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CRETACEOUS ROCKS OF THE TIERRA AMARILLA COAL FIELD AND ADJACENT AREAS, RIO ARRIBA COUNTY, NEW MEXICO

by

E. R. LANDIS, C. H. DANE,* and W. A. COBBAN
U.S. Geological Survey
Denver, Colorado 80225

ABSTRACT

The Tierra Amarilla coal field on the east side of the Chama basin is underlain by rocks of Late Cretaceous age, including the coal-bearing Mesaverde Group. The coal is of subbituminous A rank and has been mined at several places in the field. As many as nine coal beds are present in the Menefee Formation but most are thin and lenticular. The more persistent beds are locally as much as 49 inches thick. The amount of carbonaceous material in the Mesaverde Group decreases eastward and the amount of sandstone increases. The Mesaverde also appears to thin to the east and northeast.

INTRODUCTION

The Tierra Amarilla coal field, about 2 miles (3.2 km) southeast of the town of Tierra Amarilla, is made up of areas on the east side of the Chama basin that are underlain by rocks of Late Cretaceous age. The coal field, which covers an area of about 21 mi^2 (55.5 km^2), lies near major transportation routes used by early explorers, settlers, and earth scientists. However, the coal escaped the attention of, or was not recorded by, workers who remarked on other geological aspects of the area (Newberry, 1876; Cope, 1875) or who were interested in coal resources of the general area (Storrs, 1902; Campbell, 1908, 1917; Schrader, 1906; Gardner, 1909a, b). Averitt (1942) showed the area on a map of the coal fields of the United States, and subsequent workers in the area have recognized coal-bearing rocks in the area (Read and others, 1950; Dane and Bachman, 1957, 1965; Smith and Muehlberger, 1960; Trumbull, 1959; and Doney, 1966).

C. H. Dane's work on the Cretaceous rocks of the area began almost four decades ago and was carried on, with interruptions, until 1968 (Dane and Bryson, 1938; Dane, 1946, 1948, and 1960; Landis and Dane, 1967, 1969). E. R. Landis and W. A. Cobban became involved in stratigraphic studies in the area in 1963.

GEOLOGY

The rocks exposed in and near the Tierra Amarilla coal field range from Precambrian metamorphic rocks in the Tusas Mountains east of the field (Smith and Muehlberger, 1960) to Quaternary sedimentary and volcanic rocks that are present over much of the area (Landis and Dane, 1967, 1969; Doney, 1966). This report emphasize the rocks of Late Cretaceous age that underlie, and are exposed at the surface throughout most of the Chama basin. Sedimentary rocks as old as Pennsylvanian age are known to be present under and around the edges of the Chama basin; however, because of insufficient subsurface information, the distribution of pre-Cretaceous strata is not well known.

Rocks of Tertiary age were only given a cursory examination by the authors. A sequence of rocks about 300 feet (91 m) thick unconformably overlies the Cretaceous rocks at the eastern end of the Tierra Amarilla coal field; this sequence has been assigned by Dane and Bachman (1965) to the Blanco Basin Formation and the El Rito Formation of Smith (1938), both of Eocene age (Baltz, 1967).

The Tierra Amarilla area is in the central and eastern parts of the structural feature called the Chama basin, Chama embayment, or Chama platform (Kelly, 1950; Muehlberger, 1960). The axis of the north-trending Chama syncline, which marks the structurally lowest part of the basin, passes through the western part of the Tierra Amarilla coal field. The coal-bearing Mesaverde Group has been removed from most of the Chama basin by erosion that started during Tertiary time and continues to the present.

EARLY, EARLY(?) AND LATE CRETACEOUS

Burro Canyon(?) Formation and Dakota Sandstone

In the area west of the Tierra Amarilla coal field a conglomeratic sandstone unit 55-85 feet (16.7-25.8 m) thick is probably equivalent to the Burro Canyon Formation, as McPeek (1965) suggested. Dane (1948, 1960) previously included this unit in the Morrison Formation.

