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Aspects of Coal Geology, Northwest Colorado Plateau
Some Geologic Aspects of Coal Accumulation, Alteration, and Mining
In Western North America: A Symposium

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Genesis of Western Book Cliffs Coals

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ABSTRACT.—Numerous high-volatile bituminous coals occur in the Late Cretaceous Blackhawk and Price River Formations in the Book Cliffs of eastern Utah. These formations consist of continental, transitional and neritic deposits formed during the eastward withdrawal of the Mancos sea.

Many of the coals are thin local occurrences in floodplain or paludal rocks. They are products of accumulations in small swamps occupying old oxbow lakes, depressions on floodplains or sags in deltaic interdistributary areas. The commercially important seams are the thicker and more persistent ones found only in the basal portion of the Blackhawk. These may be as much as 22 feet thick and some can be traced for nearly 35 miles in a northwest-southeast direction and for even greater distances in a northeast-southwest direction. It appears that these persistent coals formed in swamps which developed along the margins of northeast trending lagoons behind similarly oriented barrier beaches. After a lagoon was filled the swamps coalesced and then spread eastward over the earlier formed beach ridges of the prograding barrier beach, commonly reaching almost to the last beach ridge. Growth of each swamp was terminated by a small scale basinal subsidence which allowed the sea to inundate part or all of the coniferous swamp forest.

Very little erosion or scouring of the peaty materials ensued during the relatively rapid landward transgression of the sea but an abundance of dinosaur tracks suggest thorough trampling before the next blanket of sediment was deposited. There was also some stream scouring, but most of the other structures characteristic of these coals are a consequence of diagenetic processes.

INTRODUCTION

The numerous seams of bituminous coal present in strata of the Blackhawk Formation in the western portion of the Book Cliffs coal field of eastern Utah have been exploited for nearly a century. As used in this report, the western Book Cliffs include that portion of the Cliffs covered by the Castlegate, Wellington and Sunnyside quadrangles (Fig. 1).

The importance of this area is indicated by estimates of coal reserves in this portion of the field. Averitt (1964) calculated the reserves of the three quadrangles to be 3,704 million short tons. This estimate was based largely on measured sections of outcropping coals along the Book Cliffs together with data from underground operations and limited drilling in near-outcrop areas. Such data reveal that some coals are local developments, whereas others are quite persistent and can be traced for many miles along the east-west trending Book Cliffs and similar distances to the south along the east side of the Wasatch Plateau. With the present rapid increase in demand for energy, these coals are being developed at an accelerated pace, and it is becoming increasingly imperative that a more precise evaluation of these coal reserves be obtained. Such an evaluation cannot be based solely on measurements obtained at the outcrop but must incorporate other parameters, such as the geometry of the sedimentary environment or environments in which the coals originated. Equally important are structural features of the deposits and a knowledge of diagenetic changes they have undergone.

Forrester (1893), who wrote about the coal fields of Utah, was probably the first to describe the coals of this area. Next came a report by Storrs (1902)

