THE PALEOECOLOGY AND FLORA OF THE BLACKHAWK FORMATION (UPPER CRETACEOUS) FROM CENTRAL UTAH

DISSERTATION FOR THE DEGREE OF Ph. D.

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ABSTRACT

THE PALEOECOLOGY AND FLORA OF
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by

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More than 7,400 fossil plant specimens, representing 118 species, were collected from the Upper Cretaceous Blackhawk Formation in Salina and Straight Canyons of the Wasatch Plateau. These plants include one thalloid liverwort-like plant, one club moss-like plant, fourteen ferns, twelve gymnosperms of various types, and eighty-six angiosperms. Angiosperms are represented by 5 monocotyledons and 81 dicotyledons. Eight ferns and 31 unidentified dicotyledons are thought to be species not previously described. This is one of only 3 large Upper Cretaceous floras of the Upper Santonian-Lower Campanian Stage described from North America. The western portion of the Blackhawk Formation consists chiefly of fluvial lenticular sandstones, siltstones, shales and coals deposited on a broad floodplain west of the Cretaceous Interior Seaway. Three major types of sedimentary environments are differentiated here: peat-forming swamps, bottomlands, and river point bars. The swamp environment supported a plant community dominated by two trees: *Sequoia cuneata*, an evergreen conifer; and *Rhamnites eminens*, a deciduous angiosperm. Subordinate trees consisted of several other conifers and angiosperms including *Protophyllocladus polymorpha*, *Brachyphyllum macrocarpum* and *Platanus raynoldsii*. *Geonomites imperialis*, a small

palm, was abundant near swamp margins; and *Cissus marginata*, possibly a woody vine, occurred in most swamps. Herbaceous angiosperms were lacking but an understory was composed of the ferns *Cyathea pinnata* and *Onoclea hebridica*. Two aquatic plants, a water lily, *Nymphaeites dawsoni*, and water chestnut, *Trapa paulula*, were present. The bottomland communities were co-dominated by four angiosperms, *Cercidiphyllum arcticum*, *Platanus raynoldsii*, *Dryophyllum subfalcatum*, and Unknown dicot 2. Several other angiosperms were present as subordinant trees, but conifers were rare and unimportant. The palm, *Geonomites imperialis*, made up at least a portion of the shrubby understory. Two vines existed in this community, *Menispermum dauricumoides* and *Cissus marginata*. Ferns seem to have been the only herbaceous plants. River point bars apparently did not support a diverse plant community. Instead, all specimens collected in these sediments seem to have been transported some distance before burial. The conifer *Araucarites* sp. was found in some abundance in widely separated point bars but was not collected in swamps or bottomlands. It probably was moved downriver from the upper delta plain environments or possibly from the piedmont. The Blackhawk floodplain communities are different in several ways from those communities which exist today but do have certain features similar to the extant plant communities of the Lower Mississippi River Valley.

Several independent methods have been used to determine the paleoclimate in which the Blackhawk plant communities lived. The most significant is the analysis of leaf physiognomy including the high portion of leaves in the microphyll and notophyll leaf size classes of Raunkiaer, and the large number of leaves with entire margins. All the methods suggest that the climate was warm and seasonal, most likely of the "subtropical-seasonally dry" type.

Descriptions of the ecologically important non-angiospermous plants are given and include the following: the ferns *Asplenium dicksonianum*, *Cyathea pinnata*, *Onoclea hebridica*, *Osmunda hollicki*, and Unknown fern 1; two unassigned gymnosperms *Nageiopsis* sp. and *Podozamites* sp.; and the conifers *Araucarites* sp., *Brachyphyllum macrocarpum*, *Moriconia cyclotoxon*, *Protophyllocladus polymorpha*, *Protophyllocladus* sp. 2, *Sequoia cuneata*, and *Widdringtonites reichii*. Many problems still exist with the characterization of fossil angiosperms, and with the exception of the palm *Geonomites imperialis*, they have been omitted from the descriptions. *Sequoia cuneata* was represented by more than 500 specimens, including two types of foliage leaves, cuticle with epidermal cell impressions, ovulate and staminate cones attached to foliage, and seeds. Enough information is added to its description that there is little doubt of its relationship to the genus *Sequoia* rather than to *Metasequoia* as had earlier been suggested.

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INTRODUCTION

The Blackhawk flora from the Wasatch Plateau in central Utah is one of only three large Upper Cretaceous floras of the Upper Santonian-Lower Campanian Stage described from North America. It is composed chiefly of dicotyledonous plants, but includes several ferns and gymnosperms. Analysis of the occurrence of these plants in the sandstone, siltstone, and shale facies provides new evidence about the several types of coastal plain plant communities which occupied the area. A study of the kinds of plants present and certain of their morphological features indicates the climatic conditions which existed during that time. The Matawan flora (Berry 1903a, 1903b, 1904, 1916) and the Magothy flora (Berry 1906, 1908, 1916; Miller 1974) both of the New Jersey-Delaware-Maryland area are the only other large floras reported adequately to date which are interpreted as contemporaneous with the floras found in the Blackhawk. Although these two Atlantic coastal plains floras were separated from the Blackhawk by a broad interior sea which was several hundred miles wide, they were probably at a comparable latitude even though the North American continent has shifted somewhat since the Upper Cretaceous (Raven and Axelrod, 1974). Several interesting floristic similarities exist between them. Other fossil floras of this Stage are known to exist but either a significant number of specimens have not been collected at this time (e.g., Knowlton, 1900; Berry, 1929; Bell, 1963; Arnold & Lowther, 1955), or they are thus far not published in detail

(Smiley, 1966, 1969). This study forms a link between the large floras of the lower Upper Cretaceous (Cenomanian and Turonian Stages) such as the Dakota, Tuscaloosa, Frontier and Raritan, and the uppermost Cretaceous floras (Maestrichtian Stage) such as the Ripley, Fox Hills, Lance, Vermejo, Laramie, and Denver.

The Blackhawk flora described here is a composite of several small florules collected at six main localities within the Blackhawk Formation. These occur in Salina and Straight Canyons on the southern and eastern escarpments of the Wasatch Plateau. The collection localities are indicated on Figure 1, where the areal extent of the Blackhawk Formation in the Wasatch Plateau is also shown. Each of these collection localities is described in Appendix I.

A number of papers have been published on various aspects of the coal, stratigraphy, and sedimentary features of the Blackhawk Formation, but the description and interpretation of fossil plants has received only passing attention. Plant microfossils, however, have been used to correlate and interpret certain Blackhawk coals. They have also been used extensively within the region in studies involving Upper Cretaceous marine and brackish water sediments.

The Blackhawk Formation is very fossiliferous throughout its exposure. Many specimens have been collected from outcrops and from within coal mines by various individuals. At the present time, small collections are housed in museums at Brigham Young University in Provo, the University of Utah in Salt Lake City, Carbon County Museum in Price, and at Dinosaur National Monument at Vernal. It is possible that additional area museums also have specimens. Many local "rock

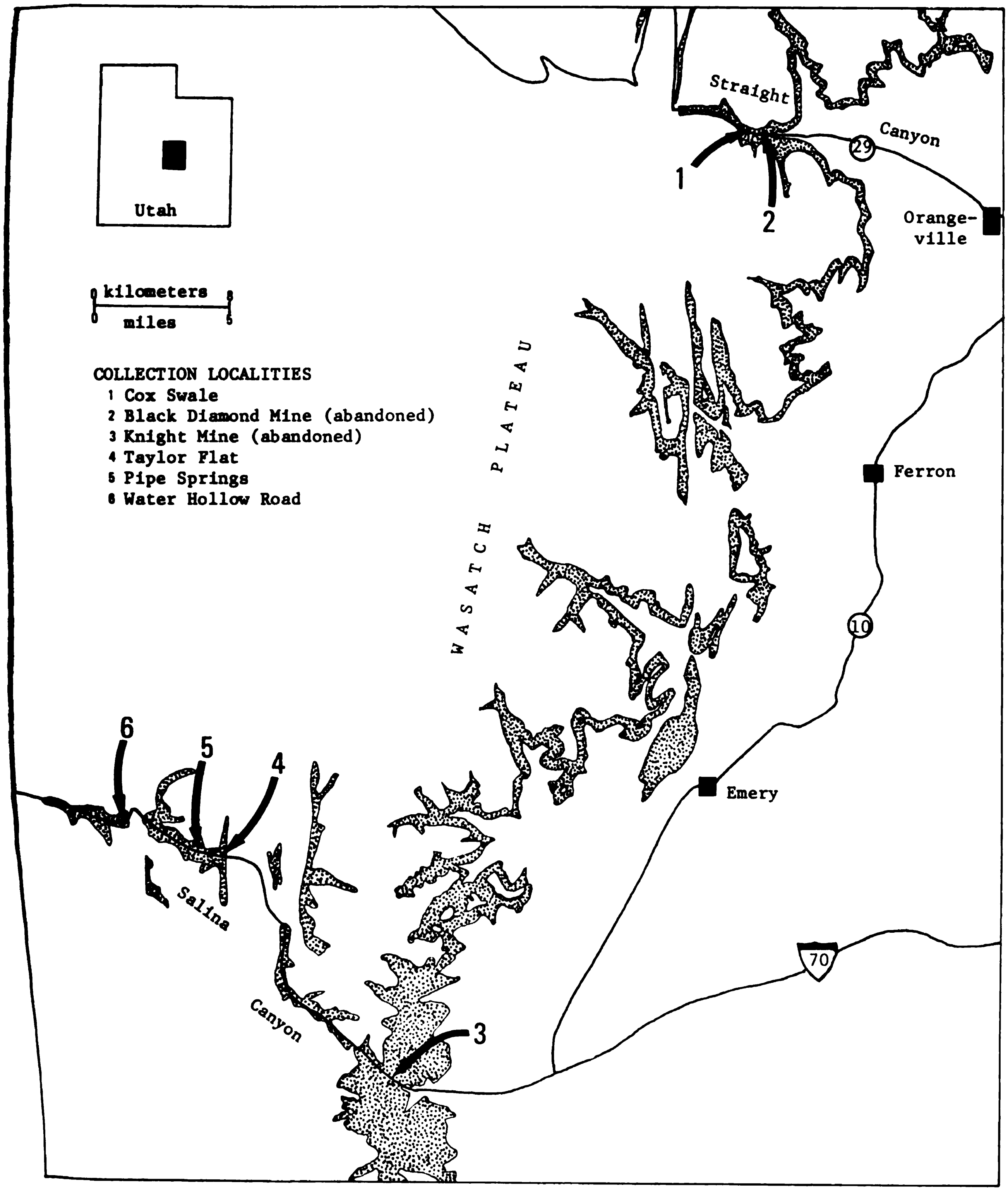


Figure 1. Index map of fossil plant collection localities in the Wasatch Plateau. The areal extent of the Blackhawk Formation is indicated by stippling.

shops" often display well-preserved specimens. A larger collection is now housed at the U.S. National Museum.

The collection examined in this report is composed of about 7,400 specimens, mostly leaf compressions, on 1,200 individual blocks, and is the largest plant fossil collection known to have been made in the Formation, or in the Wasatch Plateau. It is currently housed in the Fossil Plant Collection of the Herbarium at Michigan State University.

GEOLOGIC SETTING OF THE REGION

Physiography

The Wasatch Plateau is a gentle, westward dipping monocline of Upper Cretaceous and lower Tertiary rocks, the eastern edge of which forms a sinuous escarpment extending for nearly 70 miles (110 km) from the Price River, southward to Salina Canyon, Utah. The Wasatch Plateau escarpment and Book Cliffs intersect at Spring Canyon to form a nearly continuous series of faceted cliffs from central Utah eastward into Colorado, and are a major physiographic feature of the region (Figure 2).

The cliffs, which circumscribe the west, north and northeast sides of the San Rafael Swell, have been formed by headward erosion in strata of differing erosional resistance in the arid climate. Remnants of pediment surfaces and bajada-like deposits extend high up on the flanks of the cliffs and may be seen at several locations (Young, 1966; and field notes with A. T. Cross, 1970). The sinuousity of the cliffs is the result of local influences, chiefly faulting, such as the Valley, Gordon Creek, Joe's Valley, Musinia and Water Hollow Fault zones (Doelling, 1972), and several permanent and ephemeral streams, such as the Price River, Huntington Creek, Cottonwood Creek, Ferron Creek, Muddy Creek, Ivie Creek, and Salina Creek, some of which follow major faults through portions of their courses. Others are independent of the faulting patterns.

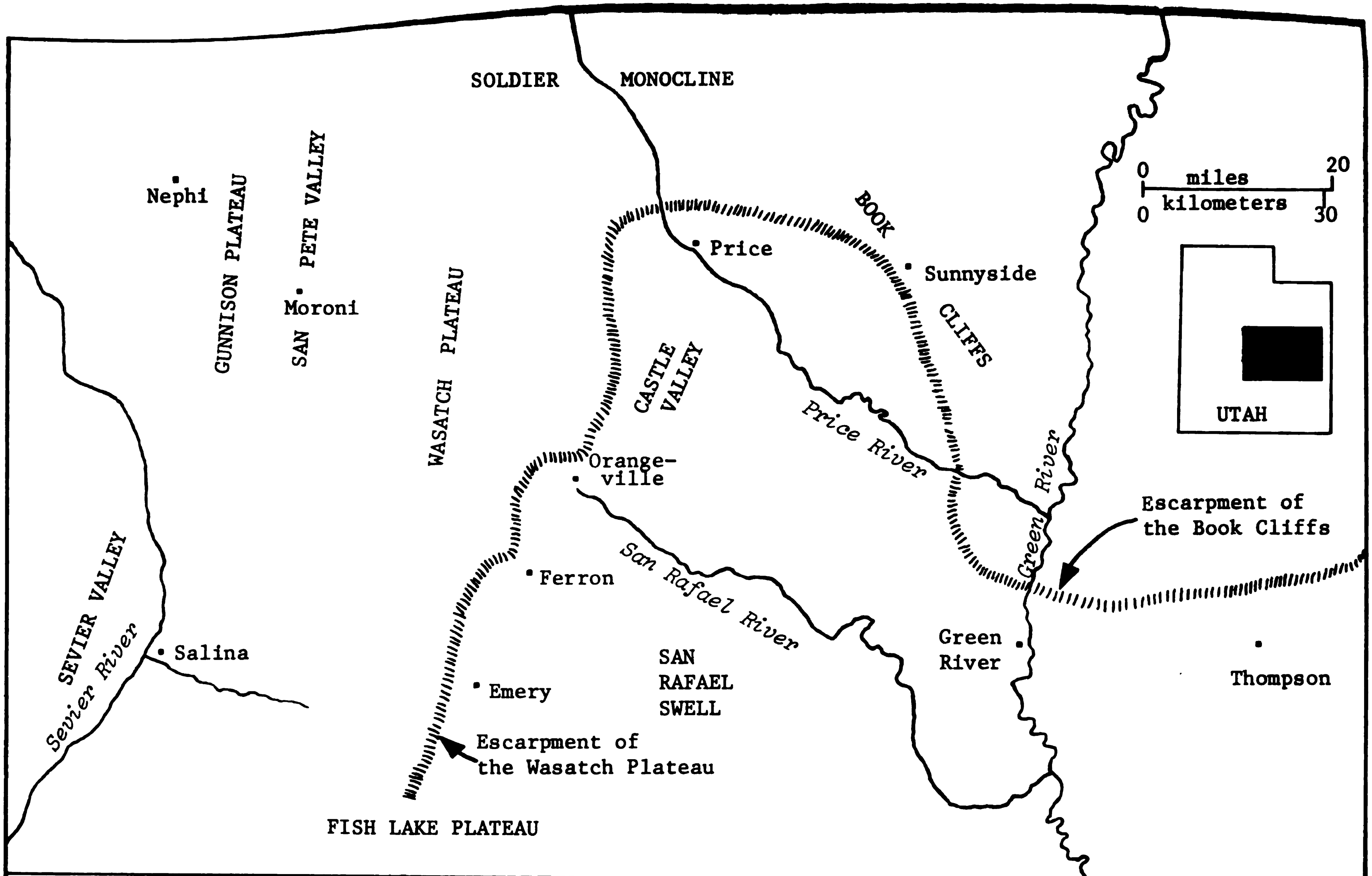


Figure 2. Index map showing major physiographic features in the Wasatch Plateau region. Note the sinuous and nearly continuous escarpment of the Wasatch Plateau and Book Cliffs for nearly 200 miles.

Elevation at Huntington, Utah, is 5,800 feet (1768 m), while only 8 miles (13 km) west the tops of the vertical cliffs of the Wasatch Plateau are 9,200 feet (2804 m). The elevation continues to rise westward, chiefly due to thick accumulations of younger Cretaceous and Tertiary sediments, eventually reaching more than 11,000 feet (3353 m) at the highest point 20 miles away (32 km).

The Wasatch Plateau is bounded on the east by the Castle Valley, formed in the Upper Cretaceous Mancos Shale, and on the south by the Fish Lake Plateau, a broad lava plain of late Oligocene age. The western edge is formed by a down-faulted block called the San Pete Valley. The northern edge of the Plateau is delimited by the northward and northeastward dipping Tertiary, lacustran sediments of the Soldier Monocline.

The Wasatch Mountains, Wasatch Plateau, and the Fish Lake Plateau form a north-south topographic barrier between the Basin and Range Province and the Colorado Plateau Province.

Exposures in the Wasatch Plateau include the slope-forming sediments of the uppermost Mancos Shale (Blue Gate and Masuk Members separated by the Emery Sandstone), the cliff-forming Star Point, Blackhawk and Price River Formations, all of Cretaceous age; the North Horn Formation, which transcends the Cretaceous-Tertiary boundary; and the Lower Tertiary Flagstaff Formation.

In the area of this study coal is being mined from the Blackhawk Formation and Ferron Sandstone.

The Wasatch Plateau, trending in a general north-south direction, nearly parallels the strand line of the ancient epicontinental sea,

while the regional east-west trend of the Book Cliffs is approximately normal to the strand line. This orientation, the extensive dissection and height of the steep cliffs, the nearly continuous exposures of fluvial and transitional coastal plain and near-shore marine features, provide an excellent display for sedimentary and paleoecological studies.

Geologic History

Spieker (1949a, 1949b), Young (1966), Armstrong (1968), McGookey (1972), and Hintze (1973) have described the regional geologic history during the Cretaceous Period, pointing out that as the Western Interior epicontinental sea expanded westward in the Early Cretaceous (Albian) its margin fluctuated in a transgressive-regressive manner rather than advancing continuously. As the seas began to withdraw in the Late Cretaceous (Campanian), fluctuations again occurred causing short term landward transgressions. These east-west pulses formed many relatively thin sedimentary units most of which thicken in a general westward direction toward the source of the sediment, the Sevier Orogenic Belt (Armstrong,1968). The Blackhawk Formation is a portion of one of the later regressive pulses. These wedges are composed of sandstones at the ancient shoreline and grade seaward into near-shore marine mudstones and/or offshore bars. Behind the beach deposits, swamps and marshes formed, many of which were cut intermittently by fluvial channels of delta distributaries and, in some instances, tidal inlets. Further landward, broad floodplains existed and extended to the western mountainous area formed by the Sevier Orogenic Belt.

The entire region as it has been uplifted and eroded into the resulting escarpments shows excellent onshore and offshore sedimentary features in the long-continuous outcrops. Studies by Spieker (1949b), Young (1955, 1957, 1966), Hale and Van de Graaff (1964), Howard (1966a, 1966b), Hale (1972), Van de Graaff (1972), and Balsley (J. K. Balsley, personal communication, 1975) interpret the sedimentary features of the Wasatch Plateau and Book Cliffs to be part of several deltaic sequences which include fluvial floodplain, lagoonal, littoral marine, near-shore marine, and offshore marine environments. Maberry (1971) describes openshelf, prodelta-slope, delta-platform, river-mouth bar, beach swamp-marsh-lagoon, estuary, and floodplain deposition at Sunnyside in the Book Cliffs. The present study provides evidence for the existence of floodplain swamp, bottomland and fluvial channel deposition in the middle and southern portions of the Blackhawk Formation in the Wasatch Plateau.

THE BLACKHAWK FORMATION

Sedimentation and Stratigraphy

The Blackhawk Formation in the Wasatch Plateau and Book Cliffs is one of the middle formations of the Mesaverde Group. As Maberry (1971) points out, the "Mesaverde Group" in Utah and Wyoming has been the subject of controversy because of the difference in age between these sections and the type section at Mesa Verde National Park in southwestern Colorado. However, he emphasizes that since the term "group" has no time significance, the "Mesaverde Group" designation is appropriate.

The term Blackhawk Formation was originally applied to the coal bearing rocks in the Wasatch Plateau by Spieker and Reeside (1925). The type section is at the Blackhawk Mine (now King Mine No. 2), west of Mohrland, Emery County, Utah. Clark (1928) extended the application of the name to the comparable sequence in the Book Cliffs. In an exposure on the west side of the Wasatch Plateau five miles east of Mount Pleasant, the Blackhawk is reported to be 1,700 feet (518 m) in thickness (Pashley, 1956; Doelling, 1972). At the east edge of the plateau, it is about 1,100 feet (335 m) thick (Young, 1966; personal field notes with A. T. Cross, 1970) and thins eastward, intertonguing with the Mancos Shale. For example, at Sunnyside, Utah, 35 miles (56 km) east of Huntington, the formation is 700 feet (213 m) thick and has an 80-100 foot (24-30 m) thick wedge of Mancos Shale in the lower portion (Maberry, 1971). The Blackhawk disappears eastward as a littoral marine sandstone near Thompson, Utah, about 80 miles (135 km) east from where it was more than 1000 feet (335 m)thick. Spieker and Reeside (1925) placed the lower boundary of the Blackhawk at the base of the lowest coal exposed in the Wasatch Plateau but later Young (1955) redefined the lowest boundary to include the upper sandstone of the Star Point Formation, the Spring Canyon Member. This sandstone is well defined along the eastern scarp of the Wasatch Plateau. The upper boundary was defined (Spieker and Reeside, 1925) as the unconformable base of the Castlegate Sandstone member of the Price River Formation, and in many sections can easily be identified; however, at Water Hollow Road in Salina Canyon, Bachman (1958) found no clear evidence of truncation of the Blackhawk and stated that it appears to be conformable. From my own examination of the Castlegate-Blackhawk contact at the Pipe Springs locality in Salina Canyon, I also agree that they are conformable. In the 1000+ foot (300 m) sequence above the Oliphant mine (abandoned) in Straight Canyon several minor unconformities exist which make it difficult to locate an exact upper boundary. In addition, fine grained sandstones, carbonaceous shales and thin coals, which appear to be lithologically comparable to those in the Blackhawk, exist above some of the unconformities while coarse-grained sandstones comparable to the fluvial sands in the lower Castlegate are found below the unconformities, making the exact boundary very difficult to identify (A. T. Cross, personal communication, 1970). No major unconformity exists at this locality, either. Spieker (1946) suggests that the Castlegate sandstone was deposited upon the slightly eroded surface of the uppermost Blackhawk. He theorizes that the uniformity of this contact in the Wasatch Plateau and the Book Cliffs indicates the lack of extensive erosion of the Blackhawk. Yet because of the marked change of facies between the sediments of the Blackhawk and the Castlegate, a major thrust or a renewed uplift must have occurred in the Sevier Orogenic Belt to rejuvenate the streams draining eastward.

