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EXCERPTS FROM WILLIAMS THESIS (1951)

Mesaverde Group

General

The Mesaverde group was named by Holmes (1877, p. 35) for Cretaceous strata having a three-fold division which are exposed at Mesa Verde in Montezuma County, southwestern Colorado. The three divisions as described by Holmes are the "lower escarpment sandstone", the "middle coal group", and the "upper escarpment sandstone". The names Point Lookout sandstone, Menefee formation, and Cliff House sandstone, respectively, were given by Collier (1919, p. 296) to the units of the threefold group. Because the individual formations are not traceable to many localities, the name Mesaverde has been used for the group throughout the west.

A threefold group of rocks which forms the upper part of Black Mesa were referred by Gregory (1917, p. 75) to the Mesaverde group. It consists of a lower escarpment sandstone, a ledge-slope coal sequence in the middle and an upper escarpment sandstone. These units are clearly exposed on the north and northeast faces of Black Mesa.

The lower escarpment sandstone has a basal member which is believed to have been formed as a beach and will be termed the "basal sandstone member". Above this sandstone is an arkosic deposit of deltaic type which is the most prominent key-bed on Black Mesa. It is a sandstone, locally an arkose, that is a con-

spicuous feature for 70 miles along the western side of the mesa. It will be termed "arkosic member".

Above the arkosic member is a series of strata consisting of thin-bedded sandstone, mudstone, lignite and coal which will be termed "coal-bearing member". Cyclic sedimentation is the most pronounced feature of this member.

Overlying the coal-bearing member is a massive sandstone. It forms the crest of the mesa in the north and northeast sections, forming a sheer cliff up to 300 feet in height. It will be termed "upper sandstone member".

The Mesaverde group is composed mainly of continental deposits with only minor amounts of marine deposits included. At the north end of Black Mesa thin marine deposits occur within 200 feet of the base of the Mesaverde group. Marine fossils from one horizon, 180 feet above the base, have been tentatively identified by the writer as equivalent to the Niobrara fauna of the Great Plains. In a section 4 miles south of Kayenta, on the northeast side of Black Mesa, Reeside and Baker (1927, p. 34) found a fauna of Niobrara age 110-185 feet above the formation base. Because the Mesaverde group of Black Mesa is equivalent in age to the Niobrara of the Great Plains, it is the same age as the lower part of the Mancos shale of the San Juan Basin. Escept for the upper sandstone member, beds of the Mesaverde are believed to be regressive deposits. Thus, the Mesaverde group of the San Juan area is of younger age than the Mesaverde of Black Mesa (Fig. 5).

The topography of Black Mesa is greatly influenced by the resistance of the coarse-grained, arkosic member and by the weak coal-bearing member that is capped by a resistant, cliff-

forming sandstone. In the southern portion of the mesa the upper members of the Mesaverde have been eroded away leaving the arkosic member as the crest of the mesa. The crest is formed by the dip slope of this member and only in a few places in this area are remnants of the upper two members preserved. Locally, sandstone beds of the coal-bearing member form ledges separated by slopes of mudstone. Still higher in the section is the upper sandstone member with several thin coal seams that cause it to break into ledges, though farther north it forms a sheer cliff (Pl. 15, fig. 1).

The thickness of the Mesaverde group on Black Mesa is greatest south of Cow Springs Trading Post and least in the northeast corner (Pl. 8 and 9). South of Cow Springs it is 1162 feet thick and in Marsh Pass 837 feet. The arkosic member (Pls. 8 and 9 is 365 feet thick south of the Cow Springs Trading Post (Section 2) and 470 feet at Longhouse Valley (Section 5) but only 265 feet at the north end of Marsh Pass (Section 11). South of Cow Springs Trading Post to Blue Canyon the lower part of the arkosic member thickens, but erosion has removed the upper part so exact measurements could not be made. The coal-bearing member is 678 feet thick at Section 2, south of Cow Springs, and 50 feet at Section 5 in Longhouse Valley. It thickens again to 272 feet at Section 11 at the north end of Marsh Pass.

The upper sandstone member which forms the crest of the mesa is thickest in the north. Because it forms the surface of the mesa, however, an undeterminable amount has everywhere been removed by erosion and its original thickness cannot be measured. The remnants of this member at Section 2, South of Cow Springs

Trading Post have a thickness of 122 feet, whereas at the north end of Marsh Pass they form a 300-foot, vertical cliff (Pl. 15, fig. 1).