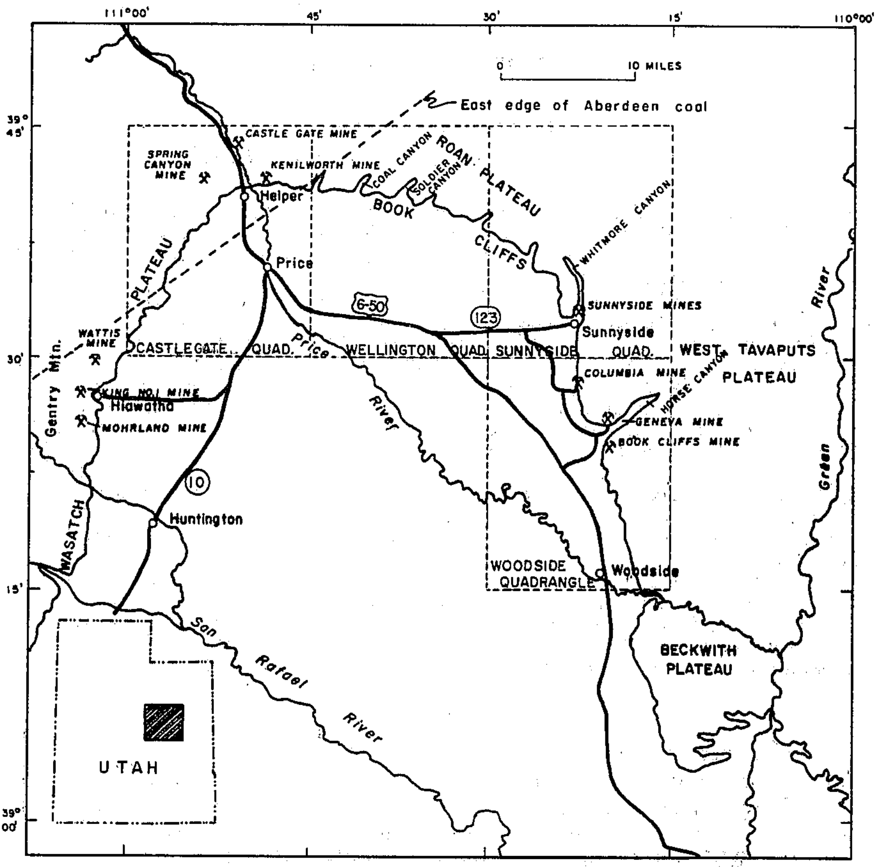

FIGURE 1.—Location Map.

on Rocky Mountain coal fields followed by studies by Taff (1906) and Richardson (1909) dealing with Book Cliffs coal resources. In 1925, Spieker and Reeside described the intertonguing relationships between Mesaverde and Mancos strata in the Wasatch Plateau and adjoining areas. Their work was followed by that of Clark (1928) who investigated the coals of the Castlegate, Wellington and Sunnyside quadrangles. More recent studies in this area include those by Thiessen and Sprunk (1937) on origin and composition of the Lower Sunnyside coal; by Spieker (1949) on sedimentary facies of the Cretaceous; by Berryhill and Averitt (1951) on coking coals; by Young (1955, 1957 and 1966) on stratigraphic relations and the cyclic nature of the coal-bearing rocks; by Abbott and Liscomb (1956) on stratigraphy of the Book Cliffs; by Gray and Schapiro (1966) on petrographic characteristics of the Sunnyside coal; and by Gray, Patalski and Schapiro (1966) and Tidwell (1966) on paleobotany of Utah and Colorado coals. Also of much value are numerous maps and reports dealing with seismic activity in the Sunnyside area (Osterwald, 1961 and 1962; Osterwald and Dunrud, 1964 and 1966; Osterwald and Eggleton, 1958; and Osterwald, Bennetti, Dunrud and Maberry, 1971) and the atlas on central Utah coal fields by Doelling (1972).

The purpose of this paper is to present a brief summary of the nature of western Book Cliff coals and to attempt a reconstruction of their depositional environments. Also included are a few notes on diagenetic changes and structural features of the coals which when used in conjunction with environmental concepts should enable geologists to arrive at more precise coal reserve estimates.

SUMMARY OF GEOLOGY

Geologic History

Cretaceous rocks of eastern Utah represent a nearly complete record of geologic events which occurred during the development and subsequent destruction of the western portion of the Rocky Mountain geosyncline. They document the vagrancies of a shallow sea which first advanced hesitantly from the east, remained essentially static for a time at its westernmost position and then made a slow fluctuating retreat back toward the east. The Dakota Group and the lower portion of the Mancos Shale were formed in continental, transitional and shallow marine environments during the westward advance. The Mesaverde Group and the bulk of the Mancos are the depositional record of the same environments during the stillstand and ensuing retreat of the sea. The source for the bulk of these sediments was the Sevier orogenic belt of western Utah. Figure 2 outlines the general stratigraphic relationships in the Upper Cretaceous of this area.

