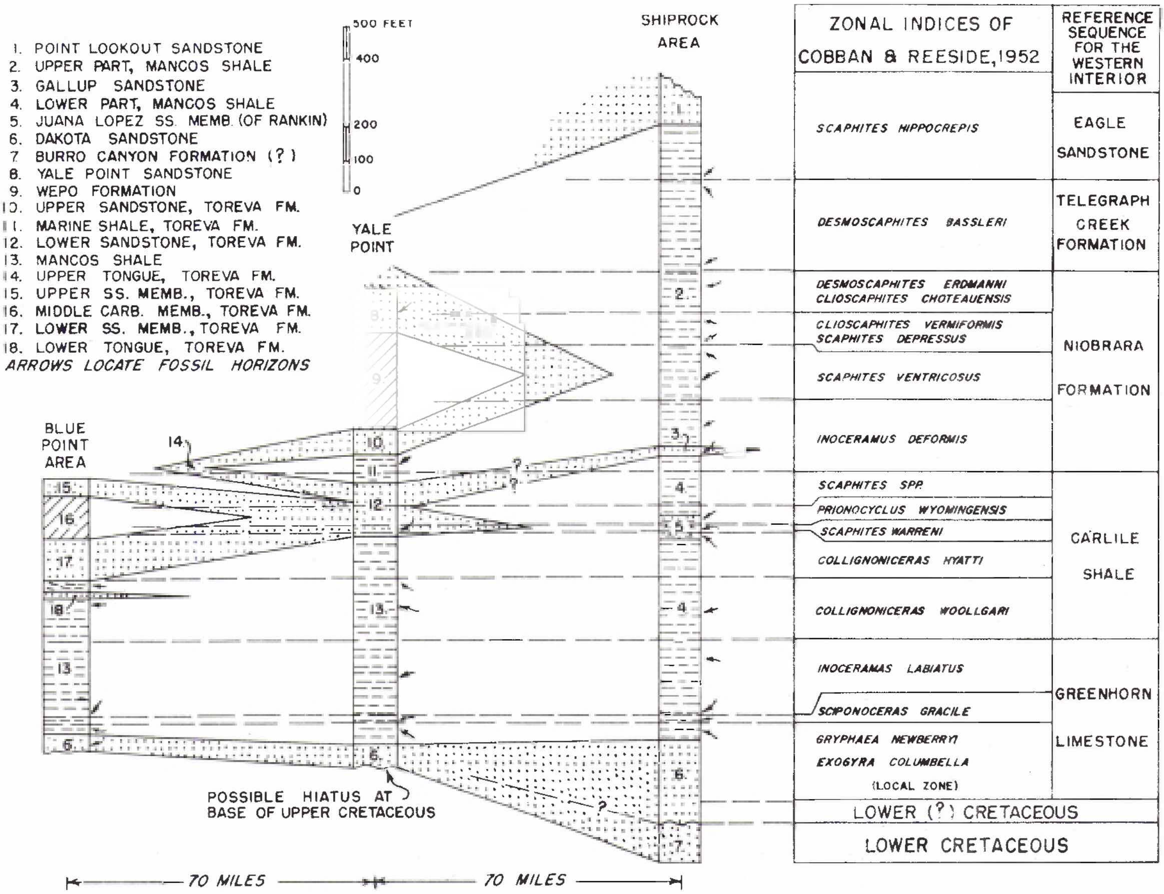

FIG. 3.—Time-lithologic correlation chart, Black Mesa to San Juan Basin. Shiprock column adapted from Reeside (1924) and Pike (1947).

part of the area, the formation includes rocks as young as basal Niobrara. The nature of the Toreva formation, which is chracterized by repeated diastems and deposits of varied environments, is such that it is impossible to say that the formation contains rocks representing all parts of the period spanned by its parts.

The Toreva formation is considered correlative with: Rankin's Juana Lopez member of the Carlile shale (1944) in the northern part of the San Juan basin, the lower part of the Gallup sandstone in the area south of Gallup, the Ferron sandstone member of the Mancos shale in east-central Utah, and an unknown amount of the basal part of the Funk Valley formation and Straight Cliffs sandstone of Utah. In the northern part of the area the upper part of the Toreva formation appears to be generally correlative with the upper part of the Gallup sandstone, the Mulatto tongue of the Mancos shale, and the Dalton sandstone member of the Crevasse Canyon formation.

WEPO FORMATION

Overlying and in gradational contact with the Toreva formation throughout most of the Black Mesa area is a sequence of beds composed chiefly of continental shale and sandstone but including some marine sandstone. This sequence is named the Wepo formation of the Mesaverde group (Repenning and Page, 1956). The type section is 7 miles northeast of the town of Pinon on the west side of Wepo Wash, where the entire Mesaverde group of Black Mesa is exposed. Above Wepo Wash at this locality are 142 feet of the cliff-forming Toreva formation and 656 feet of the slope- and ledge-forming Wepo formation, including the upper tongue of the Toreva formation, which occupies the interval from 67 to 134 feet above the base of the Wepo formation. In the type section the Wepo formation is capped by 50 feet of the overlying Yale Point sandstone of the Mesaverde group. The contrast between these two formations is an erosion surface of minor relief.

General description and field relations

The Wepo formation comprises a thick series of intercalated siltstone, mudstone, sandstone, and coal. The siltstone and mudstone units range in color from dark olive-gray through light olive-brown to medium light gray. In many places they are carbonaceous, and throughout the area they contain sandy zones and sandstone lenses. At most localities their bedding is flat, laminated to very thin, although very low-angle trough crossbedding is found in different parts of the section throughout the area. Bedding is usually masked by the shaly weathering of these units.