Lithologic Character

The Blackhawk Formation in the Wasatch Plateau consists mostly of fine to medium-grained sandstone, which varies in color from dark brown on weathered surfaces to buff and gray. These sandstones are composed primarily of somewhat rounded quartz grains, and in many parts appear to be slightly ferruginous. They are usually massive, and commonly show cross-bedding and small lenticular channel deposits cut within them (Bachman, 1958; Howard, 1966; Maberry, 1971; and personal observation). The siltstones here are light colored and contain considerable amounts of clay and organic detritus. The claystones and shales are mostly medium to dark gray in color, some being very carbonaceous. At certain horizons, there are thin layers and lenses of coal, varying from a few feet (meters) to less than one-fourth inch (.6 cm) in thickness. These fine-grained sediments (siltstone, claystone and shale) comprise about two-fifths of the sediment in the southwest area of the Wasatch Plateau, and fluvial sandstones, chiefly of point bar origin, comprise the remainder (Bachman, 1958). The fluvio-deltaic sandstone facies changes eastward where, at Sunnyside, most of the thick sandstones were deposited in a littoral marine environment (Maberry, 1971).

The thinner coal beds of the Wasatch Plateau vary considerably in thickness, locally, due to a combination of local depositional factors and perhaps to differential compaction. Bachman (1958) notes that the coals generally become slightly thinner very near the outcrop, possibly because they have been pressed out. Cross (A. T. Cross, personal communication, 1975) suggested that they may have lost volume during near-surface oxidation. However, there are other possible explanations. The thicker, minable coals are restricted to the lower third of the formation in the Wasatch Plateau, and are more regional in extent. The Hiawatha coal, for example, is traceable the length of the Wasatch Plateau above the Spring Canyon Member, from at least the Gordon Creek area to 5 miles (8 km) south of the Ivie area of Salina Canyon, a distance of 67 miles (108 km) (Spieker, 1931). The Castlegate coal, above the Hiawatha coal, is visible on the outcrop almost continuously from north of the Gordon Creek area to the Star Point area on the Wasatch Plateau, a distance of 10 miles (16 km), and then for about 40 miles (64 km) northward and eastward along the Book Cliffs.

The Blackhawk Formation in the Book Cliffs has been divided into six members, each of which is made up of a basal littoral marine sandstone and a sequence of coal-bearing rocks above (Young, 1955, 1966) (see Figure 3). Young (1955) mentions that these members are not all present throughout the area because they have been identified only where the basal littoral sandstones are developed. For example, only three of them are present in the section at Sunnyside, Utah (Maberry, 1971). The Spring Canyon Member is the only one of the six which can easily be recognized in the sections studied in the Wasatch Plateau area. Above the Spring

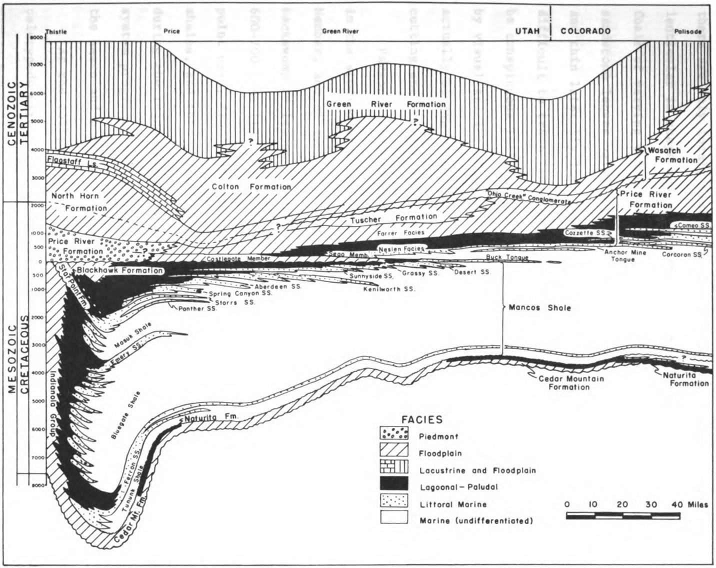


Figure 3. Stratigraphy of the Blackhawk and related formations of the western Book Cliffs area (after Young, 1966).

Canyon there are no prominent littoral marine sandstones; instead, there are only local, fluvial sands of point-bar origin. These are lenticular in shape and grade laterally into siltstones and shales. Coals of varying thickness often occur within the shales. These sandstone lenses vary in thickness from 1 to 40 feet (0.3 to 12 m), and thin laterally in a few hundred feet (meters). This makes it difficult to trace beds beyond an outcrop, even those which appear to be conspicuous locally. Any two of these lenticular sandstones which, by visual tracing along the outcrop, seem to be laterally related may actually be separated in time, representing deposits made during the cutting and filling of two separate channels of a meandering river.

Personal field observations indicate that the Blackhawk Formation in the studied sections consists of the littoral marine Spring Canyon Member, and an overlying series of shales and coals (probably of backswamp or lagoonal origin rather than fluvial swamp). The remaining 600-700 feet (183 to 213 m) of sediment is composed entirely of fluvial point bars, floodplain channels, and overbank deposits of siltstones, shales, and thin coals. Such a sequence of sediments is to be expected during the regression of a sea such as the Mancos, since, as the fluvial system prograded eastward the younger floodplain sediments would bury the beach and near-shore deposits which were previously laid down.

At the collection locality in the Ivie Creek area, marine pelecypods were collected in two thin zones above the Spring Canyon Member but below the first thick coal (the Ivie Bed of Spieker, 1931). There is no other sedimentary or biological evidence of marine deposition above these horizons at Ivie Creek, and it is probable that

these beds represent the last minor transgressive pulse of the regressing sea at that locality.

Spieker (1956) considered the Blackhawk Formation to be the probable equivalent of the upper member of the South Flat Formation exposed west of the Wasatch Plateau in the Gunnison Plateau. But later reports, based on comparisons of heavy minerals, carbonates and various isotopes (Hays, 1960), indicate that this may not be true.

Age

The geologic age and relative stratigraphic position of the Blackhawk Formation have been well established. Initially it was thought to be middle Campanian by Cobban and Reeside (1952), but recently McGookey (1972) has considered it to be slightly older. Although radioisotope dates are not available from Blackhawk sediments in this area, stratigraphic correlations with dated ash beds and index fossil zones have placed the limits of the formation within the Telegraph Creek and Eagle substages (Montana stage) of the Western Interior Reference Section. This corresponds to the uppermost Santonian and lowermost Campanian stages of the Standard Section (McGookey, 1972, p. 194).

The total thickness of the Blackhawk apparently required at least 4 million years to accumulate (McGookey, 1972). However, the lower limit of the formation in its western exposure is older than the lower limit further east (Weimer, 1960; Young, 1966; McGookey, 1972) and therefore the amount of time required for deposition at any one locality may be somewhat less than 4 million years.

RELATED GEOLOGICAL AND PALEOBOTANICAL STUDIES

General Geology

The first serious geological exploration of the Wasatch Plateau was undertaken by the Gunnison Survey which was commissioned to determine possible transcontinental railroad routes (Gunnison, 1855). Later, the Wheeler Survey also explored this portion of the state (Wheeler, 1875). Reports of both of these surveys presented geographic and geologic descriptions of the plateau and specifically mention the occurrence of coal in the southern area of the plateau. G. K. Gilbert also examined the Wasatch Plateau region in 1875. Although he did not publish this work, J. W. Powell (1876, pp. 16-17) quoted some of Gilbert's observations and published his block diagrams of the northern portion of the Musinia Graben area.

C. E. Dutton (1880) published a monograph on the high plateaus of Utah in which several features of the Wasatch Plateau were described and illustrated with structural cross sections.

Spieker (1946b) has pointed out that little of importance was published from 1880 to about 1920 except brief reports on local economic geology. These studies include Forrester's report on the coal of the Muddy, Quitchupah and Ivie Creeks (Forrester, 1893); Richardson's description of the coal and underground water in Sanpete and Sevier Valleys (Richardson, 1906, 1907); and his reconnaissance study of the Book Cliffs coal (Richardson, 1909). Taff examined the

Book Cliffs coal field west of Green River (Taff, 1906), and later, the Pleasant Valley coal district in Carbon and Emery counties (Taff, 1907). Later, Lupton described the geology and coal resources of Castle Valley (1916). In related sediments to the east, Lee (1912) described the coal of Grand Mesa and West Elk Mountains, Colorado. Although significant at the time, these studies added little to the knowledge of the regional depositional environments.

In the early 1920's a systematic examination (which included detailed geologic mapping) of the Wasatch Plateau region was begun, chiefly by E. M. Spieker, initially with the U. S. Geologic Survey, where he directed several major studies, and later with The Ohio State University. Subsequently, the Cretaceous and Tertiary units of the region were named and defined (Spieker and Reeside, 1925) and the orientation of the paleoshoreline was determined (Spieker and Reeside, 1926). After these significant points of reference were established the sedimentary and orogenic history of the transgressive-regressive sea could be explained (Spieker, 1946, 1949a, 1949b; Gilluly, 1963; Masters, 1966; Armstrong, 1968). The structure and physiography was determined (Eardley, 1934; Bartram, 1937; Stam, 1956); regional stratigraphy was worked out (Warner, 1949; Katch, 1951, 1954; Stokes et al, 1955; Abbott and Liscomb, 1956; Weimer, 1960, 1961); and the major facies interrelationships were correlated (Pike, 1947; Young, 1955, 1957, 1966; Hale, 1959; Fisher et al, 1960).

Detailed local examinations could now be properly fitted into this framework of knowledge such as studies of the fluvial Ferron Sandstone in which the sediment source was determined (Katich, 1953), the Ferron River paleoflow characteristics deduced (Cotter, 1971), depositional history analyzed (Hale, 1972), and environments of deposition were defined (Cleavinger, 1974; Cotter 1975a, 1975b). Other local detailed studies include Howard's work on the sedimentation of the Panther Sandstone Tongue (Howard, 1966a, 1966b) and Maberry's work on sedimentary features of the Blackhawk Formation at Sunnyside (Maberry, 1968, 1971). Relationships of certain units in the Gunnison Plateau to those of the Wasatch Plateau were made (Hunt, 1954; Hays, 1960; Thomas, 1960) and the relationships of Lower Cretaceous units in the region to those of the Upper Cretaceous were proposed (Stokes, 1952; Young, 1960).

Detailed geologic mapping of specific areas within the plateau region has been done largely by graduate students of The Ohio State University and the University of Utah. Childers and Smith (1970) have prepared a bibliography which contains most of these works.

A major synthesis of much of the earlier geological information has been prepared under the auspices of the Rocky Mountain Association of Geologists (McGookey, 1972). It includes a comprehensive overview of the transgressions and regressions of the Western Interior Seaway and new information on the tectonic activity, sedimentation and stratigraphy of the Lower and Upper Cretaceous system in the form of several paleoenvironmental maps, restored sections, charts and fence diagrams.

The most important geological papers which have had direct bearing upon this study are Spieker and Baker's (1928) report on the Salina Canyon coals, Spieker's (1931) work on the correlation of the coals of the Wasatch Plateau, Baughman's (1958) and Bachman's (1958) geologic

maps in Salina Canyon, and field guide road logs by Spieker (1949a); Rigby _et al_ (1966); Rigby _et al_ (1974); and Cross _et al_ (1975).

Coal

In the region of study, coal has been mined in several major coal fields. In the Wasatch Plateau, these coal fields are the Mt. Pleasant, east of Mt. Pleasant; the Sterling, east of Gunnison; the Salina Canyon, in Salina Canyon; and the Wasatch Plateau, along the eastern escarpment of the Plateau from Spring Canyon to Salina Canyon. Only the Wasatch Plateau coal field is now active. West of the study area in the Gunnison Plateau is the abandoned Wales coal field, west of the city of Moroni. Northeastward, is the Book Cliffs coal field located along the escarpment from Spring Canyon to the Green River. It is the most important in the state with respect to past and present production (Doelling, 1972). The Emery coal field, with two mines in the Ferron coal (the I-seam of Lupton, 1916), currently active, is located southeast of Emery.

The coal-bearing formations in the active coal fields are the Blackhawk Formation and Ferron Sandstone. Minor coals, some of which have previously been mined are in the Dakota Sandstone, the Six Mile Formation, the Emery Sandstone, the South Flat Formation, the Price River Formation, and the North Horn Formation.

The basis for comprehensive regional coal geology studies in the Blackhawk and Castlegate was Spieker's detailed mapping of the Salina Canyon and Wasatch Plateau coal fields (Spieker and Baker, 1928; Spieker, 1931). In these studies, nearly 600 coal-bearing stratigraphic sections were measured and correlated. Subsequently, numerous reports have been published, the most recent being Maberry's (1971) work on stratigraphy and paleoecology of the lower Blackhawk Formation and Doelling's important monograph (1972) of the central Utah coals. This monograph includes much of Spieker's earlier mapping, plus historical, stratigraphic, engineering, and economic information. Recently, Stewart (1975) has reported renewed exploration and research in areas of the Wasatch Plateau where coal is expected to be mined in the next ten years.

Three major symposia have been specifically concerned with the coals of east central Utah. They were, one meeting of the Intermountain Association of Geologists in 1956, and two meetings of the Coal Geology Division, Geological Society of America in 1966 and 1975. Individual studies published in conjunction with these symposia have dealt with regional stratigraphy, paleobotany and paleoecology, and coal petrology, engineering, and palynology (Peterson, 1956; Hamblin and Rigby, 1966; Cross and Maxfield, 1975; Cross, Maxfield, Cotter and Cross, 1975).

Paleobotany

The existence of Upper Cretaceous fossil plants in the region has been known for many years. Stanton (1894) was the first to collect fossil plants from the state when examining local stratigraphy near Coalville, probably in the Coalville Member of the Frontier Sandstone (Turonian). This collection was subsequently described by Knowlton (1900) and included 10 species. Earlier, Lesquereux (1874), who

described fossil plants from many localities in the Western Territories, examined invertebrate fossils from the Stranton locality at Coalville, but unfortunately plant fossils were not in that collection.

In rocks related to the Blackhawk Formation, several coal geologists and stratigraphers have observed the occurrence of fossil plants. These include: Richardson (1909) who collected gymnosperm and angiosperm leaves from the Book Cliffs mine of western Colorado (Mesa Verde Group?) and from Ballards mine near Thompson, Utah (Farrer Formation?); Lee (1912) who described several ferns, gymnosperms, and angiosperms from near Grand Mesa, Colorado (Paonia Shale?); Thiessen and Sprunk (1937) who identified conifer remains in coal from Sunnyside, Utah (Blackhawk Formation); Hunt (1954) who collected several dicotyledon leaves in the Gunnison Plateau (South Flat Formation); Fisher et al (1960) who collected several species near Cisco, Utah (Farrer Formation); and Maberry (1971) who collected palms and other plants from Sunnyside, Utah (Blackhawk Formation).

Mention has been made of fossil plants in Salina Canyon by Spieker and Baker (1928), Baughman (1958), Bachman (1958), and Rigby et al (1974). Parker (1968) described 20 species from two localities in that canyon. In addition, several large pieces of petrified wood have been collected near the top of the Blackhawk Formation in Tommy Hollow, in the Ivie Creek area of Salina Canyon (W. D. Tidwell, personal communication, 1970). Preliminary examination indicates that they are gymnospermous.

A large collection of ferns, gymnosperms, and angiosperms was made in Straight Canyon and Price River Canyon by Cross and Singh

(A. T. Cross and H. P. Singh, personal communication, 1970) and later by Cross and others at several additional localities in proximity to Hiawatha, Kenilworth, Castlegate, Price River and North Horn coals (A. T. Cross, personal communication, 1975).

Palynology

Plant microfossils, including algae, spores, and pollen, have received considerable attention as they have related to problems of various sedimentary environments which were associated with the transgressive-regressive Upper Cretaceous sea. These palynological examinations are numerous, but of particular importance are Upshaw (1962), Lammons (1968), Lohrengel (1969), Orlansky (1970), Thompson (1970), Kidson (1971), Stone (1971), Gies (1972), May (1972a), and Martinez-Hernandez (in preparation).

Palynological studies of the Blackhawk Formation have thus far all been directed toward the coals. These include Wheelwright (1958), May (1972b), and Cross and Singh (1976).

Regional Paleoecology

Numerous studies of regional Upper Cretaceous paleoecology have recently been published. Generally, emphasis has been directed toward brackish paludal, lagoonal and deltaic environments, and marine beach, barrier bar, and offshore environments. None of these reports have interpreted to any extent the terrestrial environments such as those of the Blackhawk floodplain. However, these studies are important in an overall knowledge of the fluctuating shoreline environments of

deposition and their contemporaneous relationship to terrestrial environments. All of the palynological reports mentioned above have discussed and often emphasized various aspects of local marine paleoecology. In other studies, features such as sedimentary structures, animal fossils and animal trace fossils have been used as paleoenvironmental indicators. Selected important papers include: Zapp and Cobban (1960), Reeside (1957), Sarmiento (1957), Toots (1961, 1962), Tschudy (1961), Hoyt and Weimer (1965), Gray *et al* (1966), Howard (1966a, 1966b, 1966c), Masters (1966, 1967), Young (1966), Maberry (1968, 1971), and Lawyer (1972).

COLLECTIONS AND METHODS OF STUDY

The first two localities which were sampled are in Salina Canyon. These were shown to me by James A. Jensen in September, 1966, in the company of J. Keith Rigby, W. D. Tidwell, and Alan T. Washburn. These localities were visited several times and, subsequently, other collecting sites were found, some of which yielded excellent fossil leaves. The entire summer of 1970 was spent in the field, for the purpose of making a large collection, gathering pertinent field data and correlating collection sites. Much of this work consisted of locating additional collecting sites which seemed to have the potential of yielding adequate numbers of well-preserved leaf specimens and which were reasonably accessible to roads. Outcrops examined were principally in Huntington, Straight, Ferron, Ivie and Salina Canyons. It was my initial intention to gather the first 500 specimens of any sort, in order to give statistical validity to analyses in the laboratory. This plan was soon abandoned as being generally impractical. Multiple fossil plant levels at each locality were also sought.

The locations of the six principal localities finally selected and studied in this report are given in Appendix I.

Collections

The correlation of the sites within the six major collection localities is shown in Figure 4, where the relationship of these sites to the overlying and underlying formations is indicated. The

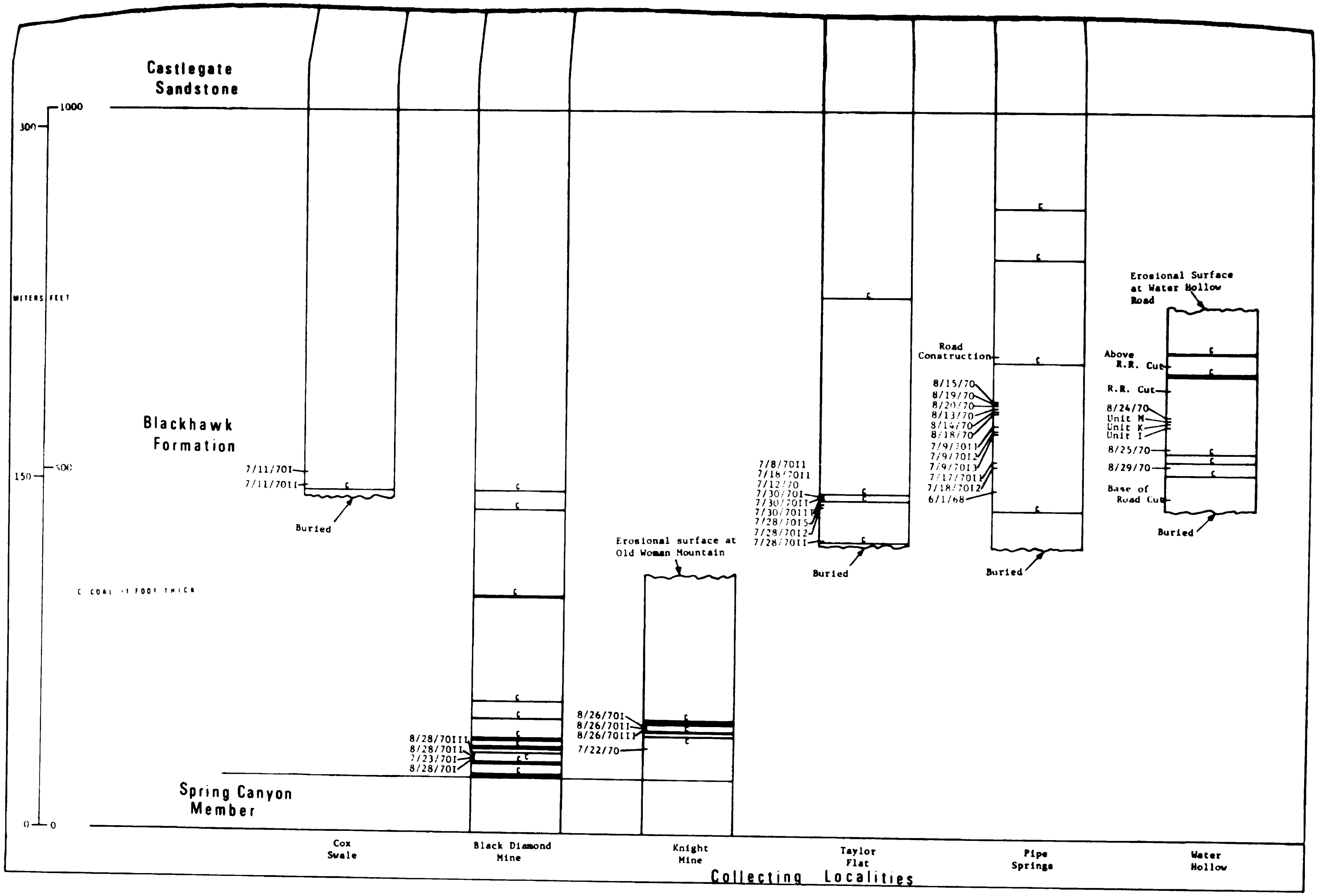


Figure 4. Stratigraphic correlation of the collection sites at the localities indicated in Figure 1.

unconformity between the Blackhawk Formation and the Castlegate Sandstone at the Cox Swale locality has been observed (A. T. Cross, personal communication, 1970) and presumably exists at the Black Diamond Mine also. No major unconformities exist at the Taylor Flat or Pipe Spring localities (personal observation). The entire Blackhawk Formation, where it was measured in Straight Canyon, was about 1000 feet (300 m) thick.