In Rio Chama Canyon at North El Vado dome, the basal conglomeratic sandstone unit consists, in ascending order, of 36 feet (11 m) of gray, brown-weathering, coarse-grained sandstone, conglomeratic sandstone, and pebble conglomerate; 15 feet (4.6 m) of light-gray, brown-weathering fine-grained sandstone, in part crossbedded, containing scattered pebbles in a few stringers; and 4 feet (1.2 m) of earthy, greenish, soft sandstone at the top. Pebbles in conglomeratic parts are black, white, red, and gray, and are composed of quartz, quartzite, and, dominantly, of dense siliceous material. Maximum pebble dimension is about 1 inch. In the basal part of the unit are angular blocks, as much as 8 inches (20 cm) on a side, of soft-green, very fine grained, clayey sandstone. Crossbedding at angles up to 20 degrees is traceable for distances of as much as 3 feet (0.9 m). Beds of this unit are cemented with silica to varying degrees and form several resistant ledges that generally make a cliff above the underlying Morrison Formation.

The overlying Dakota Sandstone consists of alternating tan- to brown-weathering sandstone in beds ranging from a few feet to 60 feet (18.2 m) thick and dark-gray carbonaceous shale and siltstone in beds ranging from thin sheets and stringers to 35 feet (10.6 m) thick. The shale and siltstone beds in places amount to as much as one-third of the total thickness of the formation. Carbonaceous material is characteristic throughout the Dakota in amounts ranging from small specks, flakes, and charcoal fragments in some sandstone beds to carbonaceous and coaly shales. Sandstone ranges from very fine-grained to granule sized, and contains some small, dense, siliceous pebbles similar to those more common in the lower beds. Sandstone