Deposits of the Mesaverde Group

Of most importance in this report are those deposits formed during the withdrawal of the Mancos sea, because they contain most of the valuable coal seams in this region. Time and space do not permit a detailed discussion of all features of these rocks, but some of the most important characteristics are summarized here.

These regressive deposits formed in both continental and transitional environments which existed between the Sevier orogenic belt and the shallow neritic sea to the east. These environments shifted or expanded and contracted with fluctuations of the strandline caused by changes in the balance between sediment supply and space available. Principle environments which can be identified include piedmont, floodplain, paludal, lagoonal, estuarine and probably deltaic. Coarse clastics of the piedmont environment are present to the west but are not present as far east as the Book Cliffs.

Strata of the Price River Formation and the Cretaceous portion of the North Horn Formation were formed almost exclusively in the floodplain environment, and it is possible to recognize deposits of specific subenvironments such as braided channel, meandering channel, interchannel, swamp and lacustrine.

Rocks of the Blackhawk formed nearer the sea and consist of deposits of paludal, lagoonal, estuarine, littoral marine and probably deltaic environments. It is also possible to recognize deposits of subenvironments within these major environments as indicated in Table 1. Most difficult to recognize are products of the deltaic environment, probably because of a poor three-dimensional picture of geologic units in this area and lack of recognizable distributary channels. Criteria for recognition of Cretaceous subenvironments have been previously tabulated by the writer (Young, 1973).