As collections were being made at specific levels, care was taken to combine as a single unit or "florule" only those fossils which seemed to have been buried contemporaneously in the sediment. These predominantly thanatocoenosic assemblages of leaves reflect the local communities more accurately than do the pollen-spore floras. They are composed of plants which lived in a specific type of community which was in and immediately near the local basin of deposition, since Chaney (1924, 1925) has shown that leaves of living trees found buried within modern sedimentary traps have not traveled far from the parent plant after being shed.

Because of several factors, all species of a living community are not preserved in nearby sedimentary traps. Therefore, the composition of the ancient community is admittedly only partially represented.

In no cases were the collections grouped from stratified zones thicker than 10 inches (25 cm). Usually they were much thinner, i.e., 4 to 8 inches (10 to 20 cm). This practice, although very simple in its concept, is used only occasionally in studying major collections of fossil plants. Many studies have been made in which all the specimens collected at various levels or zones have been

combined into units and termed "floras" even though it is obvious that such stratigraphically and areally disjunct collections do not represent the equivalent of a living flora. Considerable spans of time and often a somewhat different sedimentary environment may have separated the collection sites. For example, if collections of the Blackhawk Formation were combined, there would be several hundred feet (meters) of coastal fluvial clastics between the uppermost and lowermost, representing a span of time of about 2 to 4 million years. In addition, many paleobotanical studies have ignored the environmental and often even the evolutionary changes which may have occurred during the time the "flora" existed. A noteworthy exception is the report on the vegetation and paleoecology of the upper Miocene Sucker Creek Flora (Taggart & Cross,1974).

In a few instances in this study, unusual or especially good isolated specimens found on float blocks were also collected, but kept separate from the individual florules.

It is unfortunate that modern ecological methods have been applied so infrequently to paleobotanical studies. Chaney established a firm base for realistic paleoecological plant studies fifty years ago with his qualitative studies of the Miocene Bridge Creek flora (Chaney, 1924), and when he compared that flora with a modern redwood forest of California (Chaney, 1925). Although conclusions drawn from such studies may be controversial, the value of accumulation and interpretation of such data is indisputable. In this regard, paleozoologists and geologists have produced several important studies on what are obviously the remains of true biotic communities (e.g., Zangerl and Richardson, 1963; Baer, 1969).

Field Methods

Notes and sketches in the field were amplified with many surface and aerial photographs which were of some help in determining stratigraphic correlation of the collection sites. Several beds were followed by continuous tracing on the outcrop to verify correlations. Thicknesses of rock units were made by direct measurement or with a Brunton compass. The largest blocks that could be handled were removed from the outcrop in order to obtain the most complete specimens. All fossils were individually wrapped in newspaper and given the specific site identification number.

The rock types (matrix in which the fossils were preserved) of each collecting locality were examined for sedimentary features which might be significant, but grain size and organic content were particularly noted and recorded. Grain size measured in the field was very subjective but sandstones, siltstones, and claystones were distinguished. Determination of organic content was also subjective, based on the color of the rock; dark colors usually indicating a higher organic content than lighter colors.

Curatorial Procedures

The fossils have been placed in drawer-type museum cabinets in the Geology Storage area at Michigan State University.

Curating the collections was accomplished with a system of numbers and letters which identify the collecting site, the particular block or rock, and the individual plant specimen. An example is the following:

8/24/70
001-002

where "8/24/70" is the date the plants were collected and corresponds to field notes as being a specific collection site, since no other collections were made on that date. "001" is the number of the rock block which contains the fossil plants (one to several specimens may be on one block); "002" is the specimen number, indicating that it is the second specimen to be numbered on that block. If both halves (or several pieces) of a single block were present, they both received the same series of numbers, but they were individually designated by giving each portion a different letter at the end of the block number. In the case of specimens on these blocks which were represented by part and counter-part (obverse and reverse), each one of these was also given a different letter designation at the end of their number. Thus, the following example:

8/24/70
001A-002A and 8/24/70
001B-002B

where the numbers represent both parts of a single block which contained part and counter-part of specimen number 002. Both blocks and specimens were numbered consecutively; thus, the second block would be 002 and if two specimens were present they would be numbered 002-003 and 002-004 (001-001 and 001-002 were on the first block).

This system proved very useful in retrieving a particular specimen from its florule or separating and refiling several specimens after various types of taxonomic combinations had been made (e.g., after several specimens of *Sequoia cuneata* from different florules had been combined for comparative purposes).

Photographic Catalog

A catalog containing more than 2100 life-size photographs was assembled to facilitate study of the fossil plants by photographing and making life-sized prints of the specimens. In addition to the fossil specimens, a mm scale and the collection number were positioned so as to be within the limits of the photograph. The prints were attached to one corner of 8 x 10-1/2 inch punch cards with dry-mounting tissue. It was thought that a punch card retrieval system would be useful in identifying the specimens, but this aspect of the catalog has not been developed. Cards with similar-appearing types of plants were placed together in groups. Names and references useful for identifying the fossil plants, and other data are recorded on the punch cards.

Laboratory Techniques

Laboratory studies of the fossil plants included the following:

Cuticle preparation and study. -- The cuticle of fossil plants is often sufficiently characteristic to be of value in identification. Several fragmentary pieces of cuticle were removed from some specimens using techniques of Dilcher (1963, and D. L. Dilcher, personal communication, 1973). However, only a small percentage of the leaves yielded good cuticular preparations. Although there is often a considerable amount of dark, flakey, carbonaceous substance present including what appears to be the cuticle, it does not have the impressions of epidermal cells and stoma in it. About one out of thirty leaves examined for cuticle produced results.

In additional attempts to observe epidermal cell patterns or stomatal bands on gymnospermous leaves, a scanning electron microscope (SEM) was used. Items examined included carbonaceous leaf remains (bleached and unbleached), rubber latex and polyvinyl chloride casts of leaf impressions, and several small pieces of the actual fossil leaf impression in the rock matrix. All of the above materials were mounted on small coverglasses with double-edged tape in standard mounting procedures, coated, and examined (Taylor, 1968). Although J. W. Schopf has obtained SEM photographs of epidermal cells of *Calamites* sp. impressions (A. T. Cross, personal communication, 1972), no such cell patterns or stomatal bands could be observed on the Blackhawk specimens which were examined.

Palynological examinations. -- Several specimens of what appeared to be male gymnosperm cones, catkin-like structures and marginal sporangia of a fern were chipped from the rock matrix (often the complete specimen was used after it was photographed, while at other times only a portion of the specimen was removed) and macerated with standard palynological techniques (Cross, 1968) to remove the rock matrix and isolate whatever pollen or spores might be present. This was successful with some of the specimens, producing excellent slides of palynomorphs, which in one case facilitated identification of a megafossil fern (*Saccoloma gardneri*).

Rock matrix and coal from several different collection sites was macerated, and microscope slides were made of the palynomorphs which were isolated. The slides were examined, but no results are included in this study.

<u>Megascopic leaf preparations - excavation.</u> -- Often it was necessary to uncover or excavate partially buried leaf compressions, stems, and reproductive structures. This was successfully accomplished using small chisels with a narrow cutting edge (1/16 to 3/16 inches width). Dissecting needles or dental tools proved ineffective.

This technique was valuable to this study and resulted in many complete and nearly complete angiosperm leaves and leafy conifer twigs. More importantly, several physical connections between certain structures were determined. Some of these had not been reported before and include: the marginal sporangia (with spores) of *Saccoloma gardneri*; the attachment of *Sequoia cuneata* foliage to cones; the attachment of *Protophyllocladus polymorpha* phyllodes to a branching axis; the attachment of a *Moriconia cyclotoxon* branch to a branching axis; and the connection of several elongate lobes to one large leaf of *Manihotites georgiana*.

Identification of the Specimens

Initial identification of the Blackhawk plants was accomplished by comparing photographs of the fossils with illustrations in the literature. The "Catalogue of Mesozoic and Cenozoic Plants of North America" at Princeton University (Dorf, 1940) was used extensively and was a major aid in determining those plants which had been illustrated and previously described. This method has been justifiably criticized by Dilcher (1974), but at this time no better way is known. In addition, herbarium specimens and living plants were used in order to compare venation patterns, epidermal cell patterns, glandular

structures, cone structures, and gymnosperm branching and leaf structures. When possible, the cuticle of fossil specimens was removed from the rock matrix, cleared, then examined microscopically as an aid to determine identity. As a result, certain of the fossil plants, notably a few of the ferns, some of the gymnosperms, and a few of the angiosperms, can be reliably correlated with living plant groups, often at the generic level.

THE BLACKHAWK PLANTS AND FLORISTIC RELATIONSHIPS

Plants in the Blackhawk Formation

A total of 118 species have been collected and described in this study including leaf and twig compressions, a portion of a lignified gymnosperm log, and casts of several fruit or seed-like structures. In addition, many interesting _in situ_ plant roots and stems were seen in the field, but these were not studied.

The collection studied includes nearly 7,500 specimens, about one-half of which are well-preserved enough to be identified or characterized. The unidentified specimens are usually too poorly preserved or fragmented to be useful, but apparently they all are dicotyledon leaves. Of the plants which could be characterized, there is one thalloid, liverwort-like plant, one club moss-like specimen, fourteen ferns, twelve gymnosperms of various types, and eighty-six angiosperms. Angiosperms are represented by five monocotyledons and eighty-one dicotyledons (see Table 1). Although all the gymnosperms and monocotyledons have been previously identified, only six of the ferns and fifty dicotyledons appear to have been previously described. The eight unidentified ferns and thirty-one unidentified dicotyledons are thought to be previously undescribed species. This large number of new species, roughly one-fourth of the total in the collection, seems very large, but might be justified in two ways. First, the continental flora of the Cretaceous

Table 1. The species of the Blackhawk flora. The number of specimens of each species are indicated under the site in which they were collected.

TAXA	6/1/68	7/8/70 I-1	7/9/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/11/70 II	7/12/70	7/17/70 I-1	7/18/70 I-1	7/18/70 I-2	7/22/70	7/23/70 I	7/28/70 I-2	7/28/70 I-5	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/25/70	8/26/70 I	8/26/70 II	8/26/70 III	8/28/70 I	8/28/70 II	8/28/70 III	8/29/70	Above Rail Road Cut	Base of Road Cut	Unit I	Unit K	Unit M	Rail Road Cut	Road Construction	Total of each species
Non-Vascular Plants (1 specimen)																																										
Marchantia linearis																																							1			1
Ferns and Allies (177 specimens)																																										
Allantodiopsis erosa				1													1															1		2				1				6
Asplenium dicksonianum																										17																17
Cyathea pinnata	37																																									37
Onoclea hebridica							40												3																							43
Osmunda hollicki																	3	11	7			1		2								11	1					1				37
Saccoloma gardneri																	1	3																			2					6
Woodwardia crenata																	3		2																							5
Unknown Fern 1																																12										12
Unknown Fern 2																						2																				2
Unknown Fern 4	1																																									1
Unknown Fern 5																								1																		1
Unknown Fern 6																																1										1
Unknown Fern 7																																										?
Unknown Fern 8																										3												4				7
Unknown Fern 9			1																																							1
Selaginella sp.																		1																								1
Gymnosperms (2167 specimens)																																										
Androvettia sp.																																					3					3
Araucarites cone scale							2																			1																3
Araucarites sp.												49																							3						10	62
Brachyphyllum macrocarpum							6														4		10	134														1				155
Moriconia cyclotoxon					1		22							1								2	5	1	3																	35
Nageiopsis sp.																								1077																		1077
Podozamites sp.																				2	1		1	7			128															139
Protophyllocladus polymorpha					2		8		2	12				2	1		1			7	2	14	12	2	5	13		1		1				29			3	6		1		124
Protophyllocladus sp. 2																49																		1								50
Sequoia cuneata	15					207		3		9	1	2	1	1			1		2	45	43	9	13	69	15	31			1	6	2	9					8	6	1	6		506
Widdringtonites reichii																						12																				12
Gymnosperm Wood (lignite)																																				1						1
Angiosperms																																										
Monocotyledons (99 specimens)																																										
Canna magnifolia																			3										1													4
Cyperacites sp.														1						2	8			9										4								24
Geonomites imperialis		2		1			4		2	7	11		2	8	6							9			1				4	1				3			2		5			68
Paloreodoxites plicatus							1																																			1
Sabalites montana														2																												2
Dicotyledons (2071 specimens)																																										
Anona? robusta																																					10					10
Acer cretaceum							6																																			6
Apocynophyllum giganteum										1							14	4	3			1		2	1																	26
Celastrophyllum carolinensis							1					2																														3

Table 1. (Cont'd)

Table 1. (con't)

TAXA	6/1/68	7/8/70 I-1	7/9/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/11/70 II	7/12/70	7/17/70 I-1	7/18/70 I-1	7/18/70 I-2	7/22/70	7/23/70 I	7/28/70 I-2	7/28/70 I-5	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/25/70	8/26/70 I	8/26/70 II	8/26/70 III	8/28/70 I	8/28/70 II	8/28/70 III	8/29/70	Above Rail Road Cut	Base of Road Cut	Unit I	Unit K	Unit M	Rail Road Cut	Road Construction	Total of each species
Celastrophyllum cretaceum																	1																									1
Celastrophyllum undulatum							8																																			8
Cercidiphyllum arcticum																	146	142	47					8					5	3		3										354
Cinnamomum intermedium																				2																						2
Cinnamomum sezannense																																							8			8
Cissus marginata		1					43									2	3	1	1	1						1	24			3	6			6			1					93
Cornus denverensis														2								5			2		4							5					7			25
Cornus praeimpressa		1		5	7																	10		5	15		1		1					2								47
Dombeyopsis obtusa							1												1																							2
Dryophyllum subfalcatum		4			1	1	12					18					5	9	89			3	1	1			54			1	1			3					2			205
Dryophyllum whitneyi																											3							26								29
Fagus cretacea																									4																	4
Ficus glassconea							2																	1													1					4
Ficus laurophylla							4	1									1	1									2				4											13
Ficus planicostata																				2				9			2		5											1		19
Ficus post-trinervis																						1	1																			2
Ficus puryearensis																										1											6					7
Laurophyllum coloradensis													3				17		10													25										55
Laurophyllum meeki							4												3																							7
Liriodendron alatum							6																																			6
Magnolia amphifolia									1	2				2	1																						2					8
Magnoliaephyllum cordatum					4		2													2																						8
Manihotites georgiana										2			24															1			1	6	36					1				71
Menispermum dauricumoides																		1	8											2												11
Myrtophyllum torreyi					2	2	6						3						3				1		3						7	59						1				87
Nymphaeites dawsoni																																						1				1
Paranymphaea crassifolia					1																																					1
Phyllites craigensis																											4															4
Phyllites wilderi										1																													2			3
Phyllites vermejoensis							13										5	5	12			3		1			2					14										55
Platanus alata						7																			7									10			1					25
Platanus raynoldsii	4	9			3		3		2			4	6		4	12	28	15	52	5	9		1				15	1	1		51	8		9				1		1		244
Pterospermites undulatus																											2															2
Populus? apiculata																											1															1
Quercus stantoni																						7																				7
Ranunculus (?) sp.											1																															1
Rhamnites eminens				3			22	1	5	11				11	9				2	31	14	13	3	15	15					2	1		7							3		168
Rhamnus salicifolius																											1				1											2
Salix gardneri							3																								12			6								21
Salix lancensis																	1										4							1			1					7
Salix proteaefolia							2																			6											3					11
Salix stantoni																5											7										1			1		14
Sapindus morrisoni																							2																			2
Trapa paulula																																							1	1		2
Trapa sp.																																					1					1
Viburnum antiguum					3				1															1							1			23			1					30

Table 1. (con't)

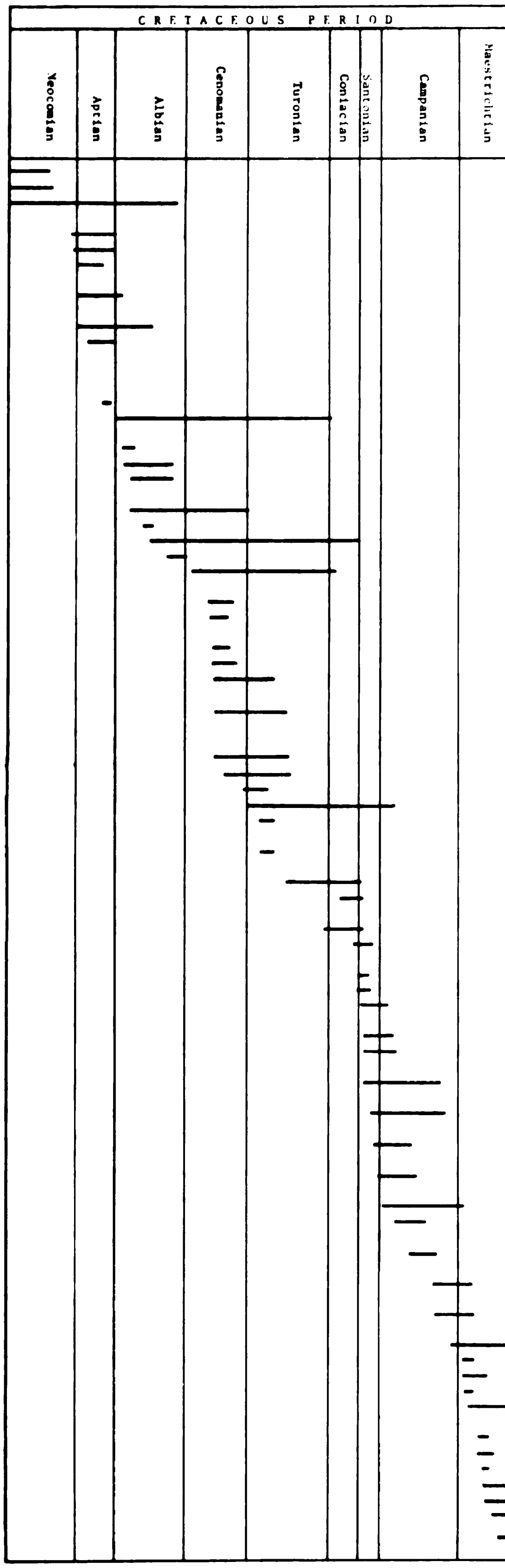
TAXA	6/1/68	7/8/70 I-1	7/9/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/11/70 II	7/12/70	7/17/70 I-1	7/18/70 I-1	7/18/70 I-2	7/22/70	7/23/70 I	7/28/70 I-2	7/28/70 I-5	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/25/70	8/26/70 I	8/26/70 II	8/26/70 III	8/28/70 I	8/28/70 II	8/28/70 III	8/29/70	Above Rail Road Cut	Base of Road Cut	Unit I	Unit K	Unit M	Rail Road Cut	Road Construction	Total of each species
Unnamed Dicotyledons (349 specimens)																																										
Unknown dicotyledon 2																											162													2		164
" " 9							1																																			1
" " 13																						9												3					26	1		39
" " 14																											2															2
" " 15																											2															2
" " 16																				1												2										3
" " 17							5																																			5
" " 18								2																							3									2		7
" " 19												6								6	2								12			1										27
" " 20																												1														1
" " 24																																1										1
" " 25							31																																			31
" " 26							2											1						1													1					5
" " 27													4					1	2																							7
" " 30							1																																			1
" " 32																								12																		12
" " 33																		1	2													3										6
" " 35									2								2						1																			5
" " 36																									1																	1
" " 37																											1															1
" " 40																											5											1				6
" " 41																											1															1
" " 44																							1																			1
" " 46																										6																6
" " 47																																2										2
" " 49																																					2					2
" " 50																																					1		1			2
" " 53																	1																									1
" " 54																										4																4
" " 55																															1											1
" " 56																									1																	1
" " 57																1																										1
Plant Structures (49 specimens)																																										
Unidentified seeds	1												8				1	3	1		4	1	1	15	1		1							4				1				42
Palaeocaster? inquirenda											6																															6
Cercidiophyllum ellipticum																														1												1
Total Taxa Per Site	5	5	1	4	9	3	30	4	7	8	3	6	8	10	5	5	19	15	20	12	9	17	14	21	14	10	22	5	8	7	14	16	4	17	1	1	18	13	8	10	1	
Unidentifiable Dicot Leaf Parts	16	21	0		78	11	330	0	12	27	1	84	53	33	31	62	134	181	138	89	48	201	51	175	24	27	435	37	29	19	180	112	7	226	0	0	10	8	33	0	0	2928
Total Characterized Specimens	58	17	1	10	24	10	468	7	15	45	8	90	45	38	21	69	235	200	253	106	87	102	53	1373	74	83	300	132	30	13	96	151	53	137	3	1	49	25	53	19	10	4565
																																					Total Specimens					7493

Santonian-Campanian Stages is not as well known (due to fewer collections in rocks of that age) as those of other stages (e.g., the Western Interior flora of the Maestrichtian stage or the Dakota flora of the Albian and Cenomanian stages), and second, it is probable that most floras represent unique communities since they are normally isolated geographically and through time from other floras. Although some of the new species found in this flora may subsequently be found in others, the Blackhawk flora should generally remain a distinctive unit. By way of interest, the Lance Creek and Medicine Bow floras (Dorf, 1942) of the well-collected Maestrichtian Stage each also have roughly one-fourth of the species described as new. Other Cretaceous and Tertiary floras have many more (e.g.,Hollick's study in Alaska, 1930, 1936).

Relationships to Other Floras

The rocks of every florule were carefully examined and the numbers of specimens of each species were recorded. Table 1 lists all the species recognized in the Blackhawk flora and was used in several paleobotanical analyses which will be described and discussed subsequently.