*Deceased

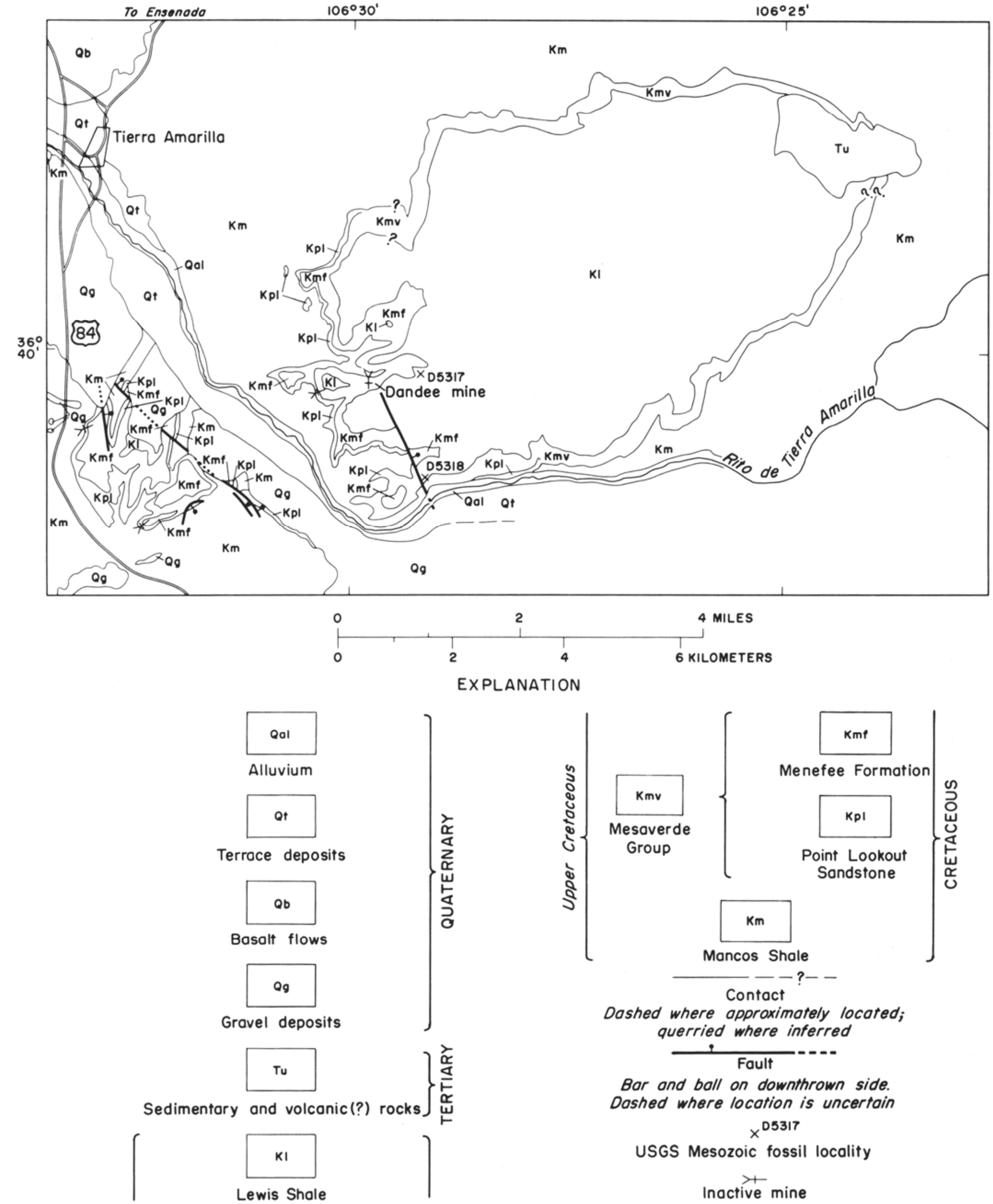

Figure 1. Geology of the Tierra Amarilla coal field area.

ranges from friable and weakly cemented to well cemented, and some, especially in the upper part, is so thoroughly cemented by silica as to be quartzite. The sandstone is thin bedded to thick bedded and massive or locally crossbedded. Ripples with a wave length of 2-3 inches (5-8 cm) mark some beds. Many sandstone beds contain the casts of numerous tubular burrows, presumably of marine worms or other organisms. On fresh fracture, the sandstone is generally light gray or pale tan but it weathers to darker colors. Thick beds make cliff-forming ledges, and the formation as a whole weathers to a steep or vertical cliff where it caps the canyon walls of the Rio Chama. A sandstone bed 2-3 feet (0.6-0.9 m) thick overlying a poorly exposed, soft, dark, silty shale unit 20-40 feet (6-12.1 m) thick forms the top of the formation in the northern part of the quadrangle. This highest sandstone bed in places weathers back considerable distances from the next underlying thick sandstone ledge of the formation and for this reason may locally appear to be absent.

The total thickness of the Burro Canyon(?) Formation and Dakota Sandstone is about 300-325 feet (91.2-98.8 m).

LATE CRETACEOUS

Mancos Shale

The Mancos Shale of the Tierra Amarilla area is about 2,000 feet (608 m) thick and contains lithologic equivalents of parts of the Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation as distinguished in northeastern New Mexico and eastern Colorado. In most previous mapping and stratigraphic studies in the northeastern part of the San Juan Basin, some or all of the units have been differentiated as members of the Mancos Shale. However, mapping in the Tierra Amarilla quadrangle (Landis and Dane, 1967) and stratigraphic studies there and elsewhere (Muehlberger and others, 1960) have shown that lithologic contacts of the beds of Niobrara age cannot be precisely located. Accordingly, Carlile and Niobrara are dropped as member names in this area. Two sandstone units of Niobrara age have been defined and mapped; the Juana Lopez Member of Carlile age has also been mapped across the area. The Graneros Shale and Greenhorn Limestone Members are retained and mapped but it is recognized that they are not wholly time-equivalent to these units at their type localities and elsewhere in eastern Colorado and western Kansas (Hattin, 1965, p. 11-15).

Much of the Mancos Shale is poorly exposed, and there are few places where complete sections of the less resistant parts of the formation can be measured. Accurate thicknesses are difficult to determine because the width of outcrop is great compared with the thickness of strata and because poor exposures, low dips with slight local variations, and slumping make it difficult to determine the true strata! attitude. Accordingly, some of the thicknesses given are not precise.

Graneros Shale Member

The Graneros Shale Member of the Mancos Shale is a soft unit 135-150 feet (41-45.6 m) thick. Though much of it is generally poorly exposed, several persistent and distinctive zones and beds nevertheless may be recognized throughout the area. Some of these are known or presumed to persist regionally.

Near the base are two zones of large brown clayey silty limestone concretions which are composed of subspheroidal aggregates a few inches in diameter. These aggregates have radial structure and, not uncommonly, incipient cone-in-cone structure. The concretions lie along two persistent bentonite beds a few inches thick that are stratigraphically 10-25 feet (3-7.6 m) apart. The lowest bentonite bed is 1-15 feet (0.3-4.6 m) above the top ledge of the Dakota Sandstone. Beds below and between these persistent bentonite beds are dark silty shale or siltstone.