Coal-bearing Member

The coal-bearing member consists of an alternation of rock types formed under conditions of cyclic sedimentation. The member contains sandstone, subgraywacke, siltstone, claystone, carbonaceous varieties of sandstone, lignite and coal. The most important coal beds of Black Mesa are in this member. Coal seams up to 14 feet have been encountered but no such thickness persists over great lateral distances.

Rocks of the coal-bearing member form the alternating ledges and slopes on the upper sides of Black Mesa (Pl. 13, fig. 2). They also form the surface over much of the mesa. They include sandstone, most of which is medium-to fine-grained and intricately cross-laminated. Much of this is a subgraywacke. Contacts between the beds of varying lithology are gradational.

The thickness of the coal-bearing member varies from 250 feet at the north end of Marsh Pass to 50 feet at the south and increases to 675 feet south of Cow Springs Trading Post. The change in thickness toward the south appears to indicate nearness to shore where fluctuations in the strand line have a pronounced effect.

The coal-bearing member is the lithologic unit that Reagan (1925) named the Zilhejini formation and to which he assigned an age equivalent to that of the Fruitland formation of northwestern New Mesico. Reeside (1924, p. 6) states that the Fruitland formation is equivalent in age to late Pierre and early Fox Hills of the Great Plains section. Reeside and Baker (1929, p. 36) consider the Zilhejini formation equivalent in age to the Niobrara of the Great Plains and the writer agrees with this interpretation.

The lower contact of the coal-bearing member has arbitrarily been placed where continental mudstone and coal become predominant and where cyclic sedimentation starts. The precise location of this contact, based on lithology, varies somewhat from place to place.

The upper contact of the coal-bearing member is clearly marked by the top of the cyclic sediments and the coal beds and by the base of a massive, cliff-forming sandstone. The cliff is 300 feet high and can easily be recognized. In addition, its lithology is very different from that of the underlying mudstone and coal.

Texture. In the coal-bearing member medium-to very fine-grained sandstone and subgraywacke grade upward into shaly siltstone, which in turn grades into normal claystone, then into carbonaceous claystone, lignite and coal. Above the coal beds this sequence of rock types, grading one into another, is repeated in reverse order (Fig. 37). Most of the sandstone does not extend laterally for more than 3 miles and, in places, sandstone facies grade into siltstone facies and these in turn are supplanted by coal. The great lateral and vertical range in lithologic types makes a textural study for correlation purposes of little value. The texture determined from 10 samples taken from the sandstone units has an average median diameter of 0.22 which is classed as fine-grained. The range is from 0.07 to 1.1 mm. Roundness of grains varies so much,

which is located 7 miles north of Cow Springs Trading Post. This mine faces east at a site approximately 3 miles east of the western rim (Pl. 44, fig. 1). Approximately 10 tons of coal per day are shipped from here by truck, 120 miles to Flagstaff, Arizona, where the owners have contracts with business firms.

A second operating mine is the Kayenta Coal Mine. It is reached from Route 1, five miles south of Marsh Pass, by a road leading 7 miles east of the western rim of Black Mesa. The coal seam is the uppermost one in the coal-bearing member. It is 6½ feet thick at the mine entrance. The outcrop is exposed in a stream cut along the valley floor.

Kayenta Coal Mine ships approximately the same amount of coal as does the Cow Springs Mine and shipments are made 160 miles to Flagstaff, Arizona, by truck.

Coal Deposits

The coal deposits of Black Mesa are extensive and of a fair quality. They are mainly subbituminous with some bituminous present. The fixed carbon content (Table 8 and 18), indicates the coal to be equal in quality to that mined and shipped at Gallup, New Mexico.

The ash content of Black Mesa coal is very high. According to men who use this coal in large furnaces, however, it is preferred over New Mexico coals because clinkers do not form. The coal leaves white to cream white powdery ash upon burning. The calorific power of the coal averages 10,500 B.t.u. which, in comparison to other western coals is low.

Cretaceous coal beds of Black Mesa are at two horizons. The lower is at the top of the Dakota (?) sandstone, and the upper is in the coal-bearing member of the Mesaverde group.

The Dakota (?) sandstone coal seam varies from inches to 7 feet in thickness. South of Cow Springs Trading Post it is in two seams, the lower up to 6 feet in thickness, and the upper only 5 inches thick (Pl. 18, fig. 2). This bed is quite variable in thickness and may become reduced from 4½ feet to 6 inches in less than a hundred yards. Thus, the Dakota (?) sandstone coal distribution is very erratic and not conducive to large scale mining.

One mine in the Dakota coal is operating at present. It is at Coal Mine Canyon approximately 16 miles east of Tuba City on Route 2. The mine is operated by Hopi Indians and the coal is shipped by truck into Tuba City for use in Government installations.