In order to compare the ages of selected Cretaceous fossil leaf floras in North America, a time correlation chart, Figure 5, was compiled from the literature. It illustrates the approximate age of the fossiliferous zones of each flora and the number of species collected. References to these floras and to the stratigraphy is



Name of Geologic Unit	Number of Species	References to Flora	References to Relative Stratigraphic Position
Patuxent Fm.	89	Berry, 1911a	Dorf, 1952
Blairmore Fm. (lower)	28	Berry, 1929b	McGookey, 1972
Potomac Group	541	Fontaine, 1889, 1905b	Dorf, 1952
Arundel Fm.	38	Berry, 1911a	McGookey, 1972
Blairmore Fm. (upper)	18	Berry, 1929c	
"Above the Morrison Equivalent"		Cockerell, 1916	?
Kootenay Series	90	Knowlton, 1907; Brown, 1946; Berry, 1929	McGookey, 1972
Kome Beds	86	Seward, 1926	
Kootenay Series	63±	Newberry, 1891; Fontaine, 1892, 1905a, 1907	McGookey, 1972
Burro Canyon	19	Brown, 1950	McGookey, 1972
Benton Shale of Dakota Ss.	96	Ward, 1899	
Trinity Group	23	Fontaine, 1893	Stepheson, 1942
Patapsco Fm.	75	Berry, 1911a	Dorf, 1952
Kaltag, Nulato & Melozi Fms.	211	Hollick, 1930	Imlay, 1954
Nanusnuk Group		Smiley, 1969	Imlay, 1954
Cheyenne Ss.	23	Berry, 1922	Cobban et al '52
Kuk River Deposits		Smiley, 1966	Smiley, 1966
Aspen Shale	14	Brown, 1933	McGookey, 1972
Frontier Fm.	34	Knowlton, 1917a; Berry, 1930a	McGookey, 1972
Dakota Group	460	Lesquereux, 1892	Cobban et al '52
Dakota Fm.	32	Lesquereux, 1895 Berry, 1939	Cobban et al '52
Dunvegan Fm.	66	Bell, 1963	Scott, 1963
Woodbine Sand	43	Berry, 1922b	Stephenson, 1942
Tuscaloosa Fm (with 3 minor fms)	151	Berry, 1919	Stephenson, 1942
Raritan Fm. & Cliffwood Fm.	256	Hollick, 1906; Hollick & Jeffery, 1909	Dorf, 1952
Raritan Fm.	170	Berry, 1911b	Dorf, 1952
Raritan Fm.	20	Berry, 1916b	Dorf, 1952
Raritan Fm.	25	Berry, 1905b, 1916	Dorf, 1952
Colville Group		Smiley, 1969	Imlay, 1954
Raritan Fm. (Amboy Clays)	156	Newberry, 1895	Dorf, 1952; Wilmarth, 1938
Frontier Fm.	8	Andrews & Pearshall, 1941	McGookey, 1972
Mesaverde Group	2	Brown, 1956	Cobban et al '52
Black Creek Fm. (Middendorf Arkos)	76	Berry, 1914	Dorf, 1952
Chignik Fm.	72	Hollick, 1930	Imlay, 1954
Eutaw Fm. (with 3 others)	43	Berry, 1919	Stephenson, 1942
Eutaw Fm.	27	Berry, 1914	Stephenson, 1942
Badheart Fm.	6	Bell, 1963	Scott, 1963
Prince Creek Fm. (Tuluvak Tongue)		Smiley, 1969	Imlay, 1954
Magothy Fm.	56	Berry, 1906	Miller, 1974
Magothy Fm.	100±	Berry, 1908, 1916; Penny, 1947	Miller, 1974
Matawan Fm.	105	Berry, 1903a, 1903b, 1904, 1916	Dorf, 1952
Milk River Fm.	28	Bell, 1963	Scott, 1963
Blackhawk Fm.	118	This Study	McGookey, 1972
Allison Fm. (lower) (= Belly River Fm)	10	Berry, 1929a	Scott, 1963
Montana "Fm."	91	Knowlton, 1900	McGookey, 1972
Prince Creek Fm. (Kogosukurk Tongue)	1	Arnold & Lowther, 1955	Imlay, 1954
Old Man Shale	1	Ramanujam & Wilson, 1969b	McGookey, 1972
Edmonton Fm.	4	Ramanujam & Wilson, 1969a	Wilmarth, 1938; McGookey, 1972
Fruitland Fm. & Kirtland Fm.	40	Knowlton, 1916	McGookey, 1972
Laramie Fm.	131	Knowlton, 1922	McGookey, 1972
Ripley Fm.	6	Berry, 1914	Stephenson, 1942
Ripley Fm.	135	Berry, 1919, 1925	Stephenson, 1942
Fox Hills Fm.	64	Dorf, 1938	McGookey, 1972
Hell Creek Fm. (Colgate Member)	19	Brown, 1939	McGookey, 1972
Lance Fm.	10	Berry, 1934	McGookey, 1972
Lance Fm.	70	Dorf, 1942	McGookey, 1972
Vermejo Fm.	108	Knowlton, 1917b	Cobban et al '52
"Laramie Group"	112	Lesquereux, 1888	McGookey, 1972
Laramie Fm.	131	Knowlton, 1922	McGookey, 1972
Denver Fm. (and other minor fms.)	145	Knowlton, 1930	McGookey, 1972
Animas Fm.	59	Knowlton, 1924	McGookey, 1972

Figure 5. The major Cretaceous floras of North America showing the approximate relative stratigraphic range of the collection localities within the formations, the number of species in each flora and references to the floras and stratigraphy. The Blackhawk study is included.

also indicated. Studies concerned with petrified wood and palynological analyses have generally been omitted.

My personal interpretation was used in placing time limits on the fossiliferous zones. If it could be determined that a fossil collection was made in a specific member or portion of the formation involved, only that member was included on the chart. Unfortunately, several authors have neglected to place any significance on the stratigraphic position of their collections and a few have omitted exact geographical localities. It has not been uncommon to group together as the "flora" those specimens collected at localities widely separated both geographically and stratigraphically. These factors have made the stratigraphic determinations difficult and not as accurate as desired.

Studies made in a single formation but of widely separated geographic locations have been considered separately on the chart.

Total species counts for each report was usually determined by counting those fossil plants discussed, inasmuch as few reports volunteered a total. This is also not as accurate as desired, since several floras have been reworked one or more times with additions, deletions, or combinations with every new study. Therefore, the number of species indicated may be subject to revision. In certain floras, total species have not been determined and thus, are not indicated on Figure 5. In other studies (Smiley, 1966, 1969), floral lists and descriptions are not yet published.

It is interesting that one or more major floras have been described from nearly every Cretaceous epoch. Floras of some epochs

have been studied more extensively but this is generally a reflection of the areal extent and thickness of the rocks of that epoch, and the length of the epoch.

At this time the Blackhawk plant species have not been critically compared to those of the other floras to determine common species. This comparison is made particularly difficult by the many name changes over the years. However, there are at least two Lower Cretaceous relict genera which were still in existence in the Blackhawk, *Nageiopsis* sp. and *Podozamites* sp., both apparent gymnosperm-like plants.

The age relationship of the Blackhawk flora to other Cretaceous floras is shown in Figure 5. Also indicated is the number of Blackhawk species; only about 10 other floras have more species, making the Blackhawk among the largest in North America.

PALEOECOLOGY

Identification of Blackhawk Fluvial Environments of Deposition

The fossil plants in this study were collected in what has been identified as fluvial sediments deposited on the broad floodplain of the Blackhawk River system (Young, 1966; McGookey, 1972), rather than from the lagoonal, paludal or littoral marine environments which were at or near the western edge of the Upper Cretaceous Mancos seaway, described by Young (1966) and Maberry (1971). These floodplain sediments formed most of the upper and western portions of the formation in the Wasatch Plateau (Spieker and Baker, 1928; Baughman, 1958; and personal field observations at Water Hollow Road with Edward Cotter, Aureal T. Cross, Timothy Cross, John Horne and Wm. D. Tidwell, October 19, 1975).

Two general types of sedimentary environments exist on modern floodplains (Fisk, 1952; Shelford, 1963; Dury, 1970; Wolman and Leopold, 1972). The first is in-channel deposition which forms point bars by lateral accretion within the river channel itself. The second is overbank deposition which occurs outside the channel during river flood stage on levees, bottomlands and swamps. The aggregate thickness of recent floodplains has been estimated to consist of at least 80% point bar deposition, while overbank flow contributes the rest of the total thickness (Wolman and Leopold, 1957). This is consistent with observations made by Bachman (1958) in the Blackhawk paleofloodplain where point bar deposition makes up at least three-fifths of the total thickness. Although in-channel deposition is significant in floodplain build-up, it is in overbank sediments that most of the well-preserved Blackhawk fossil plants have been preserved.

Specific kinds of depositional environments which are evident in the Blackhawk floodplain are in-channel features such as point bars, and non-channel features such as swamps and bottomlands. The lenticular, resistant sandstone ledges which are abundant in nearly every outcrop are usually of point bar origin, while the abundant coals and carbonaceous shales are an indication of the presence of peat-forming swamps. Some of these were formed in abandoned channels but most are on interfluve sags or lows. Less obvious are overbank sediments of bottomland origin because of their variable composition and thickness. Levees, which are common along active channels of modern rivers, are not recognized in the Blackhawk floodplain. There seems to be no good explanation for this but they may have been scoured away from shifting river activity or may have settled due to compactation of underlying sediment, particularly if there was a significant amount of organic matter under them. In this case, the levee environment is indistinguishable from other sedimentary environments of bottomland origin. On some recent floodplains, levees have their own unique plant communities (Gould and Morgan, 1962).

It has generally been difficult to distinguish specific types of fluvial deposition from cores or outcrops (Wolman and Leopold, 1957). However, examinations by Fisk (1947) allowed him to differentiate several types of environments from shallow Mississippi River floodplain cores. More recently, Visher (1972) and Schumm (1972) have established several criteria for identifying specific paleofluvial environments. In this study several biological and sedimentary criteria were used to delineate three fluvial depositional environments in Blackhawk floodplain sediments. These are described in Table 2.

Organic content, indicated by rock color, and size of mineral particles were the chief criteria used. Blackhawk rocks with a high organic content are usually composed of clay-sized particles. Often a small proportion of silt and fine-grained sand was present. Rocks of this nature are thought to have been deposited in local, swampy basins where an abundance of semi-decomposed plant and animal tissue was present; the clay settled out of nearly motionless water. Other features such as thin bedding, stratigraphic relationship to coals, and types of animal and plant fossils present, also indicated a swamp origin.

Point bar sediments are also characteristic, with certain features strongly contrasting to those of swamps. Organic content is very low, indicated by light colored rock. Grain size is coarser, ranging from fine-grained sand to fine pebble gravel. Usually these sediments were well washed, containing little clay. Sedimentary features also suggest higher energy deposition and include cross-bedding, ripple marks, thin gravel lenses, and a general lenticular form. Water-worn wood pebbles indicate high energy transportation. Load casts of various kinds can be seen in the field (E. Cotter, A. T. Cross, J. Horne, personal communication, 1975).

Bottomland sediments were more difficult to identify, but normally exhibited features which are intermediate between those of swamps and

Table 2. Criteria used for the identification of fluvial environments in the Blackhawk Formation.

Environment	Sedimentary Features	Biological Features
Swamps	1. Grain size: sandy silt to clay 2. Sedimentary features: shales thin bedding laminae often present; no current structures such as ripple marks or cross-bedding. Erodes away easily leaving overhanging ledges of point bars. 3. Organic content in shales: high, dark gray to black in color. Shales associated above and below coals of various thicknesses, or as partings in coal, or lateral to coals.	1. Small gastropod shells often present. 2. *In situ* stumps and roots. 3. Water lily and water chestnut fossils have been collected. 4. Leaf "mats" are often present. 5. Leaf preservation good.
Point Bars	1. Grain size: silty coarse to fine grained sand. 2. Sedimentary features: massive sandstones, cross-bedding often present; gravel lenses in thickest beds. Ripple marks often evident. Thickness varies from 0.5 meter to about 12 meters. Very lensy in nature, limited from 100 to 200 meters wide, lateral faces intertonguing with siltstones or shales. Forming abundant, local, overhanging ledges. 3. Organic content: very slight, composed of well-washed sands, orange to buff color, never gray. Fresh surfaces are light colored.	1. Casts of water-worn wood pebbles and small logs found near the bases of the larger units. 2. Leaf preservation poor; with some transport damage. Leaves preserved at angles to horizontal plane.
Bottomlands	1. Grain size: sandy silt to clay. 2. Sedimentary features: thin bedded, often platy; raindrop patterns; never associated directly with coals of any thickness, but may be found 2 to 4 meters above or below a coal or dark shale. Rocks often mottled. Usually more resistant than swamp deposits, but less resistant than point bar deposits. 3. Organic content: medium to low, light gray to yellow in color.	1. Meandering invertebrate trains often preserved. 2. Leaf "mats" are very abundant at every collecting site. 3. *In situ* stumps and roots present. 4. Leaf preservation good.

point bars. Grain size is usually silt, but varying proportions of clay and fine-grained sand are present. Organic content varies but is usually much less than in rocks of swamp origin. Features such as raindrop casts and invertebrate trails also indicate deposition in a terrestrial, low energy sedimentary environment.

Indications in the field are that these environments were local, rather than regional, as might be expected on the floodplain of an actively meandering river. No deltaic or neritic sedimentary features such as delta platforms, salt marshes, tidal channels, intertidal flats, beaches, river-mouth bars or offshore bars, which have been characterized by Maberry (1971) and Rigby and Hamblin (1972) could be distinguished.

Nineteen of the collection sites were found to be from rocks of swamp origin, 14 were from rocks of bottomland origin and 8 collections were made in point bars. Table 3 indicates the environments of each of these sites.

Correlation of the Fossil Plants with Environments of Deposition

Because several factors of preservation make it relatively unlikely that all species of a community will be preserved as fossils, the plants which make up the Blackhawk communities are almost certainly disproportionately represented in the collections. However, several factors including community structure in each environment can be deduced from the plants which are represented.

At the time the fossil collections were being made it became apparent that certain species seemed to be restricted to rocks of a

TABLE 3. The type of floodplain environments suggested for each of the fossil collection sites.

Collection Number	Environment
6/1/68	Swamp
7/9/70 I-1	"
7/11/70 II	"
7/12/70	"
7/18/70 I-1	"
7/18/70 I-2	"
7/28/70 I-2	"
7/28/70 I-5	"
8/13/70	"
8/14/70	"
8/15/70	"
8/18/70	"
8/19/70	"
8/20/70	"
8/24/70	"
8/28/70 I	"
Unit I	"
Unit K	"
Unit M	"
7/8/70 I-1	Bottomland
7/9/70 I-2	"
7/9/70 I-3	"
7/11/70 I	"
7/23/70 I	"
7/28/70 II	"
7/30/70 I	"
7/30/70 II	"
7/30/70 III	"
8/25/70	"
8/28/70 II	"
8/28/70 III	"
8/29/70	"
Rail Road Cut	"
7/17/70 I-1	Point Bar
7/22/70	"
8/26/70 I	"
8/26/70 II	"
8/26/70 III	"
Above Rail Road Cut	"
Base of Road Cut	"
Road Construction	"

particular lithologic character. A quantitative study to support this observation could not be made in the field, but was attempted in the laboratory after the specimens were curated, photographed and identified.

In the combined floras there were 43 species which were represented by 10 or more individual specimens. I arbitrarily considered these species abundant enough to be ecologically significant in the original forests. These 43 most important species are listed in Table 4 where the collection sites have been grouped together into major floodplain environment types. The number of specimens of each species collected within each site is indicated.

Figure 6 shows the percentage of each of the 43 species which were found in the three environments. Most of the species indicate a strong preference for a single environment, but a few species seem to overlap from one to another as might be expected in natural communities. Several species were found in only one of the environments.

This was the first indication that specific plant communities existed on the Blackhawk floodplain. Therefore an attempt was made to obtain as much quantitative data as possible about the plant assemblages of these environments.

Quantitative Paleoecology

Chaney (1925) established a sound basis for quantitative paleoecological analysis of certain fossil floras when he compared data obtained from a living redwood community with what he believed to be a nearly similar Tertiary flora. He showed that a high number of

Table 4. The 43 most important species in the Blackhawk flora. The number of specimens of each species collected within each environment is shown. The collection sites are grouped together into the 3 major floodplain environments.

Swamps

Taxa	6/1/68	7/11/70 II	7/12/70	7/18/70 I-1	7/18/70 I-2	7/28/70 I-2	7/28/70 I-5	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/28/70 I*	Unit I	Unit K	Unit M	TOTAL
Asplenium dicksonianum														17					17
Cyathea pinnata	37																		37
Onoclea hebridica		40																	40
Osmunda hollicki										1		2					1		4
Unknown Fern 1																			0
Araucarites sp.																			0
Brachyphyllum macrocarpum		6							4		10	134					1		155
Moriconia cyclotoxon		22				1				2	5	1	3						34
Nageiopsis sp.												10							10
Podozamites sp.								2	1		1	7							11
Protophyllocladus polymorpha		8		12		2	1	7	2	14	12	2	5	13		3	6		87
Protophyllocladus sp. 2																			
Sequoia cuneata	15	207	3	9	1	1		45	43	9	13	69	15	31	6	8	6	1	481
Widdringtonites reichii										12									12
Cyperacites sp.						1		2	8			9							20
Geonomites imperialis		4		7		8	6			9			1		1	2		5	43
Anona robusta																10			10
Apocynophyllum giganteum				1						1		2	1						5
Cercidiphyllum arcticum												8							8
Cissus marginata		43						1						1	6	1			52
Cornus denverensis						2				5			2					7	16
Cornus praeimpressa										10		5	15						30
Dryophyllum subfalcatum		12								3	1	1			1			2	20
Dryophyllum whitmani																			0
Ficus laurophylla		4	1												4				9
Ficus planicostata								2				9							11
Laurophyllum coloradensis																			0
Manihotites georgiana				2											1		1		4
Menispermum dauricumoides																			0
Myrtophyllum torreyi		6									1		3		7		1		18
Phyllites vermejoensis		13								3		1							17
Platanus alata													7			1			8
Platanus raynoldsi	4	3					4	5	9		1				51		1		78
Rhamnites eminens		22	1	11		11	9	31	14	13	3	15	15		1				146
Salix gardneri		3													12				15
Salix proteaefolia		2												6		3			11
Salix stantoni																1			1
Viburnum antiquum												1			1	1			3
Unknown Dicot 2																			0
Unknown Dicot 13										9								26	35
Unknown Dicot 19								6	2										8
Unknown Dicot 25		31																	31
Unknown Dicot 32												12							12

Bottomlands

Taxa	7/8/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/23/70 I	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/25/70	8/28/70 II*	8/28/70 III*	8/29/70	Rail Road Cut	TOTAL
Asplenium dicksonianum															
Cyathea pinnata															
Onoclea hebridica									3						3
Osmunda hollicki							3	11	7		11	1			33
Unknown Fern 1											12				12
Araucarites sp.															0
Brachyphyllum macrocarpum															0
Moriconia cyclotoxon			1												1
Nageiopsis sp.															0
Podozamites sp.															0
Protophyllocladus polymorpha			2				1						29	1	33
Protophyllocladus sp. 2						49							1		50
Sequoia cuneata					1		1		2		2	9		6	21
Widdringtonites reichii															0
Cyperacites sp.													4		4
Geonomites imperialis	2	1			2								3		8
Anona robusta															0
Apocynophyllum giganteum							14	4	3						21
Cercidiphyllum arcticum							146	142	47		3				338
Cissus marginata	1					2	3	1	1	24			6		38
Cornus denverensis										4			5		9
Cornus praeimpressa	1	5	7							1			2		16
Dryophyllum subfalcatum	4		1	1			5	9	89	54			3		166
Dryophyllum whitmani										3			26		29
Ficus laurophylla							1	1		2					4
Ficus planicostata										2				1	3
Laurophyllum coloradensis					3		17		10		25				55
Manihotites georgiana					24						6	36			66
Menispermum dauricumoides								1	8						9
Myrtophyllum torreyi			2	2	3				3		59				69
Phyllites vermejoensis							5	5	12	2	14				38
Platanus alata				7									10		17
Platanus raynoldsi	9		3		6	12	28	15	52	15	8		9	1	158
Rhamnites eminens		3							2			7		3	15
Salix gardneri													6		6
Salix proteaefolia															0
Salix stantoni						5				7				1	13
Viburnum antiquum			3										23		26
Unknown Dicot 2										162				2	164
Unknown Dicot 13													3	1	4
Unknown Dicot 19											1				1
Unknown Dicot 25															0
Unknown Dicot 32															0

Point Bars

Taxa	7/17/70 I-1	7/22/70	8/26/70 I	8/26/70 II	8/26/70 III	Above R.R. Cut	Road Construction	TOTAL
Asplenium dicksonianum								
Cyathea pinnata								
Onoclea hebridica								
Osmunda hollicki								
Unknown Fern 1								
Araucarites sp.		49				3	10	62
Brachyphyllum macrocarpum								
Moriconia cyclotoxon								
Nageiopsis sp.								
Podozamites sp.			128					128
Protophyllocladus polymorpha	2		1		1			4
Protophyllocladus sp. 2								
Sequoia cuneata		2		1				3
Widdringtonites reichii								
Cyperacites sp.								
Geonomites imperialis	2	11		4				17
Anona robusta								
Apocynophyllum giganteum								
Cercidiphyllum arcticum				5	3			8
Cissus marginata					3			3
Cornus denverensis								
Cornus praeimpressa				1				1
Dryophyllum subfalcatum		18			1			19
Dryophyllum whitmani								
Ficus laurophylla								
Ficus planicostata				5				5
Laurophyllum coloradensis								
Manihotites georgiana			1					1
Menispermum dauricumoides					2			2
Myrtophyllum torreyi								
Phyllites vermejoensis								
Platanus alata								
Platanus raynoldsi	2	4	1	1				8
Rhamnites eminens	5				2			7
Salix gardneri								
Salix proteaefolia								
Salix stantoni								
Viburnum antiquum	1							1
Unknown Dicot 2								
Unknown Dicot 13								
Unknown Dicot 19		6		12				18
Unknown Dicot 25								
Unknown Dicot 32								

*These collection sites may actually be on the delta plain rather than the flood plain. See text for discussion.