The overlying part of the Graneros Shale Member is chiefly dark-gray, calcareous shale, but it contains about a dozen beds of bentonite, ranging from a fraction of an inch to several inches thick, and several beds of light-gray, dense carbonate concretions. About in the middle of the member are several beds of hard calcareous siltstone less than 1 inch thick in a zone about 2 feet (0.6 m) thick. About 25 feet (7.6 m) below the top of the Graneros is a rather conspicuous, white-weathering, platy, or flaky-weathering limestone bed, about a foot thick, in which the fossil *Inoceramus pictus* Sowerby s.l. commonly occurs. In an equally persistent but far less conspicuous zone (less than a foot thick), 5 to 8 feet (1.5-2.4 m) below the top, nodular gray limestone concretions contain *Sciponoceras gracile* (Shumard). Much of the Graneros Shale Member mapped in the Tierra Amarilla area is equivalent to the lower part of the Greenhorn faunal zone as recognized in the Pueblo, Colorado area and in western Kansas (Hattin, 1965, p. 11-15; Scott, 1964).

Greenhorn Limestone Member

The lower one-half to two-thirds of the Greenhorn Limestone Member of the Mancos Shale, which is 45-60 feet (13.7-18.2 m) thick, consists of limestone beds a few inches to two feet (0.6 m) thick alternating with beds of very calcareous shale a few inches to three feet (0.9 m) thick. Limestone comprises somewhat less than half of this part of the member. The upper part of the Greenhorn is composed almost entirely of calcareous shale like that in the lower part. However, in places it contains a few beds, ranging in thickness from a fraction of an inch to a few inches, of globigerinal limestone or limestone composed largely of inoceramid prisms. The dense, finely crystalline limestone beds of the Greenhorn are light bluish gray to medium gray on fresh fracture but weather yellowish gray to nearly white. The intervening calcareous shales are medium dark gray to olive gray on fresh fracture and weather bluish gray. The limestone characteristically contains impressions of *Mytiloides mytiloides* (Manfell) and of some ammonites; the fauna is of late Greenhorn age.

Lower Shale Unit

The Greenhorn is succeeded by a shale unit, the lower shale unit of the Mancos, about 170-210 feet (51.7-63.8 m) thick that includes a lower part of brownish-gray shale and siltstone and an upper part of very dark gray shale with septarian concretions.

The lower part, about 70 feet (21.3) thick, is mostly light-brownish-gray to light-olive-gray somewhat calcareous shale that weathers pale yellowish brown, in marked contrast to the bluish- or whitish-gray, harder, more calcareous shale of the underlying Greenhorn. The lower shale unit contains fragments of fish scales, impressions of juvenile *Collignoniceras woollgari* (Mantel)), and some small oysters. In most places, the many siltstone beds a fraction of an inch to a few inches thick become locally thicker, harder, and more abundant, and so part of the unit may form a low ridge on outcrop. The lower 15 feet (4.7 m) of the unit contains three pairs of bentonite beds, each bed 1-5 inches (2.5-12.7 cm) thick, with the lowest bed at the base of the unit.

The lower brownish-gray shale and siltstone is succeeded by about 80-140 feet (24.3-42.6 m) of very dark gray to black shale; the lower part of the dark shale is very poorly exposed. The upper part of this dark shale contains septarian limestone concretions that weather yellowish gray to grayish orange. The concretions are one foot (0.3 m) to several feet thick and as much as 5 feet (1.5 m) across; the septa are composed of brown crystalline calcium carbonate. No fossils were collected from this black shale and septarian concretion unit in the Tierra Amarilla area, but about 60 miles (96 km) farther south in the La Ventana quadrangle and adjoining areas, these beds contain several species of ammonites including *Prionocyclus hyatti* (Stanton).

Juana Lopez Member

The Juana Lopez Member, about 90-125 feet (27.4-38 m) thick, consists dominantly of dark-gray to very dark-gray shale. It is distinguished particularly near the top and the bottom of beds of hard, very fine grained calcarenite that weather grayish orange to pale yellowish brown and range in thickness from a fraction of an inch to several inches. The calcarenites consist of carbonate-cemented bioclastic material, mostly broken and reworked inoceramid shells. Trails, casts, or small ripples mark many of the beds. Other beds contain numerous molluscan shell fragments and some whole mollusc shells. Some beds, particularly in the lower part, contain fish scales, teeth, and bone fragments, and a few contain some silt or very fine grained quartz. In the more shaly middle part, limestone concretions as much as 1 foot (0.3 m) thick and 3 feet (0.9 m) across weather grayish orange. The Juana Lopez is abundantly fossiliferous and can be divided into several faunal zones (Dane and others, 1966). The fauna includes *Prionocyclus macombi, Prionocyclus wyomingensis, Scaphites warreni, Inoceramus dimidus, Lucina* sp., and *Lopha* (formerly *Ostrea) lugubris. Scaphites whitfieldi* and *Inoceramus perplexus* occur in the uppermost beds.