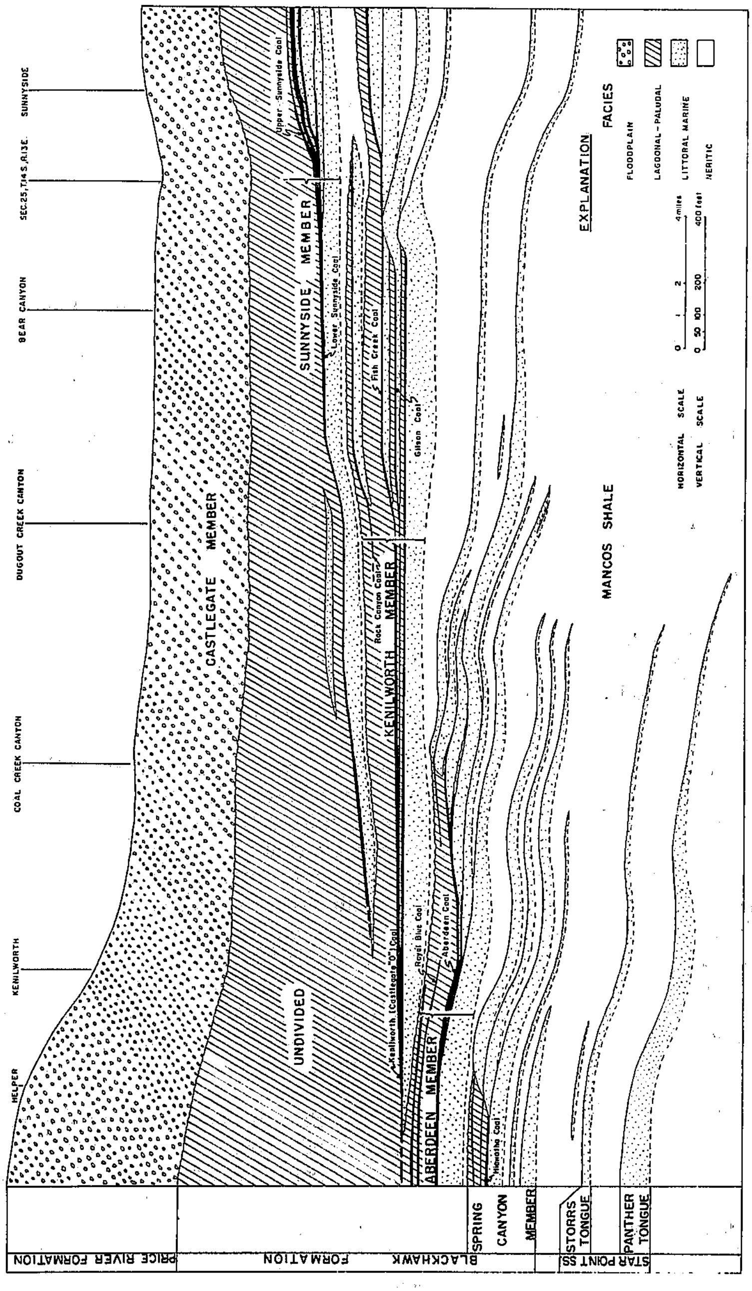

FIGURE 2.—Coal bearing rocks of western Book Cliffs.

TABLE 1
SEDIMENTARY ENVIRONMENTS IN UPPER CRETACEOUS ROCKS OF WESTERN BOOK CLIFFS.

ENVIRONMENT	SUBENVIRONMENT
Floodplain	*Braided channel*
	Meandering channel
	Interchannel
	Lacustrine
Paludal	*Braided channel*
	Meandering channel
	Interchannel
	Coal swamp
Deltaic	*Distributary channel*
	Interdistributary
	Delta front
	Prodelta slope
Lagoonal – Estuarine	*Lagoon pond*
	Salt marsh
	Tidal flat
	Tidal channel
	Tidal delta
	Washover fan
	Estuarine
Littoral Marine	*Backshore*
	Foreshore
	Breaker bar
	Offshore bar
Neritic	*Nearshore*
	Offshore
	Shoal

Another notable feature of Blackhawk deposits is their cyclic nature (Young, 1957). Like coal-bearing deposits of other systems, those of the Cretaceous appear to have formed under specific geologic and climatic conditions which recurred many times in the same general area during a long span of geologic time. This cyclic sequence of events appears to have been related to the development and destruction of the geosyncline. Where completely developed a typical Cretaceous cyclothem consists of four units. Unit 1 is a tongue of Mancos Shale resting disconformably on slightly older transitional deposits. Unit 2 is a littoral marine sandstone which grades downward and eastward into Unit 1. Unit 3 is a carbonaceous mudstone and shale of lagoonal and estuarine origin. Unit 4 is a persistent coal of the paludal environment. Because of seaward progradation of the barrier beaches (Unit 2), lagoonal deposits (Unit 3) overlie them only in a narrow band along their landward margins. Seaward from here paludal deposits of Unit 4 rest directly on beach deposits for many miles.

Obviously, the most prominent unit of the cyclothem is the massive beach sandstone. Most of these sandstones appear to have been formed as prograding barrier beaches but some are mainland beaches and others are possibly delta front sandstones as described by Howard (1966). Regardless of origin they provide a convenient method for subdividing these coal-bearing strata. The writer (Young, 1955) utilized these sandstones in subdividing the Blackhawk into a series of members, each consisting of a basal sandstone and the nonmarine sequence between it and the next higher prominent littoral sandstone in the section. Members present here, from the base upward, include the Spring Canyon, Aberdeen, Kenilworth, Sunnyside and an undivided portion. The last vestiges of Spring Canyon beach sandstone disappear into the Mancos near Soldier Canyon, those of the Aberdeen vanish some 18 miles farther southeast near Whitmore Canyon, and those of the Kenilworth and Sunnyside continue for another 50 miles before grading into Mancos near Crescent Junction.