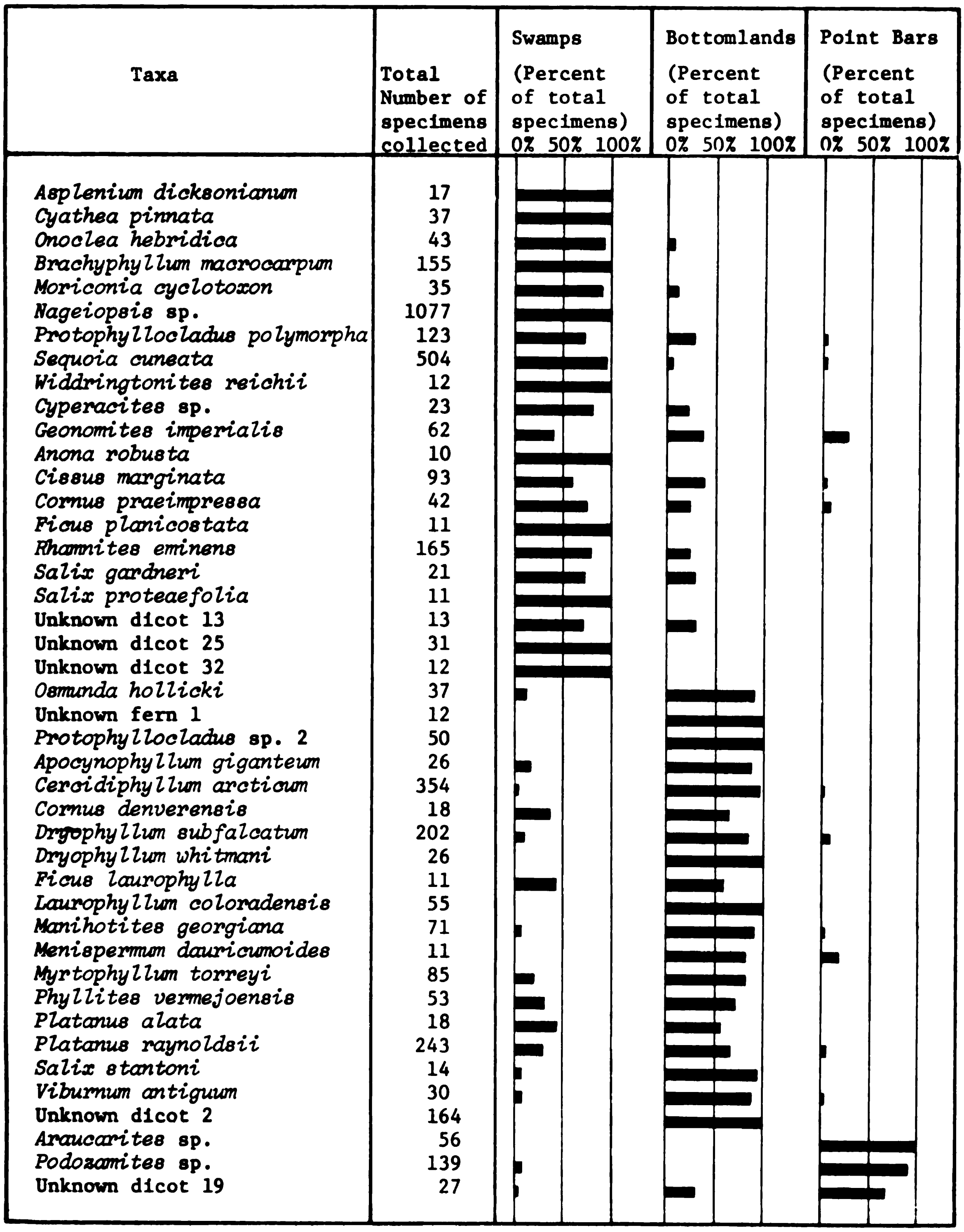


Figure 6. The percentage of total specimens collected of the most important fossil plants in each of the three Blackhawk floodplain environments. They are listed in phylogenetic order within each of the environments.

leaves of a particular species in modern fluvial sedimentary environments usually indicate a relatively high proportion of living plants of the same species in the immediate vicinity (with 50 feet or 17 meters). However, no subsequent examinations of fossil floras have used Chaney's ecological work, although numerous significant floras have been written.

In this study it is generally assumed that in each collection site, a relatively high number of leaves (or leafy twigs or phyllodes) of a particular species also indicates that the most abundant local trees were of the same species. It is reasonable to believe that leaves of certain fossil plant species which are consistently abundant in a majority of collection sites, were shed by plants which are probably the most abundant in the community. Within each major environment, the number of leaf specimens in each collection site (or florule) was analyzed together with the number from the other sites and is discussed below. This is analogous to the treatment of data obtained from individual "plots" when living plant communities are examined.

Several factors are often considered in ecological studies of living communities. Among them are cover, density, relative density, relative dominance, frequency, relative frequency, mean area, etc. (Phillips, 1959). In fossil floras, such information as cover, relative dominance, and mean area cannot be determined (at this time) because the size of individual fossil trees and shrubs normally cannot be measured. However, if the number of leaves are in proportion to the number of plants (trees) in the immediate area, and if the collection sites are treated as though they are "plots", then several

quantitative factors can be determined approximately. These are the following:

$$\text{Relative frequency} = \frac{\text{Number of points of occurrence of the species}}{\text{Number of points of occurrence of all species}} \times 100$$

$$\text{Relative density} = \frac{\text{Number of individuals (leaves)* of the species}}{\text{Number of individuals (leaves)* of all species}} \times 100$$

*This means leaves, leafy twigs or phyllodes

The following data were used for these calculations: in the Swamps there were 142 points of occurrence and 1499 individuals of all species; in the Bottomlands there were 108 points of occurrence and 1430 individuals of all species; and in the Point Bars there were 30 points of occurrence and 287 individuals of all species. This paleoecological information and the data for each species was obtained from Table 6 which shows the number of fossil leaves of each of the 43 important species in each environment.

In the analysis of modern plant communities it is common to determine an Importance Value or Index which usually combines several of the above-listed factors in order to identify the most significant organisms. One example is as follows:

$$\text{Importance Value} = \text{relative density} + \text{relative dominance} + \text{relative frequency}$$

(Phillips, 1959)

Other formulas are commonly constructed for particular communities or studies (P. G. Murphy, personal communication, 1973).

Relative dominance cannot be determined in this study because the size of the plants themselves cannot be determined.

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$$

Therefore, the Importance Index of the Blackhawk fossil plants cannot include it. The Importance Index used here is as follows:

FOSSIL PLANT IMPORTANCE INDEX = Relative Density + Relative Frequency

It should be pointed out that it is unlike the values obtained in living communities and, therefore, cannot be directly compared to them. It does, however, identify those plants which were ecologically significant in the Blackhawk plant communities.

The relative density, relative frequency and the Importance Index of each species are shown in Table 5, where the plants, for comparative purposes, are listed in the same groupings as in Figure 6. It is apparent that certain fossil species have relatively high Importance Indices while others are nearly insignificant. The specimens with high indices are normally those which were found in a majority of collection localities.

Some of the problems of using these factors in the study of fossil plant communities are the following:

1. Individual leaves were used to represent entire plants. Although Chaney (1925) indicates a correlation between the number of leaves on the ground and the number of trees, there are probably many variables involved, including the evergreen or deciduous character of the plants, local transporting media, differential preservation factors, the size of the plants, etc., which might affect this relationship.

Table 5. The relative frequency, relative density, and Importance Index of each of the important Blackhawk species within the three floodplain environments.

Taxa	Swamps			Bottomlands			Point Bars		
	Relative Frequency	Relative Density	Importance Index	Relative Frequency	Relative Density	Importance Index	Relative Frequency	Relative Density	Importance Index
Asplenium dicksonianum	0.7	1.1	1.8	0	0	0	0	0	0
Cyathea pinnata	0.7	2.5	3.2	0	0	0	0	0	0
Onoclea hebridica	0.7	2.7	3.4	0.9	0.2	1.1	0	0	0
Osmunda hollicki	2.1	0.3	2.4	4.6	2.3	6.9	0	0	0
Unknown Fern 1	0	0	0	0.9	0.8	1.7	0	0	0
Araucarites sp.	0	0	0	0	0	0	10.0	21.6	31.6
Brachyphyllum macrocarpum	3.5	10.3	13.8	0	0	0	0	0	0
Moriconia cyclotoxon	4.2	2.2	6.4	0.9	0.1	1.0	0	0	0
Nageiopsis sp.	0.7	0.7	1.4	0	0	0	0	0	0
Podozamites sp.	2.8	0.7	3.5	0	0	0	3.3	44.6	47.9
Protophyllocladus polymorpha	9.2	5.8	15.0	3.7	2.3	6.0	10.0	1.4	11.4
Protophyllocladus sp. 2	0	0	0	1.9	3.5	5.4	0	0	0
Sequoia cuneata	11.3	32.1	43.4	5.6	1.5	7.1	6.7	1.0	7.7
Widdringtonites reichii	0.7	0.8	1.5	0	0	0	0	0	0
Cyperacites sp.	2.8	1.3	4.1	0.9	0.3	1.2	0	0	0
Geonomites imperialis	6.3	2.9	9.2	3.7	0.6	4.3	10.0	5.9	15.9
Anona robusta	0.7	0.7	1.4	0	0	0	0	0	0
Apocynophyllum giganteum	2.8	0.3	31.	2.8	1.5	4.3	0	0	0
Cercidiphyllum arcticum	0.7	0.5	1.2	3.7	23.6	27.3	6.7	2.8	9.5
Cissus marginata	3.5	3.5	7.0	6.5	2.7	9.2	3.3	1.0	4.3
Cornus denverensis	2.8	1.1	3.9	1.9	0.6	2.5	0	0	0
Cornus praeimpressa	2.1	2.0	4.1	4.6	1.1	5.7	3.3	0.3	3.6
Dryophyllum subfalcatum	4.2	1.3	5.5	7.4	11.6	19.0	6.7	2.8	9.5
Dryophyllum whitmani	0	0	0	1.9	2.0	3.9	0	0	0
Ficus laurophylla	2.1	0.6	2.7	2.8	0.3	3.1	0	0	0
Ficus planicostata	1.4	0.7	2.1	1.9	0.2	2.1	3.3	1.7	5.0
Laurophyllum coloradensis	0	0	0	3.7	3.8	7.5	0	0	0
Manihotites georgiana	2.1	0.3	2.4	2.8	4.6	7.4	3.3	0.3	3.6
Menispermum dauricumoides	0	0	0	1.9	0.6	2.5	3.3	0.7	4.0
Myrtophyllum torreyi	3.5	1.2	4.7	4.6	4.8	9.4	0	0	0
Phyllites vermejoensis	2.1	1.1	3.2	4.6	2.7	7.3	0	0	0
Platanus alata	1.4	0.5	1.9	1.9	1.2	3.1	0	0	0
Platanus raynoldsii	5.6	5.2	10.8	10.2	11.0	21.2	13.3	2.8	16.1
Rhamnites eminens	8.4	9.7	18.1	3.7	1.0	4.7	6.7	2.4	9.1
Salix gardneri	1.4	1.0	2.4	0.9	0.4	1.3	0	0	0
Salix proteaefolia	2.1	0.7	2.8	0	0	0	0	0	0
Salix stantoni	0.7	0.1	0.8	2.8	0.9	3.7	0	0	0
Viburnum antiguum	2.1	0.2	2.3	1.9	1.8	3.7	3.3	0.3	3.6
Unknown Dicot 2	0	0	0	1.9	11.5	13.4	0	0	0
Unknown Dicot 13	1.4	2.3	3.7	1.9	0.3	2.2	0	0	0
Unknown Dicot 19	1.4	0.5	1.9	0.9	0.1	1.0	6.7	6.3	13.0
Unknown Dicot 25	0.7	2.1	2.8	0	0	0	0	0	0
Unknown Dicot 32	0.7	0.8	1.5	0	0	0	0	0	0

2. The sites used in this study are not comparable to those "plots" used in the analysis of modern communities. Typically these sites vary in size, are a measurement of volume instead of surface area, range geographically over a distance of 40 miles (64 km), and vary sufficiently, stratigraphically to indicate they probably were not contemporaneous.
3. There may be more than the three mentioned depositional environments represented in the portions of the Blackhawk Formation examined. There is some reason to believe that the Black Diamond Mine sediments (collection sites 7/23/70 I, 8/28/70 I, 8/28/70 II, 8/28/70 III), are actually deltaic in origin, rather than deposited on a river floodplain. In addition, there may have been a riparian and a river levee plant community which are both difficult or impossible to identify from sediment analysis.

Other fossil plant Importance Indicies are considered in Appendix II.

The plant communities of each of the environments are discussed below and, where appropriate, compared to modern floodplain communities of the world today, chiefly Mississippi River communities. In a few cases, plant species which were not represented by enough specimens for them to be added to Figure 6 or Table 5 are mentioned and discussed since they often represent a significant aspect of a particular community.

THE ENVIRONMENT OF THE BLACKHAWK SWAMPS

It has been pointed out elsewhere in this report that two types of peat-forming swamps have been preserved in the Blackhawk Formation. One type produced the thick, extensive and mineable coals of the lower part of the formation and geographically located in the eastern part of the depositional area. They were near the strandline and must have been brackish water swamps (Young, 1966; Maberry, 1971) in relatively stable basins in which great amounts of peat developed. The second type of swamp accumulation produced thinner and more localized coals in the upper and western portions of the Formation. These swamps may have been several miles from the strandline and were features of the extensive river floodplains. They were probably freshwater swamps subject to the erosional and depositional actions of the meandering river systems. Recent floodplain swamps of this nature have been formed from ox bow lakes or low-lying backswamp depressions where trapped channel water, flood water and ground water can accumulate (Voigt and Mohlenbrock, 1964).

The sedimentary and biologic remains of these freshwater swamps were examined in the field and laboratory and are considered here. A few comments relating to the Blackhawk brackish water swamps are included later. Several specific aspects of the Blackhawk swamps are compared to certain features of existing swamps in the Mississippi River Valley. There seem to be many interesting physical and biological similarities as well as a few major differences.

Arborescent Plants

The most significant trees of the Blackhawk swamps, listed by their Importance Index were:

Sequoia cuneata (conifer)	43.4
Rhamnites eminens (dicot)	18.1
Protophyllocladus polymorpha (conifer)	15.0
Brachyphyllum macrocarpum (conifer)	13.8
Platanus raynoldsii (dicot)	10.8

The high Importance Index of both *Sequoia cuneata* and *Protophyllocladus polymorpha* are unquestionably influenced by the ease with which fossils of these specimens can be identified, even when they are poorly preserved or fragmentary. By comparison it is much more difficult to identify accurately a broad-leaved fossil dicotyledon because better preservation and a physically larger specimen, with leaf tip, margin and base preserved is required. It is felt that a large proportion (nearly all) of the conifer specimens in the collection are identified, while only about one half of the dicotyledons could be identified because of poor preservation. In addition, a larger number of poorly preserved or fragmented dicotyledon leaves are probably discarded in the field than are specimens of conifers. Considering these factors, it seems possible that the number of specimens of *Rhamnites eminens* might be closer to that of *S. cuneata* while the number of specimens of the other dicotyledons might be as great or even greater than that of *P. polymorpha*. If this be possible, it appears that *S. cuneata* and *R. eminens* may have been co-dominant trees, somewhat similar, though perhaps fortuitously, to forests in existing swamps of the Mississippi River floodplain where bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa acquatica*) are the co-dominant trees of that plant community (Braun, 1950; Gould and Morgan, 1962; Voigt and Mohlenbrock, 1964). It is interesting to note that the foliage of fossil *S. cuneata* is much like the foliage of living bald cypress, to which it is thought to be distantly related, while the fossil *R. eminens* is similar in appearance and habit to the living water tupelo.

The subordinant (or less abundant) trees in the Blackhawk fluvial swamp community consisted of the conifers *Brachyphyllum macrocarpum*, *Protophyllocladus polymorpha* and *Moriconia cyclotoxon*, and the angiosperm *Platanus raynoldsii*.

Rare or less frequently occurring trees included the conifers *Androvettia* sp., *Metasequoia* sp., and *Widdringtonites reichii*, and the angiosperms *Cornus praeimpressa*, *Salix proteafolia*, *Dryophyllum subfalcatum*, *Myrtophyllum torreyi*, *Ficus glassconea* and *Manihotites georgiana*. Specimens of these plants were collected in one or, at most, a few collection sites, and are interpreted as being of only local importance. Again, the fossil conifer specimens are much easier to identify than the dicotyledons and therefore the Importance Index of the dicotyledons might be somewhat higher if all of the specimens could be identified.

Besides the abundant fossil leaves collected, many *in situ* tree stump casts have been seen throughout the exposures of the Blackhawk strata which have been studied. Undoubtedly some of these casts represent the partial burial of some of the above-listed trees. However, these casts are deformed from lateral compression and little petrified tissue remains except vitrinous rinds. These are generally not identifiable. The original dimensions of such stump casts are hard to reconstruct which makes identification even more difficult.

It is interesting to speculate on the size and form of the dominant trees in this forest, since dominant trees in modern plant communities normally are those that are taller, have a greater individual biomass and more leaf surface area than any subordinant tree (McNaughton and Wolfe, 1973). If *Sequoia cuneata* and *Rhamnites eminens* were indeed the dominant trees of the Blackhawk swamps, then they may have been very large, perhaps reaching the height of modern swamp trees, which is commonly 100 feet (30 m) (Shelford, 1963).

Buttressed tree bases and the growth of pneumatophores or "knees" are apparently characteristic of most individual conifer and angiosperm species which live in existing swamps (Anderson, 1973; Voigt and Mohlenbrock, 1964). This seems to be a response of annual trunk submergence and does not develop when the same species occur in areas where they are never submerged (Penfound, 1952). Evidence which is discussed later in this study indicates that the Blackhawk rivers flooded nearly every season. Therefore, since the ability to form buttressing and pneumatophores is an inherent, adaptive feature of several unrelated groups of modern plants, there is some basis to look for similar structures on Cretaceous conifers and angiosperms which may have responded in a similar manner to annual submergence. At this time no such structures have been observed in the Blackhawk strata.

It is noteworthy that certain living relatives of two Blackhawk conifers prefer nearly the same environment that seems to have been required by the Cretaceous species. These plants are *Taxodium distichum*, previously mentioned as a distant relative of *Sequoia cuneata*, and *Phyllocladus aspleniifolius*, the celery top pine of Australia, which is apparently related to *Protophyllocladus polymorpha*. Both living species prefer the shallow, wet-acid, peaty soils of flood-plains (Voigt and Mohlenbrock, 1964; Hall et al, 1970), similar to those which seem to have existed in the Blackhawk swamps. *Metasequoia glyptostroboides*, the Dawn Redwood, which is related to *Metasequoia* sp. of this study, also prefers moist, slightly acidic soils. This tree, however, seems to be a member of stream-side communities (Chu and Cooper, 1950). Other Blackhawk swamp conifers either have no living relatives or have living relatives with different ecological require-ments than those postulated for the fossil communities. It is generally not possible to compare ecological requirements among the angiosperms since the relationships between Cretaceous and modern angiosperm species is usually unknown. Several exceptions might be fossil members of the genera *Cercidiphyllum*, *Cissus*, *Geonomites*, *Menispermum*, *Nymphaeites*, *Platanus*, and *Trapa*, explained subsequently.

Judging from the great abundance of fossils, particularly *Sequoia cuneata* and *Rhamnites eminens*, the trees themselves could have been very numerous. The abundance of mature trees in existing swamps seemed remarkable to Penfound and Hall (Penfound and Hall, 1939; Hall and Penfound, 1943; Penfound, 1952) who counted from 438 to 650 mature trees per acre and point out that this is often twice as many trees per acre as are in mature bottomland communities adjacent to the swamps. They mention that swamp trees are usually very slender.

Hall and Penfound (1943) summarized their study of a deep swamp in Alabama and characterized the trees they examined with about the same features imagined for the Blackhawk trees. That is, they were tall, slender trees which grew close to one another, often to great height, and may have developed buttressed bases and pneumatophores.

Shrubby Understory and Vines

In most of the Blackhawk swamps there seems to be no identifiable shrubby or herbaceous undergrowth in areas where standing water was present. These elements are often lacking in parts of modern cypress tupelo swamps (Braun, 1950; Shelford, 1963; Voigt and Mohlenbrock, 1964). It is entirely possible, however, that some of the dicot leaves could have been borne on shrubby plants. In the main exposures where stumps have been found, small shrubby axes have not been recognized. In some exposures where palm trunks of smaller dimensions are recognized, these seem to be plants of limited size which grew in low thickets.

The most common shrubby understory tree was the palm *Geonomites imperialis*. It is found in nearly equal numbers in both swamp and bottomland communities, indicating that it may have grown at swamp bottomland margins. These poorly drained but normally terrestrial sites are the normal habitat for several species of modern swamp shrubs.

G. imperialis became locally abundant enough to form thickets of many individuals as close as 1 to 1.5 m apart. One of these palm thickets which was inundated by sandy overbank deposition can be seen in an overhanging ledge at the Water Hollow Road collection locality and is described below. Leaves of *G. imperialis* were normally shed

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and accumulated around the trunk bases in large numbers, forming "mats" which can be seen at several places. One rock slab observed at Taylor Flat had 8 layers of fronds in sediment which is now only 4 cm thick. Palm leaves were often found in the lower portions of the sandstones which capped a black or coaly shale, suggesting that the erect palm stems and stiff leaves apparently still attached to the stem were inundated by sandy sediment during overbank deposition while they grew on the peaty surface of the swamp.

Another shrubby palm, *Paloreodoxites plicatus*, had very short, entire leaves and probably had the appearance and general ecological requirements of certain species of *Iguanura*, which live in lowland forests of Malaya (Whitmore, 1973).

A third palm, *Sabalites montana*, was collected at Taylor Flat in arenaceous, swampy sediments. W. D. Tidwell (personal communication, 1968) reported that a specimen of this palm had been collected in a sandstone in Huntington Canyon. It seems to have required about the same habitat as *Geonomites imperialis*, but was much less frequent, apparently occurring as scattered, isolated plants.

Nageiopsis sp., a small, shrubby gymnosperm, was present at only one site where more than 1000 leaflets of this plant were collected. These specimens were close to one another in the rock matrix and could have been shed from a single plant. Specimens of another gymnospermous plant, *Podozamites* sp., were collected in a few swamp sites but this plant also seems to have been an infrequent member of the community.

None of the dicotyledonous angiosperms collected in the swamps can positively be said to have had a shrubby growth form.

Cissus marginata (Vitaceae) was abundant in this community but is thought to have been a liana, closely related and probably similar in appearance to wild grape species (Brown, 1962). Extant species of the genus *Cissus* are almost all tendril-climbing vines restricted in distribution to warm and tropical climates (Lawrence, 1951). If *C. marginata* was a vine it would have required abundant large plants in both Blackhawk swamps and bottomlands for support. This species is among those few fossil plants with leaves similar enough to living species within the family that identification is thought to be accurate (Dorf, 1942, Brown, 1962). Grape-like seeds have been collected in Paleocene rocks of Wyoming, but were not found associated with leaves (Brown, 1962). Spackman (1949) found seeds and Traverse (1955) found pollen of *Vitis* and *Parthenocissus* in the Brandon lignite (Oligocene or early Miocene).

Herbaceous Understory

The herbaceous understory of the swamp consisted chiefly of two ferns, *Cyathea pinnata* and *Onoclea hebridica*. Both ferns were collected in about half of the sites. From the number of specimens collected, they appear to have been locally abundant. Interestingly, extant species in the genus *Cyathea* are known as "tree ferns" because of their tall, slender palm-like growth habit. However, there is no evidence that the fossil *Cyathea pinnata* was a plant of large size. A living species of this genus, *C. glabra*, is small in size or "stemless" and grows directly on the organic substrate of peat-forming swamps in Malaysia (Anderson, 1961).

Certain living species of the genus *Onoclea* are able to tolerate swamp habitats and areas of acid soil. One species, *O. sensibilis*, is an abundant and important member of the herbaceous layer in the cypress-gum swamps near New Orleans (Penfound and Hathaway, 1938), but is widespread and occurs in other habitats as well (Fernald, 1950). Both of these living ferns generally inhabit an environment similar to that postulated for their Cretaceous relatives.

A third fern, *Asplenium dicksonianum*, was so closely associated with the remains of what appeared to be a single fallen trunk or branch of *Sequoia cuneata* that one must consider the possibility that it may have been an epiphyte on that trunk. This might be similar to several living species within the family Aspleniaceae which are epiphytes in warm, humid areas today (Bierhorst, 1971). Leaves of the fossil were elongate and have the appearance of being able to clasp or wrap around stems. Many specimens were in direct contact with *S. cuneata* twigs, particularly a thick (2 cm) stem. Few other species were collected at this locality (Water Hollow, Salina Canyon, 8/24/70).