Middle Shale Unit

The top of the Juana Lopez Member nearly everywhere in the area forms a dip slope, above which succeeding beds are very poorly exposed. Where seen, these beds are dark-gray, fissile shale, containing in the basal part a marine fauna like that of the youngest faunal zone of the underlying Juana Lopez Member. Only a few feet of these beds are exposed. The overlying shale consists of finely micaceous, olive-gray, silty shale that weathers medium gray, contains minute carbonaceous plant fragments, and has a blocky or chunky fracture. The base of beds of Niobrara age occurs at an, as yet, undetermined level in the shale. In the southeastern part of the Tierra Amarilla quadrangle (Landis and Dane, 1967) and in discontinuous outcrops in the Boulder Lake quadrangle, which is immediately west of the Tierra Amarilla quadrangle, this shale is succeeded by a thin, medium- to coarse-grained, glauconitic sandstone. The thickness of the lower part of the middle shale unit between the glauconitic sandstone, designated the Cooper Arroyo Sandstone Member of the Mancos Shale, and the Juana Lopez Member is probably 80-100 feet (24.3-30.4 m).

The shale overlying the Cooper Arroyo Sandstone Member is about 150-180 feet (45.6-54.7 m) thick and consists of medium- to dark-gray silty shale, calcareous shale, and a few thin bentonite beds. In the upper and lower parts are a few thin beds of calcareous siltstone less than an inch thick, some of which are slightly glauconitic. Richly foraminiferal calcareous shale forms a few thin laminae, and a few beds contain *Inoceramus platinus* Logan encrusted with *Pseudoperna congesta* (Say) (formerly *Ostrea congesta).*

Cooper Arroyo Sandstone Member

At the type section in the Boulder Lake quadrangle, the Cooper Arroyo consists of 2 feet, 81/2 inches (0.8 m) of coarse- to medium-grained glauconitic sandstone (Landis and Dane, 1967). At a few localities, the Cooper Arroyo Sandstone Member has a small fauna that includes *Inoceramus inconstans* Woods (of Fiege), which is an index species of early, but not earliest, Niobrara age, *Placenticeras* sp. *Ostrea congesta,* and fish teeth.

El Vado Sandstone Member

The El Vado Sandstone Member of the Mancos Shale crops out extensively in the Tierra Amarilla area. The member is 90-100 feet (27.4-30.4 m) thick and typically forms low escarpments and cuestas, because it is slightly more resistant than adjacent parts of the Mancos. At the type section in the Boulder Lake quadrangle, the El Vado consists of 56 feet, 7 inches (17.2 m) of sandstone and siltstone in beds 5-17 feet (1.5-5.2 m) thick, interbedded with 43 feet, 3 inches (13.1 m) of shale and silty shale in beds 1-27 feet (0.3-8.2 m) thick (Landis and Dane, 1967).

In many exposures in the area, the El Vado Sandstone Member contains fragments of *Inoceramus platinus* encrusted with *Pseudoperna congesta* comminuted fish remains, ripple marks, and trace fossils.

Upper Shale Unit

The upper shale unit of the Mancos Shale was determined by computation to be about 1,200 feet (364.8 m) thick. Somewhat more than the lower half of this unit is of late Niobrara age, as determined by the presence of *Inoceramus platinus,* which, when occurring in large fragments or flat pieces of shell, is usually encrusted by *Pseudoperna congesta.* At or near the base in some places is an oyster coquina siltstone several inches thick, with locally abundant fragments of fish bone and teeth. Similar, thinner, oyster coquina beds occur at higher levels. Shales of late Niobrara age are calcareous, fissile, brownish gray and olive gray. The more calcareous shales weather light gray to white. A few fine-grained sandstone beds contain small fragments of carbonaceous material. The upper part of the beds of late Niobrara age is less calcareous than the lower part, but continues to be distinguished by the presence of fragments of *Inoceramus platinus* shells.