The production of this mine varies with consumption. No statistics could be obtained. The coal seam is 6½ feet thick at the mine entrance but contains several thin bone layers.

The Mesaverde coal horizon is in the upper part of the formation. The cyclic sedimentation which is so pronounced referred to in this paper as the coal-bearing member, in this member is responsible for a great many thin coal seams (Pl. 8). The greater percentage of the coal present in Black Mesa occurs in this member. Only 10 of the seams exceed 3 feet in thickness. The thickest single coal seam is 14 feet. This thickness is not consistent but becomes less in both directions along the outcrop.

Two coal mines are at the present time operating at the Mesaverde horizon in the western part of the mesa.

The Cow Springs Coal Mine is located 7 miles north of Cow Springs Trading Post and 3 miles back from the edge of the Mesa (Pl. 1) (Pl. 44, fig. 1). The mine is being developed along on two coal seams which are 30 to 90 feet below the massive sandstone that caps the mesa. Approximately 10 tons of coal per day are shipped by truck into Flagstaff, Arizona, 120 miles to the southwest.

A proximate analysis of the coal is as follows:

Moisture content----------17.4 per cent

Volitile material----------37.0 per cent

Fixed Carbon----------41.6 per cent

Ash content---------- 4.0 per cent

B.t.u. content----------10,450.

When this coal arrives in Flagstaff it consists of pieces approximately the size of walnuts. The rough roads are undoubtedly the cause of secondary breakage. Excessive fine fragments produced in this manner make the coal dangerous for shipment. Before rail shipments could be made, this coal probably would require washing to remove coal-dust.

The second coal mine in operation in the Mesaverde sandstone at present is the Kayenta or Maloney Coal mine. The road to this mine leaves the main road (Route 1) approximately 5 miles south of Marsh Pass. The mine is located about 7 miles in from the mesa rim. The mine is on the bank of a stream which dissects the floor of one of the interior valleys (Pl. 1). It is poorly located, however, because gravity cannot be used in handling the coal. The seam measures 6 feet at the entrance to the only adit. Stratigraphically it is approximately 30 feet below the upper sandstone member in the Cretaceous sequence.

The coal at the Kayenta mine is bituminous. It breaks into large chunks and even after trucking to Flagstaff (150 miles) the chunks measure up to 10 inches in diameter. A proximate analysis of this coal is as follows:

Moisture content	-	11.0 per cent
Volatile material	-	37.7 per cent
Fixed carbon	-	47.1 per cent
Ash content	-	4.2 per cent
B.t.u. content	-	11,640

This analysis places the coal in the bituminous rank. Several factors present problems which must be overcome before Black Mesa can produce much coal. The first is the inaccessability of the Mesa. The nearest railroad is the Santa Fe which is 90 to 150 miles to the south. To transport the coal for such a distance makes the cost prohibitive. The continual bouncing that the coal receives on such along haul produces a great amount of coal-dust.

A second factor related to economic production of the Black Mesa coal is the water requirement. Mining and washing of coal products necessitate great quantities of water which at the present time are not available near Black Mesa. A last factor, but one which probably with time could be remedied, is an adequate market for selling the coal. Only a few local industries in and about Flagstaff are now using the coal.

The Black Mesa coals are not good coking coals. Complete combustion of the coals leaves only a very white ash. Furthermore, the sulphur content of the coals is very high as evidenced by thin layers of sulphur immediately above the coal seams.

The limited portion of Black Mesa covered by this report does not permit one to make a logical estimate of the total tonnage of coal present. Campbell and Gregory (1911, p. 2381) estimate the tonnage from beds with a thickness of 3 feet or more to exceed 8 billion. The writer has been unable to make any estimates.

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Texture. In the coal-bearing member medium-to very fine-grained sandstone and subgraywacke grade upward into shaly siltstone, which in turn grades into normal claystone, then into carbonaceous claystone, lignite and coal. Above the coal beds this sequence of rock types, grading one into another, is repeated in reverse order (Fig. 37). Most of the sandstone does not extend laterally for more than 3 miles and, in places, sandstone facies grade into siltstone facies and these in turn are supplanted by coal. The great lateral and vertical range in lithologic types makes a textural study for correlation purposes of little value. The texture determined from 10 samples taken from the sandstone units has an average median diameter of 0.22 which is classed as fine-grained. The range is from 0.07 to 1.1 mm. Roundness of grains varies so much,

Coal. The coal seams which are found in the coal-bearing member vary in thickness from a few inches up to 14 feet. A statistical study shows 38 coal seams to total 115 feet for an average of 3 feet per seam. If the coal seams under 9 inches are omitted then 24 seams total 105 feet for an average of 4.4 per seam. By using 3 feet as the minimum mining width, then 10 coal seams with a total of 68 feet remain for an average of 6.8 feet per seam.