None of these herbaceous plants appear to be adapted to areas where the soil surface was covered by water, therefore, they may have been restricted to swamp margins, or existed as epiphytes on tree trunks. Epiphytic plants are common on buttressed bases of living swamp trees and include many species of lichens, moss, liverworts, ferns, and angiosperms (Braun, 1950; Hall and Penfound, 1943; Penfound and Hall, 1939; Shelford, 1963; Voigt and Mohlenbrock, 1964). Hall and Penfound (1943) note that a parasitic angiosperm (*Phoradendron flavescens*) lives on swamp trees. It is a reasonable conjecture that the Blackhawk swamp trees may also have supported a variety of epiphytic plants so we should be continuously watching for such plants while collecting.

Another substrate on which herbaceous Blackhawk plants might have grown was the surface of floating logs and decaying stumps. Hall and Penfound (1943) observed abundant floating logs in swamps and describe their significance in supporting a variety of mosses and wet-land herbs. Others have reported these floating "micro communities" and point out that decaying tree stumps are also usually populated with herbaceous plants (Braun, 1950). The low level of probability of optimum conditions for preservation of both stumps or fallen logs and leaves of such plants as may have grown on them makes this type of a fossil record little more than a curiosity.

Of the angiosperms collected in the Blackhawk swamps, none seems to be identifiable as an herbaceous plant except the aquatic types, which will be discussed subsequently, and perhaps Unknown Dicot #26. All the rest of the dicotyledon leaves, about 80 species, have the appearance of being coriaceous and rigid and are therefore believed to have been produced by woody plants. Unknown Dicot #26 appears to have had a very thin texture but seems, because of the shape of its base, to have been a leaflet on a much larger compound leaf. Its general appearance is unlike any known living dicotyledon observed in this study.

Chaney (1924) said that the small number of ferns and other herbaceous plants in the fossil Bridge Creek flora he examined cannot be taken as an indication of their scarcity in the living forest. He suggests that there were many more ferns in the forest but preservation factors were strongly biased against them. Evidence supporting this idea was obtained from the living Muir Woods forest. Here, there were 4 fern species which were very common, some living at the borders of the pools where he made counts of shed leaves, but, only one fragment from each of 2 species was collected. Therefore, although an herbaceous plant might be extremely abundant in a living forest it normally does not become buried by sediment since its leaves are low to the ground (not dispersed by the wind) and not often shed from the plant, but usually dry up and disintegrate while still attached.

Chaney (1924) recognized that the Muir Woods and fossil Bridge Creek environments were different from other fossil floras where broad, overbank deposition on floodplains would have an opportunity to engulf and thus preserve more herbaceous plants.

If there were several herbaceous dicotyledon or other species in the Blackhawk flora it is reasonable that at least a few specimens of some of them would have been preserved and recognized, since delicate fern foliage was preserved in many types of sediment. Some of the nearly 3,000 individual leaf specimens which could not be identified might have been from herbaceous species. However, though some of the unidentified specimens appeared to have curled or shriveled before burial, all have the general appearance and character of the identified species, so there is no basis for suggesting that any were herbaceous.

The apparent lack of herbaceous Blackhawk angiosperms supports the general conclusions reached by others who suggest that plants with herbaceous growth forms did not diversify and become important until the Tertiary (Arnold, 1947; Darrah, 1960).

Aquatic Plants

It is significant that the aquatic plants found in the collection were obtained in rocks of swamp origin. These include a water lily, *Nymphaeites dawsoni*, and a water chestnut, *Trapa paulula*. In addition, several cattail-like leaves (*Cyperacites* sp.) were collected although it is not certain that this was truly an aquatic plant. Specimens of these plants were not common, but provide additional evidence for the existence of the swamp communities.

The depth of water where these plants grew probably could not have been greater than one m because such plants must root in soil under the water (Shelford, 1963). In addition, species of the modern genus *Nymphaea* require open, well-illuminated water (Shelford, 1963), conditions presumed to be comparable to those required for the Cretaceous species.

No evidence of any free-floating aquatic plants was found in Blackhawk swamp sediments, although several species of ferns and angiosperms are commonly found on the surface of modern swamps in such abundance that they completely cover the surface in areas where the water is not flowing (Hall and Penfound, 1943; Shelford, 1963). It seems probable that plants of this form existed at some time on some of the Blackhawk swamps, since several species of free-floating Salvinaceae are known from the Cretaceous (Ellis and Tschudy, 1964; Hall, 1975; Matsuo, 1967, Tschudy, 1966; Weber, 1973). Blackhawk rocks have not been carefully examined for megaspores of these plants.

The infrequency of aquatic vegetation in these swamps supports a study by Ostrom (1964) who examined the reports of several Upper

Cretaceous floras in order to determine the amount of aquatic vegetation which was present as potential food for hadrosaurian (duck bill) dinosaurs. He concluded that there was little evidence for an abundance of soft aquatic and herbaceous vegetation which had long been considered to be a possible basic food source for these animals. He suggested instead that these herbivores ate the coarser vegetation of the abundant woody conifers and angiosperms.

Several fresh water gastropod shells were collected in rocks which are considered to be of swamp origin.

Palm Thickets

Stems of a number of buried palm trees, *Geonomites imperialis*, were seen in an overhanging ledge of gray sandstone (Unit O) at the Water Hollow collection locality, Salina Canyon. All such stems were buried vertically and extend up into the overlying sandstone (Figure 7). Several of these are about 10 cm in diameter and spaced about 1.5-2 m from one another. All were preserved with an outer rind of carbonaceous material less than 1 cm thick and a central cast of siltstone. Radiating away from the periphery of these stems were compressions of wedge-shaped leaf petiole bases connected directly to the trunk. These petioles extended outward from the trunk into the surrounding sediment about 20 to 25 cm before being distorted or becoming indistinguishable in the accumulation of other palm leaves. The leaves in such compressed layers were very numerous, overlapping one another, and lying with longitudinal axes in various directions around the buried trunks. A thin, 12 cm, coaly shale lies immediately below the gray sandstone (Unit N) in which the palm stems were rooted.

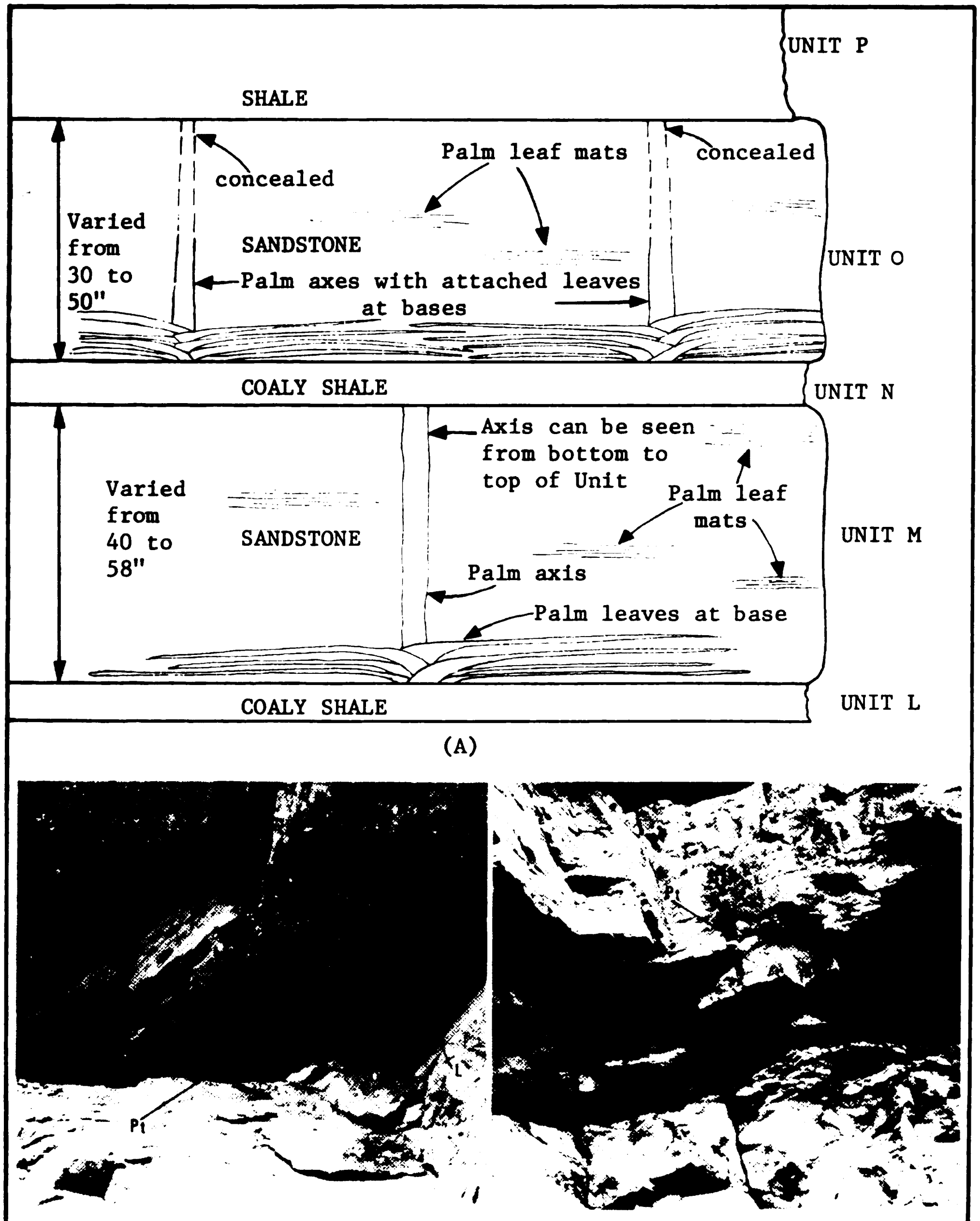

Figure 7. (A) Diagramatic reconstruction of units M, N, and O at the Water Hollow Road collection locality indicating the relative size and position of the buried palm trunks (*Geonomites imperialis*) and palm leaf mats in Units M and O. (B) Palm trunks (Pt) and palm leaves (L) in Unit O viewed from below as they are exposed in the bottom of an overhanging ledge.

It seems apparent that these vertical axes were buried in place as they were rooted on the surface of a peaty swamp soil. The small diameter of the trunks and the vertical exposure of a trunk in Unit M, below, indicate that they were short, not more than 2 to 3 meters tall, and had persistent leaf bases, much like the growth habit of species of the living genus *Geonoma* (Corner, 1966). The flattened manner in which the leaves were preserved suggests that they must have remained quite stiff as they lay on the ground after being shed. Individual leaves measured here were 2 m long. In the living condition this must have made a very tangled thicket since the trunks themselves were only about 2 m apart.

Because the stumps are nearly all the same size, they may have begun growth from seed or rhizome the same season, possibly during annual drought, when surface water was absent. It is probable that while they existed, standing surface water was very shallow or lacking. Several species of living swamp palms can withstand saturated soil and even water burial for short periods, but normally they cannot tolerate these environments (Anderson, 1961).

This small palm thicket appears to have been buried during overbank deposition. Because there are actually several individual layers of palm fronds in the lower 30 cm of the sandstone, it seems that some dead leaf litter may have been buried as it lay on the surface of the swamp or low-lying bottomland and later some of the leaves still attached to the stems were inundated by several successive floods bearing arenaceous sediment.

On examination of the sandstone below (Unit M), remains of another, earlier palm thicket are evident. Although not as well preserved as the one above, there are numerous palm leaves and a single trunk that extends vertically through the thickness of the sandstone, about 1 m. This trunk is 7 to 8 cm in diameter and also has leaves attached peripherally near the base. A latex cast of leaves was made on the undersurface of this sandstone. The thin, coaly shale under this sandstone indicates another peaty substrate for these palms.

Lateral to both of these buried thickets are several horizontal log casts, some as large as 20 to 25 cm in diameter. Exposed portions of these logs were .5 to 1 m long but they must have been much longer in total length. These logs may have been fallen swamp trees lying or floating on the surface of the swamp.

Swamp Conifers

One interesting aspect of the Cretaceous swamps is the relatively large number of gymnosperms (chiefly conifers) which occurred together in these communities. One collection site (Pipe Springs, Salina Canyon, 8/19/70) yielded 6 species of gymnosperms which grew within several meters of one another, and two sites (Pipe Springs, 8/18/70 and Cox Swale, Straight Canyon, 7/11/70 II) had 5 species in similar close association. Other sites had fewer species.

Several conifers are commonly found in modern swamps and include species in the following genera: *Abies*, *Chamaecyparis*, *Dacrydium*, *Juniperus*, *Larix*, *Picea*, *Pinus*, *Podocarpus*, *Taxodium*, *Taxus*, *Thuja*, and *Tsuga*. Certain of these species are completely restricted to swamp habitats while others may only occasionally overlap into these areas (Buell, 1939; Penfound, 1952; Anderson, 1961). However, it appears that in modern swamp or bog communities there are rarely ever more than 3 or 4 conifers growing together, and when they are it is apparently due to a mixing of representatives of two or more successional stages (Penfound, 1952).

This large number of Cretaceous conifers seems to reflect the intermediate position of the Blackhawk flora between the earlier Mesozoic floras dominated by conifers and the later Cenozoic floras dominated by angiosperms. Of these conifers, six genera became extinct before the end of the Cretaceous Period (*Androvettia, Brachyphyllum, Moriconia, Nageiopsis, Podozamites, Widdringtonites*), and another genus (*Protophyllocladus*) was eliminated from the Northern Hemisphere late in the Paleocene (or early Eocene). Only *Metasequoia* and *Sequoia* continued on into the Tertiary in North America, where late in the Tertiary *Metasequoia* disappeared from the Western Hemisphere. Though the genus *Sequoia* is present in North America today, the species *S. cuneata* disappeared from the record by the end of the Paleocene. Eight of these extinctions correlate with the disappearance of the extensive fluvial and coastal swamp habitats associated with the Western Interior Seaway. This suggests that they were mostly restricted and highly adapted to swamp or wet-acid environments and became extinct when these environments were reduced in size and isolated as the sea receded. Most of these species seem to have been restricted to the coastal plains or shores of this seaway throughout the Cretaceous Period.

Seedling Growth, Water Fluctuation and Depth

In describing deep swamp communities, Penfound (1952) mentions that seeds of all woody fresh water species require "dewatering" or "strandage" if germination is to be accomplished. Braun (1950) and Shelford (1961) support this conclusion in their observation of swamps on the Mississippi River floodplain. In order for certain trees, including the bald cypress, to become established, the seeds must sprout when they are not submerged and the seedlings must grow to sufficient height during the first year to stay above the floods which occur the second year (Penfound, 1952). Wells (1942) says that cypress and gum seeds will germinate only in the presence of gaseous oxygen and not in water. Mangrove trees (*Rhizophora*), however, drop young seedlings directly into the mud even though some water may be present. The seeds of this plant germinate within the drupaceous fruit while still on the twig and the young plant grows to a length of several cm.

It is reasonable that Blackhawk tree seeds were able to germinate only on temporarily-drained swamp surfaces. This infers that the swamp water level must have been lowered at least often enough for the trees to reproduce themselves. This periodicity in modern swamps is usually an annual occurrence associated with the dry summer months (Penfound, 1952).

The depth of the swamp water where the trees grew was probably also similar to existing swamps where it rarely remains deeper than 7 feet (2.1 m) for long periods or deeper than 12 feet (3.7 m) at the height of floods. Usually, these trees occur in much shallower water, 2 to 3 feet (.6 to .9 m) deep (Braun, 1950; Shelford, 1963). In addition, floating-attached plants rarely can become established in water deeper than 6 feet (2 m) (Shelford, 1962).

Water depth appears to be the major factor in the distribution of various species of swamp plants and probably was the case with Cretaceous species also.

Swamp Soil

The kinds of rocks seen in the Blackhawk swamp sediments are indicative of the soil or substrate upon which the trees grew. These rocks vary from light gray shales and siltstones, which contains a minimum organic content, to coals, which are largely comprised of organic remains.

Evidence that the trees were actually living rooted in both the mineral and the organic soils is shown by the presence of *in situ* trunks in sandstones between coals as well as in sandstones which directly overly coal zones (as described in the discussion of the Cox Swale Swamp, below). Most of the dark shales do not contain identifiable roots but perhaps this is because they were formed in a part of the swamp where water was too deep for trees to grow. In some instances the lack of roots in the black shales might be due to extensive decay.

A. T. Cross (personal communication, 1975) indicates that roots are found throughout the depth of most peat, lignite and coal beds. These roots are preserved from former levels of plant growth and accumulation since the roots of the living generation usually penetrate less than 1 m. He further states that some levels contain few identifiable roots among the plant debris, while other layers contain many roots of

various sizes. Occasional clay, sandstone or siltstone partings in the coal or peat may or may not have roots present probably due to preservation. Huttel (1975) shows that most of the roots larger than 5 mm in diameter are found within 70 to 80 cm of the surface. He indicates that the clay below 80 cm may actually inhibit root growth.

This growth position of living tree roots is significant in the interpretation of the roots in the Blackhawk swamp sediments. The Blackhawk swamp forest trees, buried by overlying sediments which poured in over the standing vegetation, were not rooted in the clay and silt beneath the swamp but were rooted directly in the peat. This demonstrates, as in modern swamps and marshes, that the roots were chiefly oriented in a shallow, horizontal plane in the upper part of the underlying soil (clay, silt, sand) or peat. As the peat was buried, compressed, and coalified, the roots became deformed and cannot be distinguished in the coal or coaly shale at this time. This accounts for the low numbers of roots collected or seen in the field.

It could be assumed that the Blackhawk peat-accumulating bogs were acidic, having a low pH similar to most existing swamps, perhaps as low as pH 5.3 (Hall and Penfound, 1943). Some modern bogs are alkaline, but they are apparently very rare (Buell, 1939). Alkaline bogs or swamps are not characteristic of river floodplains (Penfound, 1952).

Hall and Penfound (1943) mention that the soil in an Alabama swamp was firm enough to easily walk on, but the soil of a Louisiana swamp was much too soft (Penfound and Hall, 1939). As a matter of interest, abundant dinosaur tracks have been seen and collected from the surface of the mineable coals in the Blackhawk Formation, indicating that the peat of some of the swamps was consolidated enough to support the weight of these large animals. Some animals may have been partially supported or buoyed up by water inundating such swamps. Casts of dinosaur tracks found in the Kenilworth and Sunnyside mines and in collections of the Utah Museum of Natural History and the Price Natural History Museum are 5 to 30 cm thick, indicating the animals sank into the substrate at least to that depth.

Size and General History of the Fluvial Swamps

After examining many of the very thin coals and coaly zones, it is apparent that the size of the fluvial swamps on the Blackhawk floodplain varied in extent from 50 yards (46 m) to a mile or more and generally were in existence for only brief periods before being covered or modified by the return of the sinuous channels and shifting interfluves of the Blackhawk river meander belt or upper delta plain. They often indicate a cyclic history similar to that described for the lower Mississippi Valley and delta system by various workers. These swamps were in local basins such as cut-off river channels, ox bow lakes and interfluve depressions which developed by irregular compaction of muds between sandstone channel fills, rather than in the much larger and more stable basins associated with coastal lagoons and off-shore bars in which the Sunnyside and Hiawatha coals accumulated (Young, 1966; Maberry, 1971).

Normally, there exists a distinct dark or black shale below and above each coaly zone. This dark shale often grades into a light colored siltstone which in turn is overlain by a sandstone unit of variable thickness. The sandstones below the coals are often white. The best fossils are usually found in the shales and siltstones between the coals or coal zone and the overlying major sandstones.

This lithologic sequence suggests the creation of a swamp, perhaps through the following processes: a river meander loop is isolated to form an ox bow lake. The lake is infilled by silts and clays during annual floods until it is shallow enough that plants encroach upon it and across it. Gradually an accumulation of organic matter or peat occurs. Finally the eutrophic ox bow lake is silted-in with overbank sediments, the vegetation is swamped with silt or sand, swamp conditions give way to drier site communities and eventually the swamp is completely sealed by the deposition of sand, mud or silt. Later, if the river makes a major change in its local channel, channels may again meander across the former swamp site and point bar accumulations mark their migrating course. In other instances the swamp may be initiated by depressions due to compaction of less competent muds between competent sandstone lenses buried below the surface of the floodplain. The history of such a swamp development would differ only in starting as a swamp rather than as a lake or other open body of water.

In a number of instances it was observed that a sandstone lay directly over the surface of a coal. This must be interpreted as the sudden deposition of sand over the swamp, perhaps during a breaching of levees along the old channel, such that the new channel lay directly upon the peat; or perhaps the river may have poured out sheets of sand and silt (overbank deposits) over the swamp during a flood. In several

of these swamp-capping sandstones pea-sized gravel is present indicating considerable current action. Many vertical tree stumps can be seen in most of the thinner (2-6 feet or .6 to 1.8 m) sandstone units, and wood pebbles are found within the lower portions of the sandstone indicating erosion of one portion of the swamp, and deposition of the scoured out peat and sand in another portion of the swamp.

The Cox Swale Fluvial Paleoswamp

Sedimentary history. -- The sedimentation, coal, and plant fossils found at the collection locality near Cox Swale in Straight Canyon indicate that a peat-accumulating swamp existed here which was repeatedly buried by river overbank deposition. The fossils from the collection 7/11/70 II were obtained here, see Figure 8. The basal member of the section is an 18 inch coaly shale, Unit A (Figure 8). This is the remains of a thicker accumulation of peat and clay, but has been compressed and dewatered, in part, by the weight of the overlying sediment. No identifiable plant fossils or standing tree stumps can be seen, probably due to deformation during compaction and degradation of the plant tissue. The length of time for this material to accumulate must have taken hundreds of years. Trees were growing on the surface of this swamp. Therefore seasonal water depth never exceeded more than about 7 feet (2 m) (Shelford, 1963) and may normally have been much less.