About 550 feet (167 m) below the top of the Mancos Shale, a sequence of medium-gray shale contains large, gray, limestone concretions that weather yellowish orange and contain *Scaphites hippocrepis* and *Stantonoceras* sp., ammonites diagnostic of early Montana age. Higher in the unit, sandstone beds are present in the uppermost part, predominating over interbedded shale in a zone transitional into the Point Lookout Sandstone at the base of the overlying Mesaverde Group.

Mesaverde Group

The Mesaverde Group in the northeastern part of the San Juan Basin comprises three widely recognized units—the Point Lookout Sandstone, the overlying Menefee Formation, and the La Ventana Tongue of the Cliff House Sandstone (see J. E. Fassett, this volume), which overlies the Menefee Formation. In the Tierra Amarilla coal field, however, only the Point Lookout and the Menefee have been recognized. Strata equivalent to La Ventana may be present in the uppermost part of the Menefee but were not recognized. The Menefee and the Point Lookout were not separately identified in the eastern part of the coal field because the lithology changes laterally to the east and the beds are poorly exposed.

In the western part of the Tierra Amarilla coal field and in exposures on the eastern flank of the San Juan Basin, regressive nearshore marine sandstone that comprises most of the Point Lookout Sandstone is overlain by lenticular sandstones, clay shales, carbonaceous shales, and coal beds of lagoonal, swamp, bay, and terrestrial origin that make up the Menefee Formation. In the eastern part of the coal field the Mesaverde Group is composed largely of sandstone.

The Mesaverde Group is as much as 180 feet (54.7 m) thick in the western part of the Tierra Amarilla coal field, but may thin to 120 feet (36.5 m) at the eastern end of the field.

No fossils were found in the Mesaverde of the Tierra Amarilla coal field but, as mentioned earlier, fossils of early Montana age are present near the middle of the upper shale unit of the Mancos, about 600 feet (182 m) below the base of the Mesaverde. The oldest fossils the authors collected from the Lewis Shale, which overlies the Mesaverde, in the Tierra Amarilla field come from the ammonite zone of *Baculities maclearni.* As thus bracketed, the Mesaverde in the Tierra Amarilla coal field is of early Montana age and may all lie within the early Campanian.

Point Lookout Sandstone

The Point Lookout Sandstone is a littoral marine sandstone deposited as the Cretaceous sea regressed to the cast and north across the San Juan Basin. The sandstone is light gray, fine to very fine grained, weathers yellowish gray to grayish yellow, and generally forms bold cliffs or steep slopes above the softer Mancos Shale.

In the western part of the Tierra Amarilla coal field, the upper part of the Point Lookout tends to be silty, carbonaceous, and poorly cemented, and it forms recessive slopes above the main mass of the unit. In the eastern part of the field, equivalent rocks are similar to the sandstone below, though they tend to be less well cemented.

Vertical and horizontal transitional relationships between the Point Lookout and the underlying Mancos Shale are well exposed in the cliffs at the western end of the coal field.

The small-scale intertonguing relationships of the units cannot readily be mapped. Therefore, the contact between the two units is drawn at the base of cliff-forming massive sandstone that crops out as one bed. As thus drawn, the upper part of the Mancos contains sandstone beds, some of which are tongues of the Point Lookout extending into the dark shales of the Mancos. Accretion of sandstone beds to the base of the Point Lookout causes thickness variations in the western part of the coal field. In the easternmost part of the field, the base of the Point Lookout is not exposed. The Point Lookout Sandstone ranges in thickness from less than 40 feet to 67 feet (12.2-20.4 m) at the thickest section measured.

Menefee Formation

The Menefee Formation is a complex interlayered sequence of lagoonal, swamp, bay, and terrestrial sedimentary rocks that conformably overlies the Point Lookout Sandstone and that forms the middle part of the Mesaverde Group in much of the eastern San Juan Basin. The upper part of the Mesaverde Group in nearby areas, La Ventana Tongue of the Cliff House Sandstone, is not recognized in the Tierra Amarilla coal field, and the Menefee as discussed in this report may include units representative of the La Ventana.