COAL DEPOSITS

Many coal seams are present in the Blackhawk and Price River Formations in the western Book Cliffs, but only seven are widely traceable (Fig. 2). Each is more than 14 inches thick and all occur in the lower 500 feet of the Blackhawk. They are, in ascending order, the Aberdeen (Castlegate "A"), Kenilworth (Castlegate "D"), Gilson, Fish Creek, Rock Canyon, Lower Sunnyside and Upper Sunnyside. All of these coals can be described as high-volatile bituminous coals ranging in rank from A to B. They are highly attrital with interspersed vitrain bands, varying amounts of exudation resin and some finely dispersed fusain. Most show closely spaced cleat which may be coated with jarosite or alums at the outcrop and with pyrite in the subcrop. Petrographic data (Thiessen and Sprunk, 1937; and Tidwell, 1966) indicate that these coals are composed primarily of stems, twigs, bark, seeds and needles of conifers. Table 2 indicates the range of chemical characteristics of these coals based on numerous analyses.

Description of Seams

The Castlegate "A" (Aberdeen) seam, named for exposures near Castlegate, can be traced more or less continuously for about 18 miles from the westernmost exposures in Spring Canyon to Coal Creek Canyon where it termi-

TABLE 2
AVERAGE ANALYSIS OF WESTERN BOOK CLIFFS COALS

Moisture (as received)	4.5—10.5
Volatile matter	39.3—41.9
Fixed carbon	46.3—53.3
Ash	5.1—11.2
Sulfur	0.4— 0.72
Btu (as received, per lb.)	11,500—14,700

nates between two barrier beach sandstones. Spieker (1931) traced it southward from Spring Canyon for a distance of 12 miles along the east face of the Wasatch Plateau before it pinched out on the north face of Gentry Mountain. A line connecting these pinchouts indicates a N 60° E trend for the seaward edge of the Castlegate "A" seam (fig. 1.). Its thickness is variable, ranging up to 19 feet 10 inches at the Kenilworth Mine. Along its western margin it overlies lagoonal-paludal deposits, but elsewhere it rests directly on the massive basal sandstone of the Aberdeen Member.

The Castlegate "D" (Kenilworth) seam is a widespread, lenticular coal which reaches a maximum thickness of 18 feet 9 inches at Kenilworth and averages about six feet eight inches in the Castlegate and Wellington quadrangles. At its thickest point it appears to include the Gilson and Fish Creek seams which split from it a short distance to the east. From here the Castlegate "D" continues to thin eastward to a feather edge near Sunnyside. In most places this coal rests directly on the underlying basal sandstone of the Kenilworth Member, but Clark (1928) traced it beyond the western edge of the sandstone to near the western edge of the Castlegate quadrangle where it overlies lagoonal deposits.

The Gilson seam is a relatively unimportant coal but does reach a thickness of about 11 feet near Soldier Creek. As noted above, it splits from the Castlegate "D" near Kenilworth and can be traced eastward to a feather edge near Sunnyside.

Another split from the Castlegate "D" near Kenilworth is the Fish Creek seam, which attains a maximum thickness of about five feet. It can be traced at least as far east as Whitmore Canyon.

The Rock Creek seam first appears in the Soldier Creek area and can be traced to Whitmore Canyon. It reaches a maximum thickness of 7 feet 9 inches near Soldier Creek and thins progressively eastward.

The most widespread and uniformly thick coal in the western Book Cliffs is the Sunnyside seam, which is being mined intensively in the Sunnyside area. This coal first appears in exposures near Kenilworth and can be traced nearly to Woodside, some 20 miles southeast of the southern edge of the Sunnyside quadrangle. It rests on lagoonal-paludal rocks along its western margin but elsewhere it rests directly on the basal sandstone of the Sunnyside Member. In the Wellington quadrangle it appears to be a single unit but north of Whitmore Canyon it splits into three seams. The lower seam thins rather rapidly to a pinchout near Horse Canyon. The middle seam (Lower Sunnyside) continues southward resting directly on the next higher barrier beach sandstone of the member (south of Horse Canyon this seam splits again with the lower part pinching out in a short distance and the upper part continuing to Woodside on top of the inner edge of the next beach sandstone). The upper seam (Upper Sunnyside) can be traced to a feather edge about 10 miles south of Woodside. The Lower Sunnyside coal is 14 feet thick near the southern edge of the Sunnyside quadrangle and attains a maximum thickness of 22 feet in the Horse Canyon area. Maximum thickness of the Upper Sunnyside is about 6 feet 2 inches at Water Canyon south of Sunnyside. Both the Lower and Upper Sunnyside seams are excellent coking coals.