This swamp and the trees growing on it were buried by 40 inches (1 m) of sand, Unit B. This is a gray, fine-grained sandstone with poorly-defined bedding. It does not have the shape of a channel fill

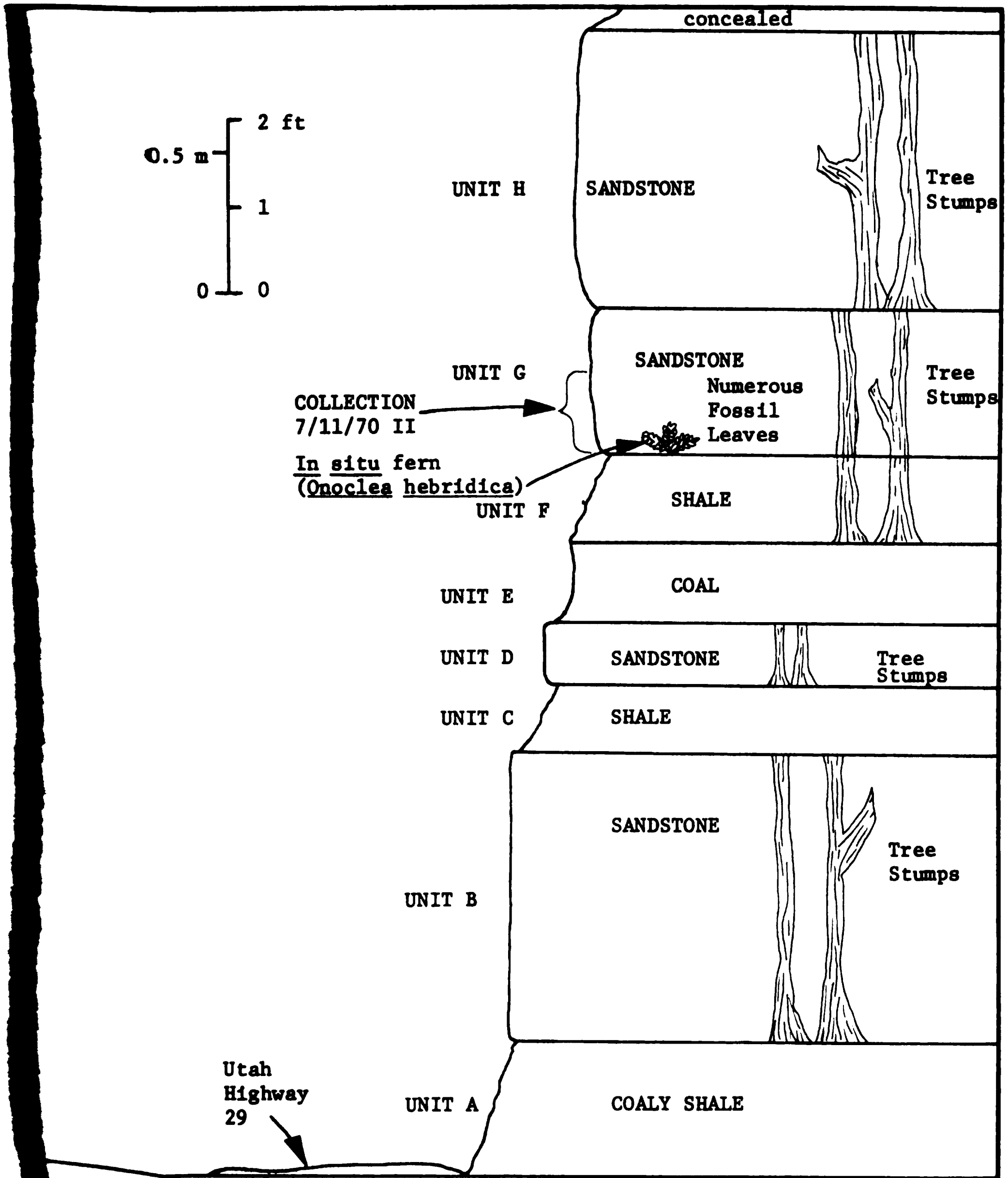

Figure 8. Generalized stratigraphic section at the Cox Swale Collection locality. The lithologic units have been designated letters A through H, the fossil collection site is indicated, and fossil tree stump casts are shown.

and it does not have cross-bedding. In addition, it directly caps Unit A with no evidence of stream-channel scouring of the peat swamp. The tree trunks preserved in it extend vertically from the surface of Unit A to Unit C. For these several reasons, it appears that this sand was deposited quickly, during a single flood (perhaps in hours or days) as overbank sedimentation rather than deposition within the river channel. (An alternative consideration is that Unit B accumulated as overbank sedimentation during several successive annual floods and the bases of the trees were more or less gradually buried to the depth of 40 inches or 100 cm.) The trees thus buried were almost certainly killed as the depth of the sand cut off the oxygen to the roots or the weight of the sand compressed them in the peaty soil. The tree trunks are thus preserved as vertical casts (Figures 8 and 9). No plant fossils other than these tree stump casts were recovered from this sand. As compression and sinking took place, the water of the swamp was able to return to its original position.

It was undoubtedly necessary for the woody plant community to become established again before large amounts of peat accumulated. Three possibilities exist which would allow the redevelopment of this community. The first is that the swamp returned to its original position as compression and sinking took place. If this occurred, then several successive stages may have been required, similar to those which Penfound (1952) and Sheldon (1961) describe in modern, peat-accumulating fresh water swamps. Their observations suggest that water cannot be more than 2 m deep for these successive stages to begin, because the first group of plants, the submerged-attached

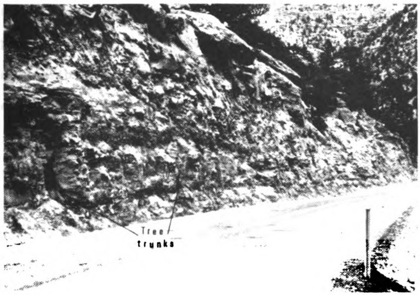

Figure 9. Vertical tree trunk casts in the swamp sediments at Cox Swale. The Units A through H indicated here are the same as those in the generalized stratigraphic section in Figure 8.

plants, cannot survive the low light intensity in deeper water. These plants are succeeded by floating-attached plants which give way to others in succession until a soil is sufficiently built up. Eventually the woody plants replace the others and remain dominant.

Another possibility for the redevelopment of the swamp is that the surface of Unit B may have remained more or less dry but was covered during annual or ephemeral flooding. This would allow the immediate establishment of a woody community and by-pass the long successional sequence required in more or less permanent, deep water. Cross (personal communication, 1975) prefers this alternative to the re-establishment of the woody plants, since there is no evidence of successional stages in the pollen-spore assemblages he has examined in the coals.

A third possibility for the redevelopment of the woody community is that although the sinking of Unit B may have allowed immediate return of deeper swamp water as above, woody plants might have established themselves during successively dry years while the surface was free from water.

As the swamp re-established itself, peat was mixed with a large amount of clay, silt and sand, perhaps indicating numerous small floods. The river may have changed its course and was much nearer the swamp than it was during the accumulation of Unit A. This latest peaty or organic rich mud (shale) accumulation is Unit C. It is well bedded, with an almost varved appearance. Some compaction must have taken place from its original thickness because of the large amount of organic matter in it. The tree stumps originating in Unit A are not visible in Unit C because they rotted away before deposition of Unit C (or were deformed as later compaction occurred). A possible origin of the arenaceous sediment in this unit is the sand of Unit B, below, which may have been scoured up at one place in the swamp and redeposited at this locality. The accumulation of Unit C also represents a long period of time.

Trees were growing directly on the surface of Unit C, but no plant megafossils were recovered.

The swamp of Unit C was subsequently capped by a thin sand with thickness varying from 6 to 12 inches (15 to 38 cm) at this outcrop. This is Unit D, and is similar in appearance to Unit B. It is also thought to have resulted from overbank deposition in a single flood. The trees still growing on the peaty surface of the Unit C swamp when sands of Unit D were deposited were also probably killed when inundated by sediments which accumulated to form Unit D. Eventually compaction occurred, the swamp re-established itself, and peat accumulated as before. Unit D is also barren of plant megafossils except for tree casts.

Unit E is a coal ten inches thick, representing perhaps 50 to 100 inches (120 to 250 cm) of peat accumulation over the surface of Unit D. Little mineral sediment is present indicating a very long period of uninterrupted organic accumulation. This may represent the longest time period visible in the section. The lack of mineral sediment suggests that the river channel was possibly some distance away during this time, since annual flooding does not seem to have affected this swamp. It is probable that the river flooded many times during the accumulation of peat in Unit E (Leopold et al, 1964). No identifiable fossils are present in Unit E, but the plants growing on this surface and the surface of Unit F are important in the interpretation of the swamp flora. These plants were preserved in Unit G, where many were collected and identified.

The 12-inch (30 cm) thick coaly shale of Unit F indicates that a large proportion of clay was being mixed with peat of the swamp. The clay could have been derived from overbank river flooding, suggesting a much closer position of the river channel than during the accumulation of Unit E, or by deepening of the swamp by compaction so that seasonal flooding carried clay in suspension into the open swamp waters. Sediment accretion in either case probably resulted from several successive floods which alternated with periods of organic deposition. The bases of the trees growing on the surface of Unit E at the time mud began to accumulate were buried by a minimum depth of 12 inches (30 cm) of mud and probably 2 or 3 feet (.6 or .9 m) of mud before later compaction and dewatering occurred. These trees were still standing and probably alive when Unit G covered Unit F. It does seem apparent that the formation of Unit F may have been much more rapid than the formation of Unit E.

The fern *Onoclea hebridica* which will be discussed subsequently was growing directly on the surface of Unit F immediately before burial by Unit G. This suggests that the surface of F was not covered by swamp water, nor had it been for the length of time required for the fern to become established (at least part of one season and probably several seasons).

Unit G, a 20-inch (51 cm) gray sandy siltstone, covers Unit F. It is apparent that at least the sediment in the lower portion of this unit quickly inundated the existing vegetation, causing plants of *Onoclea hebridica* and several trees to be preserved in growth position. (This fern and the palm *Geonomites imperialis* mentioned earlier are the only identifiable plants found *in situ* in the entire collection.) *O. hebridica* was obviously a member of the herbaceous understory and lived on swampy soils devoid of water. Because no reproductive structures were found among the 40 specimens collected here, it is possible that burial occurred early (spring) in the growing season before the fertile fronds developed. This is also the most likely time of year for flooding. It should be noted, however, that Fernald (1950) indicates that the fertile fronds of living species of *Onoclea* are often not developed.

Slightly above the *O. hebridica* fossils, but within the lower 12 inches (30 cm) of Unit G, more than 450 leaf and stem compressions were collected. They were generally preserved in a horizontal manner and were often clustered into "mats" of many individual specimens overlying one another. These fossils were found on the bedding planes of the siltstone at many different levels, suggesting that deposition was apparently not in a single short flood, but consisted of several periods of sedimentation. However, this period of time probably was not of many years duration because tree stumps continue through Unit G, indicating that they had either survived partial burial for several years or, they had not rotted away even though they may have been killed early in deposition of this siltstone. The leaves preserved in this swamp undoubtedly fell from the living trees whose stumps casts are still present.

Compaction again occurred from the weight of Unit G over the lower peat accumulations; swamp waters returned and a period of stabilization followed. Tree trunks from Unit G do not penetrate into Unit H, indicating that they rotted away before Unit H was deposited or were deformed in later compaction. Trees eventually grew directly on the surface of Unit G, so it can be assumed that some succession must have taken place and the water was not deep if present. These trees are the largest (greatest in diameter) of any seen at this locality.

Unit H is a gray sandstone, 4 feet (1.2 m) thick with a well-bedded, platy appearance. This sandstone buried the trees growing on Unit G to a depth of 4 feet (1.2 m) indicating that it too must have occurred relatively rapidly, or the trees would have rotted away. This unit is devoid of any leaf compressions.

At this point, the section is buried by colluvium and it is not possible to deduce further history of this swamp.

The sandy and clayey flood-borne sediments which periodically capped peat accumulations in this swamp (Units B, C, D, F, G, and I) seem to have been broadly lens shaped or of variable thicknesses and therefore may have been very local in extent. It is possible that they did not cover the entire swamp, particularly if the swamp was large. Certain areas of the swamp may have been completely unaffected by flood deposition, which moved sandy sediment to this locality, or instead of burial by sand, these areas may have been buried by silts or clays, lateral to the sands. On the other hand, swamp areas peripheral to this location could have been partially or completely destroyed by the scouring of flood waters. This may explain the high carbonaceous detrital content of the sandstones deposited above the dark shales; the peat being scoured from one area of the swamp, mixed with sand and redeposited at this site.

If these lensy sediments were deposited on only a portion of the swamp, the result would be "split coals." Two such coals exist in roadcuts in the Blackhawk Formation, one at the Water Hollow Road collection site, the other at the Pipe Spring collection site, both in Salina Canyon. A particularly obvious one exists in a roadcut on Interstate 70, 4.7 miles (7.6 km) east of Fremont Junction (south of Emery, Utah) in the upper part of the Ferron Sandstone (Cross _et al_, 1975). These split coals result when only a portion of the peat swamp is inundated with sediments; the heavy sediments so deposited, gradually sink as the underlying peat is compressed and the swamp surrounding the sinking area gradually spreads back over; peat accumulation resumes. Such sedimentary lenses form "partings" in the later resulting coal seam. In examining the sedimentation of floodplain swamps, areas might be found with uninterrupted accumulations of peat, while laterally, a thick wedge or "parting" of mineral sediments might be present.

Flora of the Cox Swale paleoswamp. -- The collection site in Unit G, 7/11/70 II, yielded about 450 specimens, making it the second largest florule of the collection. More than 30 species have been identified, but only 8 were represented by 10 or more specimens.

These species are:

	Number of Specimens	Importance Index
Sequoia cuneata	207	43.4
Cissus marginata	43	7.0
Onoclea hebridica	40	3.4
Unknown Dicot 25	31	2.8
Moriconia cyclotoxon	22	6.4
Rhamnites eminens	22	18.1
Phyllites vermejoensis	13	3.2
Dryophyllum subfalcatum	12	5.5

The remaining species are represented by less than 10 specimens and are arbitrarily disregarded here as statistically minor components of the local community.

This florule contains 5 coniferous plants including *Araucarites* sp. (cone scales), *Brachyphyllum* sp., *Moriconia cyclotoxon*, *Protophyllocladus polymorpha*, and *Sequoia cuneata*. It also includes 9 plant species (an unusually large number) which were not collected at any other locality and appear to be previously undescribed. These include: *Araucarites* sp. (cone scales), *Acer cretaceum*, *Palorodoxites plicatus*, and Unknown Dicots 5, 9, 12, 17, 25 and 30.

The most important trees were a mixture of gymnosperms and angiosperms with *Sequoia cuneata* the most abundant tree. *Rhamnites eminens* and Unknown Dicot 25 are also important members of the community. *Moriconia cyclotoxon*, Unknown Dicot 3, and *Dryophyllum subfalcatum* were of lesser significance. Two species with small leaves or leaflets, Unknown Dicots 16 and 50, may have been shrubs. The vine, *Cissus marginata*, appears to be in unusually high proportions. Palms are represented by two species, *Geonomites imperialis* and *Palorodoxites plicatus*, both of which were small and shrubby in appearance. The fern *Onoclea hebridica* was the only herbaceous plant; no aquatic plants were collected.

Unlike other Blackhawk swamps, specimens of *Sequoia cuneata* far outnumber specimens of any other species. *Rhamnites eminens* was a little less abundant than expected.

The soil-like surface of Unit F was not covered by water and may have remained quite dry for some time on the basis of the evidence of the fern in growth position on it. If this period was several seasons in length and it appears to have been, then the clayey substratum could have become similar to certain bottomland soils which would have allowed the growth of nearby bottomland species. If the trees growing on Unit E, below, were still alive or slowly dying because of burial by the clay, leaves of swamp-dwelling trees could have been mixed with leaves of typically bottomland species as they were shed. The presence of 12 specimens of *Dryophyllum subfalcatum*, an apparent bottomland species, may support this speculation.

THE ENVIRONMENT OF THE HARDWOOD BOTTOMLAND COMMUNITY

Most of the total land surface of recent floodplains is low-lying, not many feet above the surface of the river. These areas are known as bottomlands with soil conditions and a flora which is different than neighboring swamps and river channels (Shelford, 1963; Voigt and Mohlenbrock, 1964).

Those floristic and physical factors which are known about the Blackhawk bottomland are described below.

The Arborescent Plants

The most significant trees of the Blackhawk bottomlands, listed by their Importance Index, are as follows:

Cercidiphyllum arcticum	27.3
Platanus raynoldsii	21.2
Dryophyllum subfalcatum	19.0
Unknown Dicot 2	13.4

These angiosperm species are all represented by more than 100 specimens in the bottomland florules and they all have a relatively high frequency and Importance Index. This community, therefore, appears to have been co-dominated by these trees, much like existing bottomland forests where slight changes in elevation, nearness to the river channel and other factors allow one or another species to become extremely abundant locally (Voigt and Mohlenbrock, 1964), otherwise they occur together in various mixtures. The fossil trees probably formed a forest which had the appearance of the modern "hardwood bottoms", adjacent to cypress-tupelo swamps on the Mississippi floodplain, where the canopy is nearly 100 feet (30 m) high and shades a normally sparse shrubby and herbaceous understory (Barrett, 1962; Shelford, 1963; Voigt and Mohlenbrock, 1964).

Subordinant but locally abundant trees were *Laurophyllum coloradensis*, *Manihotites georgiana*, *Myrtophyllum torreyi*, and *Phyllites vermejoensis*. The conifers *Sequoia cuneata* and *Protophyllocladus polymorpha* were also subordinant trees.

Besides the abundant fossil leaves collected, many *in situ* tree stump casts have been seen in the field, buried within bottomland sediments. Undoubtedly, some of these casts were formed from the burial of the above-listed trees but they are too poorly preserved or deformed to be identifiable.

There are a number of characteristics or features of modern bottomland trees which probably would have been advantageous to the Cretaceous trees living in such habitats. These include: an ability to thrive on poorly aerated, often saturated bottomland soils; seedlings which can tolerate submergence for several weeks; adventitious root production when basal areas are buried by silt; and very rapid growth (Voigt and Mohlenbrock, 1964).

The presence of *Cercidiphyllum arcticum* in such abundance (more than 350 specimens were collected) indicates that it was a significant and perhaps the most important member of the floodplain community. In certain sites it was apparently dominant and seemed to exclude the other co-dominant trees. Its high Importance Index reflects its occurrence in nearly every collecting site. This genus was widespread and diverse in the Cretaceous Period and, interestingly, is represented by one living species today, *Cercidiphyllum japonicum*. Its leaves are characteristic as are certain other features which make it unique among living angiosperms. In China and Japan, where it is endemic today, it prefers well-drained bottomland soils but can tolerate a wide range of soils including wet-acid, swamp types (Numata, 1974).

Platanus raynoldsii is interesting since its leaves closely resemble those of several living species of *Populus* (cottonwood), particularly *P. deltiodes* which is often a dominant member of the bottomland forest on portions of the upper Mississippi River floodplain (Voigt and Mohlenbrock, 1964). This tree appears to have been a widespread and abundant tree of the Blackhawk floodplain, normally found in bottomlands but occasionally found in swamp communities.

Dryophyllum subfalcatum, a supposed live oak-like plant, is one of the most widespread of the Cretaceous angiosperms. Brown (1937) and Dorf (1942) both used it as an index fossil of the late Cretaceous.

One of the most interesting plants is *Manihotites georgiana*. A few fragmentary specimens were collected in swamp deposits, but the species seems to have strongly preferred bottomland habitats. The broad leaf-blades are the largest of any dicotyledon in the collection, up to 30 cm long and attached to a stiff, narrow petiole at least 18 cm long. At the collection site near the mouth of the Black Diamond Mine (abandoned) in Straight Canyon, more than 20 nearly complete leaves and fragments of about 50 others could be seen. Recently, A. T. Cross (personal communication, 1975) collected additional specimens at several points along the outcrop near this locality. At the same places he also collected several fleshy fruits which may belong to this plant. Balsley (personal communication, 1975) has also collected numerous specimens from Blackhawk deltaic sediments in Price Canyon, Utah. In addition, *Manihotites* has been collected in the Upper Cretaceous Olmos Formation (Maestrichtian) of the Sabinas Basin of northern Mexico near Coahuila (*fide* Cross, 1973). The original collection of this species was in the Santonian Eutaw Formation of Georgia (Berry, 1914).

The infrequency of conifers in bottomland sites further emphasizes that these plants were normally restricted to swampy soils. Only 4 conifer species were collected in these sites and include: *Moriconia cyclotoxon* (2 specimens), *Protophyllocladus polymorpha* (35 specimens), *Protophyllocladus* sp. 2 (49 specimens) and *Sequoia cuneata* (22 specimens). The occurrence of these conifers may be explained in several ways. First, they may have been relic trees left at a specific locality as the local sedimentary environment shifted, or secondly, perhaps as individual trees invading bottomlands from an adjacent swamp, or they may have been more broadly adapted to both swamp and bottomland sites. The presence of *Protophyllocladus* sp. 2 is explained later in the discussion of the communities at Taylor Flat.

The Shrubs and Vines

The only bottomland plant which is known to be of shrub size was the palm *Geonomites imperialis*. It was collected in about one third of the bottomland sites, but no thick palm leaf-mats were observed here as they were in swamps. Corner (1966) reports that all species of the modern genus *Geonoma* are members of the understory in Brazilian bottomland forests.

Four bottomland dicotyledons had very small leaves which may have been shed from shrubby plants. These species are rare and unimportant members of the community and include: Unknown Dicots 16, 52, 53, and 57. There are more possible shrubs in bottomlands than in swamps possibly because there was more soil surface area in bottomlands.

Menispermum dauricumoides, another dicotyledon, was probably a bottomland vine. Leaves of this plant are remarkably similar to those of the living moonseed vine, *Menispermum canadensis*, a common plant of bottomland forests of North America today (Voigt and Mohlenbrock, 1964).

Cissus marginata, a woody vine which was abundant in the Blackhawk bottomlands and swamps, has been described earlier in the section on shrubs and vines of the swamps. It apparently was a more important member of this community than it was in the swamps.

Braun (1950) has noted that several woody and herbaceous vines are usually present in the modern bottomland communities.

The Herbaceous Understory

The herbaceous understory consisted of several ferns, *Osmunda hollicki* being the most frequent. Specimens of this fern were collected in about one third of the sites. Several extant species of the genus *Osmunda* flourish in wet woodland or bottomland soils and often form an extensive understory apparently similar to *O. hollicki* (Voigt and Mohlenbrock, 1964).

There is no evidence in the bottomland community of the presence of any herbaceous dicotyledons.

The Bottomland Soil

The kinds of sediments seen in the Blackhawk bottomland strata are indicative of the soil upon which the trees grew. These rocks are chiefly siltstones but they normally have a high percentage of clay or sand. Some are highly organic and dark colored, but usually they are light in color with much less organic matter than rocks of the swamps.

Barrett (1962) describes the bottomland soils of the Mississippi River floodplain as being composed of fine to coarse sediments in poorly drained sites.

In situ stump casts were often observed in bottomland deposits of the Blackhawk, but no root systems were evident.

Raindrop prints were observed in the rocks at two sites. For these to have been made and preserved the individual drops must have landed on a soft, fine-textured surface which was free of standing water, and was barren of a litter layer and not covered by a canopy of herbaceous plants, but freely exposed. It had not rained enough for water to form puddles at these particular locations since movement of water might have obliterated the casts even if they had formed on exposed surfaces. Settling out of suspended clayey material in a body of standing water could have preserved these splash marks as casts. They might also have been buried by a sheet of water-borne silty sediment, perhaps after a period of hardening or drying. This kind of environment would most likely be found on existing bottomlands rather than in swamps.