The Menefee is composed of fine grained to very fine grained, well bedded to massive sandstone, fissile clay shale, lumpy bedded claystone, and coal, most of which are carbonaceous and silty. Individual rock units tend to be lenticular, but lithologies representing some particular environments persist far enough laterally to allow correlation of measured sections. For example, the lower part of the Menefee is persistently carbonaceous and coaly throughout the Tierra Amarilla coal field, though individual rock units are not. In the same way, the middle part of the Menefee is persistently sandy throughout the field and the rocks above the sandy middle part are persistently carbonaceous wherever exposed. The uppermost part of the Menefee is covered or very poorly exposed at all places where it was examined, but it seems to be largely soft silty claystone and medium-gray clay shale interbedded with some soft fine grained to very fine grained generally silty poorly bedded yellow weathering sandstone. The contact with the overlying Lewis Shale is at best tentatively located in all exposures, but lithologic criteria from nearby areas suggest assigning yellow-weathering, soft, silty, medium-gray, clay shale and limestone concretions mostly to the lower part of the Lewis, and ironstone laminae and concretions and soft yellow-weathering sandstone mostly to the Mesaverde Group.

Between the western and eastern parts of the field, the Menefee Formation seems to thin and become much more sandy. The Menefee ranges in thickness from as much as 120 feet (40.8 m) in the western part of the Tierra Amarilla coal field to 99 feet (30.1 m) or less in the easternmost part.

Lewis Shale

The Lewis Shale, which conformably overlies the Mesaverde Group, is at least 1,000 feet (304 m) thick in the Tierra Amarilla coal field. A more accurate determination cannot be made because only small parts of the Lewis are exposed at any place in the field owing to a thick forest cover and very extensive slumping and landsliding.

The Lewis is largely medium-gray, yellow-weathering soft, partly silty, clay shale that contains a few interbedded silty sandstone and sandy siltstone beds. Yellow-weathering calcareous concretions as much as 6 feet (2.1 m) long are present in the lower part of the exposed Lewis, and calcareous concretions of various sizes, some fossiliferous, are sparsely present throughout the Lewis. Two collections of fossils obtained from the Lewis in the Tierra Amarilla coal field consist of *Inoceramus* aff. I. *proximus* Tuomey (USGS D5317) and *Inoceramus* sp. and *Baculites maclerni* Landes (USGS D5318).

Collection D5317, from about 0.6 mile (1 km) east of the Dandee mine, is possibly from the ammonite zone of *Baculites gregoryensis,* which extends through a large part of the Red

Bird Silty Member of the Pierre Shale of Wyoming (Gill and Cobban, 1966) as well as through the lower part of the Hygiene Sandstone Member of the Pierre Shale near Denver, Colo. (Scott and Cobban, 1965).

Collection D5318, gathered from the lower part of the Lewis in the southwestern part of the coal field, is from the ammonite zone of *Baculites maclearnii.* The *Baculites maclearni* zone extends through the upper part of the Sharon Springs Member of the Pierre Shale into the lowest part of the overlying Mitten Black Shale Member in eastern Wyoming (Gill and Cobban, 1966) and through the lower shale unit of the Pierre near Denver (Scott and Cobban, 1965).

COAL

The coal resources of the Tierra Amarilla coal field were investigated by Landis and Dane (1969) and the following discussion is excerpted from that report:

Coal beds are present at as many as nine separate stratigraphic positions in the Menefee Formation. Six of the coal beds and associated carbonaceous shale and siltstone beds can be placed in two groups, an upper group and lower group, which are separated by a dominantly sandstone unit that contains three very thin and nonpersistent coal beds.

The upper group of coal beds is exposed only—and may be present only—in the western part of the Tierra Amarilla field. Three of the four beds in the group appear to be laterally persistent for up to 0.7 mile (1.1 km). The maximum observed coal thickness in the upper group was 20 inches (50 cm).

The lower coal group makes up the lower 10-15 feet (3-4.6 m) of the Menefee and contains two persistent coal beds. The lower of the two beds was 31 inches (0.8 m) thick at one locality but is generally much thinner. The upper coal bed of the lower coal group is the thickest, most persistent, and most mined and prospected bed in the coal field. The bed is present at nine of the eleven localities at which the lower group was examined. The bed is 49 inches (1.2 m) thick at one locality and more than 2 feet (0.6 m) thick at four other localities.

The coal is known to have been mined at four localities. The history of mining in the field is obscure at best, but one mine, the Dandee, operated for at least ten years, and large slack piles at another locality indicate a fair-sized operation at one time.

The Tierra Amarilla field contains normal banded coal of the humic series (Tomkeieff, 1954), which comprises most of the world's coal—particularly the coal of economic importance. Analyses (Table 1) of two tipple samples collected in 1944 from the Dandee mine indicated that, on the basis of heating value, the rank of the coal could be either high-volatile C bituminous or subbituminous A.[1] No information about agglomerating characteristics is available, but the coal has been grouped as subbituminous A (Walker and Hartner, 1966, p. 22), probably because of its moisture content which is higher than that of most bituminous coals.