The above figures seem to indicate that the coal deposits of Black Mesa are extensive and should warrant mining operations. The principal trouble encountered is the failure of any one seam to maintain its thickness over an appreciable distance. Measured sections including a typical coal seam are shown in Figure 38.

Much of the coal on Black Mesa is both underlain and overlain by lignite which might offer some mining problems. It would cause dilution of the coal during its extraction.

The composition of Black Mesa coal varies in different seams, with the better grades being closer to the top of the section. The results of 12 proximate analyses are shown in Table 18. The variation in the grade of these coals is indicated by the analyses. The B.t.u. content was determined on two samples and is given in Table 18.

Coals on Black Mesa are sub-bituminous in rank and contain considerable ash, but as previously discussed have a desirable white ash. Very few samples show a red ash.

Two mines are at present actively mining and shipping coal from the Mesaverde zone. One is the Cow Springs Coal Mine

which is located 7 miles north of Cow Springs Trading Post. This mine faces east at a site approximately 3 miles east of the western rim (Pl. 44, fig. 1). Approximately 10 tons of coal per day are shipped from here by truck, 120 miles to Flagstaff, Arizona, where the owners have contracts with business firms.

A second operating mine is the Kayenta Coal Mine. It is reached from Route 1, five miles south of Marsh Pass, by a road leading 7 miles east of the western rim of Black Mesa. The coal seam is the uppermost one in the coal-bearing member. It is 6½ feet thick at the mine entrance. The outcrop is exposed in a stream cut along the valley floor.

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The ash content of Black Mesa coal is very high. According to men who use this coal in large furnaces, however, it is preferred over New Mexico coals because clinkers do not form. The coal leaves white to cream white powdery ash upon burning. The calorific power of the coal averages 10,500 B.t.u. which, in comparison to other western coals is low.

Cretaceous coal beds of Black Mesa are at two horizons. The lower is at the top of the Dakota (?) sandstone, and the upper is in the coal-bearing member of the Mesaverde group.

The Dakota (?) sandstone coal seam varies from inches to 7 feet in thickness. South of Cow Springs Trading Post it is in two seams, the lower up to 6 feet in thickness, and the upper only 5 inches thick (Pl. 18, fig. 2). This bed is quite variable in thickness and may become reduced from 4½ feet to 6 inches in less than a hundred yards. Thus, the Dakota (?) sandstone coal distribution is very erratic and not conducive to large scale mining.

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A proximate analysis of the coal is as follows:

Moisture content----------17.4 per cent

Volitile material----------37.0 per cent

Fixed Carbon----------41.6 per cent

Ash content---------- 4.0 per cent

B.t.u. content----------10,450.

When this coal arrives in Flagstaff it consists of pieces approximately the size of walnuts. The rough roads are undoubtedly the cause of secondary breakage. Excessive fine fragments produced in this manner make the coal dangerous for shipment. Before rail shipments could be made, this coal probably would require washing to remove coal-dust.

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The coal at the Kayenta mine is bituminous. It breaks into large chunks and even after trucking to Flagstaff (150 miles) the chunks measure up to 10 inches in diameter. A proximate analysis of this coal is as follows:

Moisture content	-	11.0 per cent
Volatile material	-	37.7 per cent
Fixed carbon	-	47.1 per cent
Ash content	-	4.2 per cent
B.t.u. content	-	11,640

This analysis places the coal in the bituminous rank. Several factors present problems which must be overcome before Black Mesa can produce much coal. The first is the inaccessability of the Mesa. The nearest railroad is the Santa Fe which is 90 to 150 miles to the south. To transport the coal for such a distance makes the cost prohibitive. The continual bouncing that the coal receives on such along haul produces a great amount of coal-dust.

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The Black Mesa coals are not good coking coals. Complete combustion of the coals leaves only a very white ash. Furthermore, the sulphur content of the coals is very high as evidenced by thin layers of sulphur immediately above the coal seams.

The limited portion of Black Mesa covered by this report does not permit one to make a logical estimate of the total tonnage of coal present. Campbell and Gregory (1911, p. 2381) estimate the tonnage from beds with a thickness of 3 feet or more to exceed 8 billion. The writer has been unable to make any estimates.