Origin

In considering the origin of these Cretaceous coals, one naturally thinks of those localities where decaying vegetation is accumulating today, such as Dismal Swamp in Virginia, the coastal swamps of southern Florida, the Mississippi River delta, the muskeg (peatland) of Canada, and numerous others. However, none of these environments seem capable of producing coal deposits of the magnitude of those present in the western Book Cliffs. Students of Pennsylvanian coals have encountered the same problem, but have postulated a variety of coal-producing environments. Wanless and others (1964) lists eight environments including deltas, unfilled alluvial channels, estuaries prior to drowning, coastal plain marshes, lagoonal marshes behind barrier islands, oxbow lakes, areas of abrupt marine regression, and surfaces smoothed by depositional filling of initial topographic irregularities.

Coals of the western Book Cliffs do not appear to have had such a wide spectrum of origins. The thin local lenses in the Price River and North Horn Formations most likely formed in old oxbow lakes, and some equally minor seams in the Blackhawk Formation formed in either oxbow lakes or tidal marshes. However, there must be another explanation for the seven thicker and more persistent beds. Spieker and Reeside (1925) proposed that these more pervasive coals formed in extensive swamps on a broad coastal plain. Fisher (1936) thought that they formed from forests of figs, palms and magnolias thriving on coastal plains.

In a previous paper the writer (Young, 1955) noted that each major coal forming stage followed the filling of a lagoon which was protected by a barrier beach. The coal swamp began as strips bordering each side of the lagoon but as the lagoon filled, the strips coalesced to cover the entire lagoonal surface. The swamp generally was not confined to the old lagoonal area but spread seaward aided by compactional subsidence until it covered the more landward portions of the broad sand aprons formed by the prograding barrier beach. As a consequence, in much of the area covered by a major seam the coal rests directly on a barrier beach sandstone or is separated from it by as much as a foot or so of carbonaceous mudstone or shale. The direct contact of the acid swamp waters with the beach sand caused kaolinization of feldspars and leaching of iron, resulting in a white cap or bleached upper portion of the underlying sandstone.

The type of barrier capable of protecting such a swamp from the sea is somewhat in question. If one traces a coal seaward on a barrier beach sandstone, he commonly finds that it thins to the vicinity of the youngest beach crest before disappearing. This suggests that the swamp was protected from the sea by the last beach crest which may not have been more than five to ten feet above mean sea level. Obviously, the tidal range was low and storm waves must have been essentially absent.

There is then the question of what caused the beach to cease prograding. It is possible that it was because of a diminishing supply of sediment for longshore transport by southwest moving currents in the sea. In this event, subsidence due to compaction would have soon ceased and swamp growth would have ended. The organic deposit would then have been subjected to oxidation and erosion and would probably have been largely destroyed before complete burial. A more plausible explanation is one which allows for preservation of the coal beds. In this concept, seaward growth of the beach and its piggy-back swamp was abruptly ended by a sharp but small-scale subsidence in the geosyncline. In the deeper portions of the basin, subsidence may have been on the order of 50 feet or so; but along the western shore, because of a tilting effect, subsidence may have been only 8 to 10 feet. A few miles inland the subsidence would have tapered off to zero and effectively marked the limit of the ensuing minor marine transgression. Landward from here the swamp may have continued to thrive and eventually spread seaward over the next prograding beach. This would explain the coal splits so prominent in the Kenilworth and Sunnyside coals.

Evidences of Origin

Some of the more important evidences for origin in the manner described above can be cited from the sedimentary record as follows:

1. Geometry of the coal swamps. From available data on extent of these coals it appears that the major coal swamps were elongate parallel to the shoreline. Widths ranged from 12 to 35 miles or more and lengths were as much as 70 miles and perhaps several times that great.