The total sulfur content of United States coals and the form in which the sulfur is present have become of national concern because of air pollution problems. The coal from the Dandee mine contains from 1.0 to 1.1 percent sulfur, which places the coal at about the boundary of the low- and medium-sulfur content categories of DeCarlo, Sheridan, and Murphy (1966,

Table 1. Analyses of tipple samples from the Dandee mine. (Analyses by U.S. Bureau of Mines)

	PROXIMATE ANALYSIS				ULTIMATE ANALYSIS							
Sample/ Condition	Moisture	Volatile matter*	Fixed C	Ash	H	C	N	O	S	Ash	Calorific Value (Btu)	Ash Softening Temp. (°F)
No. C--30859, 8 tons												2260
1-inch lump:												
As received	17.9	33.1	41.3	7.7	6.1	57.2	1.3	26.7	1.0	7.7	10,110	
Air dried	7.6	37.3	46.4	8.7	5.4	64.4	1.5	18.8	1.2	8.7	11,380	
Moisture free		40.3	50.3	9.4	5.0	69.7	1.6	13.0	1.3	9.4	12,310	
Moisture and ash free		44.5	55.5		5.5	77.0	1.8	14.3	1.4		13,600	
No. C--30860, 2 tons												2200
1-inch slack:												
As received	19.5	32.1	39.1	9.3					1.1		9,640	
Air dried	7.5	37.0	44.8	10.7					1.3		11,080	
Moisture free		39.9	48.6	11.5					1.4		11,980	
Moisture and ash free		45.1	54.9						1.6		13,540	

Samples collected by Herbert Fowler, U.S. Bur. of Mines Nov. 30, 1944.

* Determined by modified method.

[1] The standard specifications for the classification of coals by rank, as established by the American Society for Testing and Materials (1967), was used for rank determination.

p. 3). Walker and Hartner (1966, p. 22) presented analytical data on the form of the sulfur in sample C30859 that indicated that 0.02 percent is present as sulfate sulfur, 0.59 percent as pyritic sulfur, and 0.44 percent as organic sulfur. Removal of organic sulfur by conventional coal-cleaning processes is not generally possible, but considerable reduction of pyritic sulfur can often be made, the amount of reduction depending on the size and distribution of the pyritic minerals in the coal.

The coal resources of the Tierra Amarilla coal field cannot be quantitatively evaluated in much of the field because of a lack of information. However, data collected in the western part of the field are sufficient to allow some general conclusions about the thickness, persistence, and distribution of some individual coal beds, and to allow some very conjectural resource estimates.

In the western part of the field, the stratigraphic sequence that contains the lower bed of the lower coal group was examined at seven different localities; however, the coal is either absent from or very thin at all but three localities. In the dissected southwestern part of the field, the coal bed is about 28 to 31 inches (0.7-0.8 m) thick over an area of about 15 acres and may be 14 to 28 inches (0.4-0.7 m) thick in an additional area of about 270 acres.

The upper bed of the lower coal group seems to be very lenticular in the part of the coal field west of Rito de Tierra Amarilla and is more than 14 inches (3.6 m) thick in only two small areas. The bed is more persistent, however, in the area surrounding the Dandee mine; there it is from 28 to 36 inches (0.7-0.9 m) thick over an area of about 205 acres. The bed is probably from 14 to 28 inches (0.4-0.7 m) thick over an additional contiguous area of about 855 acres.

If these assumptions are true, the lower bed might have originally contained as much as 60,000 tons of coal where it is more than 28 inches (0.7 m) thick and as much as 835,000 tons where it is 14 to 28 inches (0.4-0.7 m) thick; the upper bed might have originally contained as much as 945,000 tons of coal where it is 28 to 36 inches (0.7-0.9 m) thick and as much as 2,650,000 tons where it is 14 to 28 inches (0.4-0.7 m) thick. Because of a lack of data on past production in the field, no allowances have been made for coal that has been mined or rendered unrecoverable by past mining activities. It must be emphasized that because of the sparseness of thickness measured and the demonstrated extreme lenticularity of the coal beds, the foregoing resource estimates are very conjectural and should be categorized as "inferred identified resources."

The resource potential of the eastern part of the field is largely unknown, but existing information indicates that the Mesaverde Group probably contains little or no coal in that area.

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