Sandstone units in the Wepo formation are crossbedded and are generally yellowish gray. They vary from weakly cemented, very argillaceous units, which weather into a slope physiographically indistinguishable from the mudstone and siltstone slopes, to firmly cemented, cliff-forming units as much as 40 feet thick. The sandstone is poorly sorted and composed of very coarse- to fine-grained subrounded to subangular clear and frosted quartz. Altered feldspar, mica, and black minerals are present at most localities as accessories. The thicker sandstone units are conglomeratic in part, with a concentration of conglomerate near their base. Iron-rich concretions, mud pellets, silty lenses, and carbonized plant remains are common.

Coal beds are common in the siltstone units in the vicinity of major sandstone units, and hard red baked shale resulting from burned coal is typical of the formation throughout the area.

The Wepo formation thins northeast across Black Mesa as a result of tonguing in that direction into the underlying Toreva formation and into the overlying Yale Point sandstone. This thickness variation cannot be demonstrated in the southern half of Black Mesa because of removal of the upper part of the formation by recent erosion. The thickness of the entire formation ranges from 743 feet east of Cow Springs to 318 feet near Rough Rock.

Age assignment and correlation

On the basis of fossils collected above and below the Wepo formation and intertonguing relationships, it is considered equivalent in age to the lower part of the Niobrara formation of the Colorado Front Range, with the possibility that some upper Carlile equivalents exist in the formation in the southern part of the area.

The Wepo formation is considered correlative to the Crevasse Canyon formation (Allen and Balk, 1954; not the Crevasse Canyon of Reiche, (1941, fig. 3) of the southwestern part of the San Juan basin in the vicinity of Gallup, New Mexico. However, it is possible that some of the time of the Wepo formation is represented in the upper part of the Gallup sandstone in that area, and certainly the Gallup sandstone and part of the Mancos shale overlying the Gallup in the Shiprock area are comparable in age with parts of the Wepo formation. North of Black Mesa a medial part of the Straight Cliffs sandstone is considered correlative to the Wepo formation.

YALE POINT SANDSTONE

At the type section, three-fourths of a mile west of Yale Point, and to the west along the northern escarpments of Black Mesa the massive Yale Point sandstone forms a continuous vertical cliff overlying the Wepo formation and capping Black Mesa. The cliff is a sheer face 200 feet high at Yale Point and maintains that thickness across a distance of more than 40 miles, except for several wind gaps.

The Yale Point sandstone crops out in only a small area. Although its 40-mile scarp is spectacular, in many places the formation is present as only a very narrow ridge along its area of outcrop and nowhere extends for more than 20 miles southward which is an exceptional distance. The southward disappearance of the formation is due partly to recent erosion, but principally to its intertonguing with the underlying Wepo formation to the south.

The lower contact of the Yale Point sandstone in the type area is a sharp surface of minor erosion. On a regional scale it is arbitrary because of the intertonguing relations. No younger sediments overlie the formation and its upper limit is the surface of recent erosion.

General description and field relations

The Yale Point sandstone is yellowish gray, weathering grayish orange, and is composed of coarse- to medium-grained subrounded to subangular clear quartz. It has fair sorting and contains large amounts of altered feldspar and mica as accessory minerals. Bedding of the formation is lenticular, and individual units have medium- to low-angle, medium-scale, trough type crossbedding. Thin silty units are present at widely spaced intervals, which are not apparent in the cliff face but on less precipitous exposures permit the formation to weather into a series of ledges and minor slopes. South of the northern escarpment of Black Mesa, intertonguing with the Wepo formation introduces many finer-grained units into the Yale Point sandstone and its outcrop is decidedly ledgy. Minor amounts of coal are present in the slope-forming units.

The Yale Point sandstone is 204 feet thick at Yale Point. Its variations in thickness along the northern escarpment of Black Mesa are controlled entirely by erosion. The maximum thickness observed was slightly more than 300 feet, at the north end of Marsh Pass. Southward the formation decreases markedly in thickness because of intertonguing with the Wepo formation, and it is only 50 feet thick west of Wepo Wash north of Pinon, 20 miles south of the northern escarpment. The thickness of the underlying Wepo formation shows an equal increase over this distance, suggesting that most of the loss in thickness of the Yale Point sandstone is due to intertonguing rather than erosion.

Age assignment and correlation

Fossil evidence from Yale Point of Black Mesa places its age at middle Niobrara.

Based on genetic and paleontologic evidence, the Yale Point sandstone is considered correlative with the Hosta tongue of the Point Lookout sandstone, as used by Allen and Balk (1954, p. 90) in the southwestern part of the San Juan basin in New Mexico. North of Black Mesa the Yale Point sandstone appears, on the basis of lithologic thickness and sequence, to be correlative with the highest unit of the Straight Cliffs sandstone shown in Gregory's section at Collett Canyon (1931, p. 109, unit 31); however, field evidence has not been collected to support this correlation. From Gregory's generalized section of the Kaiparowits Plateau (Gregory, 1917, pl. 5) it would seem that this unit is slightly more than halfway up the Straight Cliff section of that area.

UPPER BOUNDARY OF CRETACEOUS ROCKS

Although considerable thicknesses of Cretaceous rocks younger than the Yale Point sandstone are present in the San Juan basin and in the Kaiparowits Plateau area, none are present in the Black Mesa area. However, it seems reasonable to assume that some of the units were once present and continuous between the two areas, but recent erosion has removed them across the area of Black Mesa. The next later depositional record in the Black Mesa area is that of the Pliocene Bidahochi formation, which overlies the Dakota, Mancos, Toreva, and Wepo formations in the southern part of the area. The hiatus between the Cretaceous rocks and the Bidohochi formation in the Black Mesa area represents a long period of deposition, diatrophism, and erosion.

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