2. Coals formed on both lagoonal and littoral marine strata. As noted previously the major coals rest on old beach sandstones everywhere except along their western or landward margins. Also the coals are thicker in their western portions over the old lagoonal deposits and the landward portions of the sand aprons.

3. The presence of a white cap beneath coal in most places. It has been noted that the upper portion of the beach sandstone beneath a major coal is a type of seat-rock in which clay has been kaolinized and iron redistributed. That swamps actually grew on these old sand sheets is attested to by the presence in some areas of roots and stumps in the white-capped portion of beach sandstone.

4. At least one terminal beach ridge has been preserved. South of Woodside in a vertical cliff the last vestiges of the Kenilworth coal swamps disappear on the landward side of an upward thickening of the underlying beach sandstone. This thickening is on the order of eight to ten feet but persists for only a short distance before the sandstone thins to its original thickness and then continues to thin rapidly seaward to disappear into the shale in a few miles. In many other localities the outermost beach ridge of a sand sheet, after being submerged, appears to have served as the beginning point for the next overlying barrier beach.

5. Some irregularities in coal thickness may be due to buried beach ridges. As noted previously, thicknesses of major coals tend to vary con-

siderably along the outcrop. Much of this variation is interpreted to be a consequence of deposition on an irregular surface characterized by beach crests and intervening troughs of the old barrier beach sand sheets.

6. Abundant dinosaur tracks in roof rock indicate trampling after shallow submergence. The roof rock above some coals, such as the Kenilworth, contain the casts of tracks of a multitude of dinosaurs, tracks of both large sauropod and small theropod types. These casts consist of tidal channel sandstone or lagoonal mudstone and are associated with turtle shells and with some large logs and branches showing no particular orientation. From the density of the tracks and the presence of associated wood fragments it can be assumed that the swamp had been recently submerged and that the few trees remaining upright were broken over and destroyed by a horde of dinosaurs searching for vegetation to devour or perhaps enjoying the shallow waters of a newly formed lagoon. A possible catastrophic dying off of dinosaurs as the result of the destruction of their feeding grounds is suggested by the presence in some areas of tidal channel sandstones with lenses of conglomerate consisting almost entirely of dinosaur bone pebbles.

Structural Features

The coal seams of this area exhibit a variety of structural features of depositional, diagenetic and tectonic origin.

Depositional structures include those features formed during the depositional process as well as those formed by erosion and other disturbances prior to burial and/or diagenesis. In this category are partings of various types. Along the western margins of these coal beds partings of carbonaceous mudstone or shale (bone) may divide the seam into splits. Similar splitting occurs along the eastern edges of the coal seams where the partings are carbonaceous mudstone or wedge edges of eastward thickening sandstone tongues. Partings of volcanic ash are common in older Cretaceous coals in this region, but none have been reported in the Blackhawk coals. "Wants" or "Cut-outs," due to current scouring, are relatively common in this region (Spieker, 1931, and Howard, 1969). "Horsebacks," which represent old beach crests or dunes, are present in many areas. Fossilized turtle carapaces up to two feet across are found occasionally, but the most common evidences of life are the abundant dinosaur tracks noted above.

Diagenetic structures include well developed cleat, which facilitates mining of these coals. Roughly cone-shaped masses of slick ensided rock, referred to variously as "bells," "pots," "kettles," "camel-backs" or "tortoises," are relatively common in the mines of the area. In some mines the coals have been subjected to considerable differential compaction resulting in the production of small wrinkles or "knuckles." Related features are clastic dikes or "spars" which pass completely through the coal at high angles. Where these are well developed in the eastern Book Cliffs and the Axial Basin area near Craig, Colorado, they tend to form roughly circular patterns in plan view.

Tectonic structures are relatively unimportant in this area. The beds dip gently north and northeast off the north end of the San Rafael Swell, a large north-south trending anticline. In the eastern portion of the area this homoclinal dip is broken by a few small normal faults.

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