The invertebrate trails collected at two bottomland sites were of two types, pascichnia (feeding trails) and repichnia (directed locomotion or trails) (terminology after Seilacher, 1964). Both are less than 1/8" (.3 cm) in width and cover an area of about 6" square. It is probable that they were formed at the bottom of a temporary puddle of water, since there is no evidence to indicate a permanent lacustrine habitat. These trails were collected in the same rock slabs as leaf specimens. Little organic matter is in the rock matrix of the pascichnia and it is unknown what the animal was feeding upon. These features also do not seem to be formed in a peat-accumulating swamp, but, in recent soils, are a feature of bottomland habitats.

It seems reasonable to believe that dinosaur and other animal footprint casts should also be found in bottomland deposits as they are in the swamps. To my knowledge, none have yet been collected.

Alternation of Bottomland and Swamp Environments at Taylor Flat

Characters of the florules and lithology of the section at the Taylor Flat locality indicate repeated development and burial of swamp and bottomland environments. Like the environment of the Cox Swale swamp discussed above, this locality suggests a dynamic sedimentary environment chiefly due to the constantly meandering river system, compaction of underlying sediments, infilling of backswamps and ox bow lakes and other floodplain activities.

An idealized stratigraphic and environmental history has been constructed, Figure 10, and the sequence of fossil plants collected in the several florules is shown, Table 6. The section begins on the south side of the bed of Salina Creek where the creek passes over a white, fine-grained sandstone, termed Unit A. This sandstone is apparently the top of a fluvial point bar. No fossils were collected in this unit. A swamp formed over the surface of Unit A, perhaps as a low place developed concurrently with the gradual subsidence or foundering of this channel sand into the less competent mudstones below. Units B, C, D, and E were formed in the swamp, indicating the deposition of clay, 4 to 6 feet (1 to 1.8 m) of peat, and finally the deposition of additional clay over the peat, perhaps as the river channel shifted closer to the swamp, thus allowing more frequent flooding. These swamp sediments were all unfossiliferous except for several standing stumps seen in Units B and E.

Unit F, an orange, sandy siltstone with little organic matter, was deposited directly upon the swamp. However, it did not sink into the swamp, or, at least the swamp water did not influence the sedimentation or the plants which lived concurrently on this unit. This swamp may have been partially drained by the river as it shifted to a much closer position to this locality. The florule collected in Unit F, 7/28/70 II, contains 5 species. The most abundant is obviously a member of the genus *Protophyllocladus*, but the phyllodes are much shorter, broader and seemingly thinner than *P. polymorpha*. This may merely be an environmental modification of *P. polymorpha* caused by burial of the trunk bases of trees living on the surface of

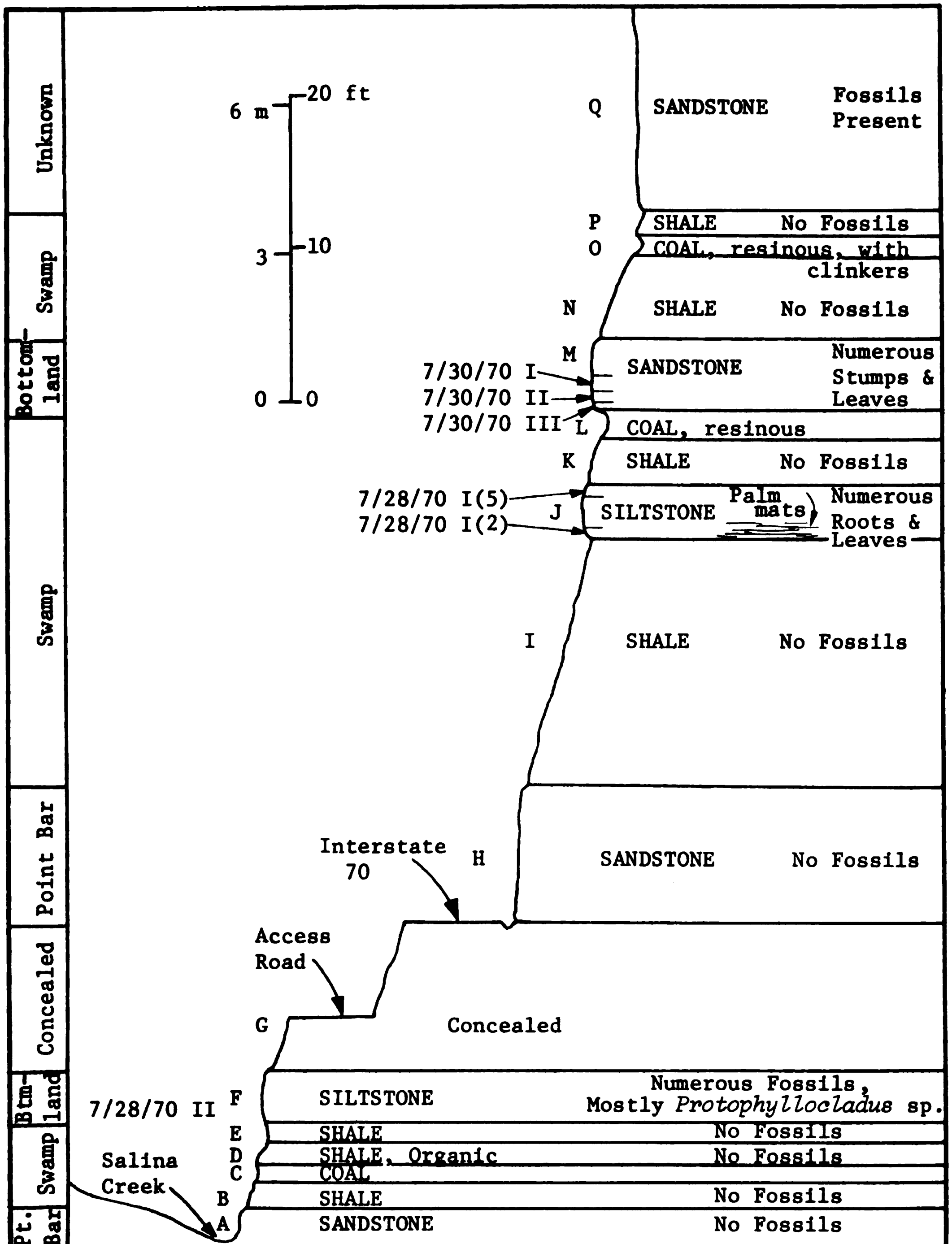

Figure 10. Alternation of bottomland, swamp and channel deposition at the Taylor Flat locality. Indicated are the collection sites in the lithologic units, the letter designations (A through Q) of the units, the presence of fossil stump casts and the relation of this section to Interstate 70 and a dirt access road.

Table 6. The species and number of specimens collected in the Taylor Flat sites. The sites have been arranged in stratigraphic order such that the lowermost is on the left and the uppermost is on the right.

TAXA	7/28/70 I1	7/28/70 I2	7/28/70 I5	7/30/70 III	7/28/70 II	7/28/70 I
Onoclea hebridica				3		
Moriconea cyclotoxon		1				
Protophyllocladus polymorpha		2	1			1
Sequoia cuneata		1		2		1
Cyperacites sp.		1				
Geonomites imperialis		8	6			
Sabalites montanus		1				
Cornus denverensis		2				
Magnolia amphifolia		2	1			
Rhamnites eminens		11	9	2		
Seeds		8		1	3	1
Selaginella sp.					1	
Allantodiopsis erosa						1
Osmunda hollicki				7	11	3
Saccoloma gardneri					3	1
Woodwardia sp.				2		3
Canna magnifolia				2		
Apocynophyllum giganteum				3	4	14
Cercidiphyllum arcticum				47	142	146
Cissus marginata	2			1	1	3
Dombeyopsis obtusa				1		
Dryophyllum subfalcatum				89	9	5
Ficus laurophylla				•	1	1
Laurophyllum coloradensis				10		17
Laurophyllum meeki				3		
Menispermum dauricumoides				8	1	
Myrtophyllum torreyi				3		
Platanus raynoldsii	12		4	52	15	28
Salix lancensis						1
Trapa paulula					1	
Unknown Dicot 3				12	5	5
" " 26					1	
" " 27				2	1	
" " 33				2	1	
" " 35						2
" " 52						1
" " 53						1
Protophyllocladus sp. 2	49					
Salix stantoni	5					
Unknown Dicot 57	1					

the swamp which produced Unit F. These trees may have lived for some time after their bases were buried and other swamp species eliminated. Three other species in Unit E are typical bottomland types: *Platanus raynoldsii*, *Salix stantoni*, and *Cissus marginata*. The fifth plant at this locality, Unknown Dicot 57, was not found at other localities and only a single specimen was collected. It appears to be undescribed.

The section above Unit F is concealed for about 10 to 20 feet (3 to 6 m) by the recent construction of an agricultural access road and Interstate 70.

The section was next observed on the north side of Salina Canyon, about 100 meters due north of the lower portion. At this locality Spieker and Baker (1928) measured the rest of the section up to the base of the Castlegate Formation. Unit H at this position is a thick, massive lenticular sandstone, probably of point bar origin since sedimentary features such as cross bedding and lenticular siltstones are present. The lack of fossils and its low organic content also suggest its origin as an in-channel deposit.

After the river abandoned the channel in which Unit H was formed a swamp developed over its surface at least locally, probably due to its foundering in the soft sediment below. This environment appears to have been stable for a great length of time, allowing deposition of the thick, gray shale of Unit I. Although fossils were collected in these shales, they were poorly preserved and fragmentary. The water of the swamp may have been locally too deep for the preservation of complete leaves and twigs. It seems that clays suspended in overbank flood waters settled into the basin and buried partially-decomposed plants.

This swamp was abruptly covered with the coarser sediments of Unit J. The thin beds of this unit are sandy siltstones with a great deal of clay and organic matter. Thin, 1/8 inch (0.3 cm) coals are present throughout as are abundant plant fossils. One of the most abundant of these was the palm *Geonomites imperialis*, judging from the number of palm leaf-mats present. Another palm, *Sabalites montanus*, was also collected here but it was not abundant. The growth of palms at this location is probably an indication that water did not cover the soil surface as it seems to have done during the history of the preceding swamp. This may have resulted from the lowering of the water level as the river shifted close enough to the edge of the swamp to drain it. The arenaceous sediments of Unit J also indicate a closer river channel. The large amount of organic material in Unit J probably included some which was scoured up from the surface of the swamp as flood waters moved across it.

More than 500 fossil specimens were collected at several sites within Unit J. However, since they were so fragmented, only specimens in sites 7/28/70 I-2 and 7/28/70 I-5 were identified. These species were chiefly those of other swamp habitats, including a fern, three conifers, six angiosperms and several unidentified seeds. Few conifer remains were collected, probably due to the apparent local dominance of *Rhamnites eminens*, perhaps similar to certain recent swamp habitats where pure stands of living *Nyssa aquatica* exclude other trees (Voigt and Mohlenbrock, 1964). Apparently Unit J was deposited over a period of time as indicated by the many successive levels of palm mats. No major floristic changes occurred from the time of preservation of the plants in the lower ten inches of sediment in this unit to the time of the preservation of the plants in the uppermost ten inches.

The surface of Unit J supported the growth of tree-sized plants for at least a short time before its eventual burial since many *in situ* vertical and horizontal roots can be seen. Some were of large proportions, extending from the upper surface of Unit J downward, a length of about 4 feet (1.2 m). One root cast was 2 inches (5 cm) in diameter and tapered slightly for more than 30 inches (76 cm) downward. Several circular branch root scars were evident on the surface of this root and casts of branch roots extended away from it. Its general appearance was similar to certain specimens of the Paleozoic genus *Stigmaria*, but of course no relationship to that extinct group is inferred. These roots post-date the fossil leaves found within Unit J and may be a factor in their poor preservation. This unit seems to have been deposited by a series of floods.

Deep-water swamp conditions seem to have returned and formed Unit K, but this dark carbonaceous shale had no identifiable fossils within it. Subsequent to Unit K, 10 to 12 feet (3 to 3.7 m) of peat accumulated, becoming the coal of Unit L. A thin black shale over this coal indicates that the river-swamp relationship had changed, such that much more clay was being mixed with the peat.

Capping Unit L is coarser sediment, Unit M. The lithology and fossil plants collected herein indicate the termination of the swamp environment, deposition of a series of arenaceous overbank sediments and the formation of a bottomland community. Again, the river may have shifted closer to this locality, draining the swamps which

produced Units I, J, K, and L, or lowering the water table enough for the development of a bottomland community. The closeness of the river channel probably also accounts for the deposition of coarser sediment.

Three significant bottomland florules were collected in the lower portion of Unit M, each being 10 inches (25 cm) thick. The plants collected in each of these florules are mostly bottomland species, dominated by *Platanus raynoldsii*, *Cercidiphyllum arcticum* and *Dryophyllum subfalcatum*, see Table 6. Several aspects of the development of the bottomland community on the sandy substrate laid down over the swamps can be seen because the collections were kept distinct from one another.

The drier conditions of the bottomland in which the sandy substrate covering the swamp of Unit M was deposited probably terminated the growth of the typical swamp forest. However, two typical swamp plants were present in the lowermost florule, *Onoclea hebridica* and *Rhamnites eminens*, as though they were able to survive the change in environment. The fact that they were collected in the first few inches of sediment overlying the swamp sediments and not in many other bottomland florules (*O. hebridica* in one bottomland site and *R. eminens* in five) adds weight to other evidence which indicates that they generally were characteristic of swamp habitats.

Another feature of this bottomland community is that *Cercidiphyllum arcticum* is represented by 46 specimens in the lowest florule, and more than three times that number in the middle and upper florules. This may indicate that it required some period of time to become established or that it could not flourish in the thinner, perhaps saturated soil immediately over the swamp. Also interesting is the decrease in total number of specimens of both *Dryophyllum subfalcatum* and *Platanus raynoldsii* from the lower to the upper portions of Unit M. These trees may have preferred the shallower soils over the swamp or could not withstand competition by *C. arcticum*. If *C. arcticum* replaced these two trees in the community, then this may be an example of fossil plant succession. Other sequences where these species occur will have to be investigated to determine the validity of this suggestion.

Canna magnifolia and *Menispermum dauricumoides* are also restricted to the lowest florule, but little can be said of other species because not enough specimens were collected to be meaningful. Significantly few conifer remains were collected in these bottomland sediments and no palms.

This bottomland community eventually became engulfed by another swamp which is characterized by highly organic clays and peat accumulation (Units N, O and P). This is capped by Unit Q, apparently another major overbank deposit. No fossils were collected in these units but the resinous bodies in the thin coal (Unit O) indicate gymnospermic wood, if this compares with similar resinous coals which have been examined in the area (A. T. Cross, personal communication, 1976).

THE ENVIRONMENT OF THE BLACKHAWK POINT BARS

The point bar sandstones observed in Salina and Straight Canyons are lens or wedge-shaped. The largest, which are commonly 30 or more feet (9 m) thick, taper horizontally and rarely can be traced more than 200 to 300 yards (180 to 275 m), even in nearly vertical exposures which have no talus accumulation or plant growth to conceal them. Laterally, these sandstone bodies are finer grained and have numerous siltstone and shale partings. They taper channelward into sandy siltstones and shales. Spieker and Baker (1928), Baughman (1958), and Bachman (1958) all indicate the difficulty of tracing individual sandstone beds laterally for any great distance because they thin laterally and disappear. This lensy feature of point bars in the Blackhawk Formation of the Wasatch Plateau is illustrated in Figure 11. All of these point bars, near the Pipe Springs sites in Salina Canyon, overlap one another; none may be traced along the entire horizontal distance exposed in the cliff here. Casts of logs and water-worn wood pebbles are usually associated with thin lenses of gravel. Many thin lenses of gravel, sand, silt, and clay may be seen within them, similar to such sediments in recent point bars (Wolman and Leopold, 1957).

Transported Plant Remains

Most of the leaves and twigs collected within point bar sediments were also recovered in both the swamp and bottomland environments. Generally, all were damaged and most of them are preserved lying at

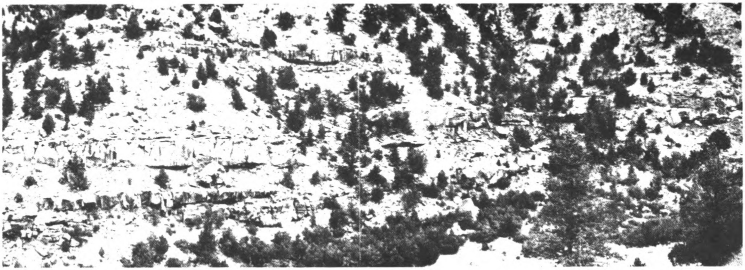

Figure 11. The lensy nature of the fluvial in-channel point bar sandstones within the middle region on the Blackhawk Formation at Pipe Springs in Salina Canyon.

angles to the normal horizontal bedding, suggesting that they had been picked up by the river from adjacent swamps and bottomlands, transported downstream, and were piled up with some crumpling or distortion on point bars where they were later buried. Shelford (1963) observed this process happening on the Mississippi River, and reported that a great amount of leaves, twigs and wood are annually buried in point bars.

The two species which were most commonly found in this environment were *Araucarites* sp. and *Podozamites* sp. These gymnosperms also seem to have been slightly damaged in transport but neither were collected in swamp or bottomland sediments, and do not appear to have been members of those communities. The living araucarians and cycads, the presumed closest living relatives of these plants, are not invaders of the well-washed, often saturated, sandy substrate of point bars. Instead, they prefer mature, well-established stable communities and well-drained, sandy soil with a good deal of humus. They are also slow-growing, unlike those species which are known to invade point bars (Chamberlain, 1935; Hall et al, 1970). Therefore, the origin of these plants seems more likely to have been the piedmont or upper delta plain environment of the Sevier Orogenic belt, near the head of the floodplain.

Both the leafy twigs of *Araucarites* sp. and the leaflets of *Podozamites* sp. seem to have been durable enough that they withstood transportation by river flood waters without much mechanical abrasion, while the broad leaves of dicotyledonous plants were severely damaged. The araucarian specimens were almost all small twigs and the cycad specimens were all unattached leaflets as though there had been some sorting action to separate the larger and more complete pieces from these smaller ones. In contrast, *Sequoia cuneata*, which was preserved in swamps near where it grew, was represented by both large and small specimens of leaves, twigs, thick branches and cones. No sorting action had separated them.

During August, 1968, while at the U. S. Forest Service Desert Experimental Range Station west of Milford, Utah, I witnessed several aspects of conifer transportation by flood waters. Several thousand small, 1 to 6 inch (2 to 15 cm), leafy branches of *Juniperous scopulorum* were transported by flash flood waters more than ten miles to a playa lake where they were deposited. Upstream from the playa were larger branches up to three feet long many of which were buried within the stream channel muds. None of them seemed damaged in any way. Many dicotyledon leaves, small twigs and roots of other species were associated with the *J. scopulorum* branches but were generally transported in a damaged and unidentifiable state. It was interesting that all the conifer twigs were green, having been recently removed from living plants. Dead conifer twigs were not observed, perhaps because they were broken into very small particles by the turbulent water. This flood may be somewhat similar to Blackhawk paleofloods which apparently allowed undamaged transportation of *Araucarites* sp. and *Podozamites* sp., while other plant species were badly eroded.

A possible explanation for certain leafy stems not being significantly damaged by flood water is that they are carried high in the water, rather than under the surface, presumably due to the high water density from its increased sediment load (A. T. Cross, personal communication, 1973).

In Situ Plant Remains

In spite of the great amount of drift which accumulates on recent point bars, many woody plants do grow rooted in them. In North America these usually include species of willows, poplars or cottonwoods (Shelford, 1963). Older portions of point bars become covered with fine silt and thereafter support a typical bottomland flora (Barrett, 1962).

Three *in situ* casts of root axes were collected in a sandstone of point bar origin at the 8/26/70 III site in the Ivie area of Salina Canyon. They all were carrot-shaped, about 9 inches (23 cm) long and 2 inches (5 cm) in diameter at the top. Because of their size, they probably were formed by a shrub or small tree. All specimens had several thick secondary roots (or rhizomes) one-fourth inch (0.6 cm) thick, which diverged from the main axes extending horizontally several inches into the sandstone until they disappeared. These structures may have been adventitious roots formed after repeated burial of the main axis. This type of growth occurs in several modern point bar species (Shelford, 1963). Two of these root specimens were collected at one level and a third was collected about 8 inches (20 cm) below, as though it had been buried in an earlier flood. All were collected within two feet of one another as though clumped. None of these specimens could be identified, but they most likely were of a single, angiosperm species, similar to willows and other point bar plants which grow in clones. No other root or stem axes which might be interpreted as a member of a point bar community were observed.

With the general lack of herbaceous plants in this Cretaceous flora, it seems likely that the river point bars were normally barren of plant growth except for random clumps of woody shrubs, presumably angiosperms.

PROBABLE DECIDUOUS PLANTS

Twenty-two of the collection sites exhibited well defined leaf "mats" made up of a great abundance of leaves within a single bedding plane. They usually overlapped one another or were piled such that several could be observed in sediment 1 to 3 mm thick. Numerous species were represented in individual mats.

A possible explanation of these mats is that the leaves were shed at roughly the same time, probably at the end of a growing season (see the section of Paleoclimatic Interpretation). They seem to have accumulated in local basins near the base of the trees and were buried in single pulses of overbank sediment before decay had destroyed them.

Eight species are of particular interest because they were represented by very large numbers of specimens (an arbitrary number of 50) at one or more sites. These plants are the following:

Cercidiphyllum arcticum, at sites 7/30/70 I and 7/30/70 II, making up 62% and 71%, respectively, of the total specimens collected at these sites.

Dryophyllum subfalcatum, at sites 7/30/70 III and 8/25/70, making up 35% and 18%, respectively, of the total specimens collected at these sites.

Manihotites georgiana, at sites 7/23/70 I and 8/28/70 III. (Fewer than 50 specimens were collected, but at least twice that many more were seen at the collection sites on slabs which could not be moved.) These specimens are at least 53% and 68%, respectively, of the total specimens collected at these sites.

Myrtophyllum torreyi, at site 8/28/70 II where 39% of the total specimens collected were of this species.

Nageiopsis sp., at site 8/19/70, where 78% of the total specimens collected at this site were of this species.

Platanus raynoldsii, at sites 7/30/70 III and 8/28/70 I, making up 21% and 53%, respectively, of the total specimens collected at these sites.

Podozamites sp., at site 8/26/70 I, making up 97% of the total specimens collected at this site.

Unknown Dicot 2, at site 8/25/70, making up 54% of the total specimens collected at this site.

Because of the large numbers of leaves of these plants, ranging from 18% to 97% of the total leaves in those sites, they might be identified as those which were probably deciduous. Presumed living relatives of two of these fossil species are deciduous, *Cercidiphyllum japonicum* and *Platanus* spp. Other Blackhawk species may have also been deciduous.

It is interesting that all the leaf mats were associated with various types of small seeds or fruits, suggesting that they too were shed at the end of a season. Cross et al (1975) report that probable *Manihotites georgiana* fruits were collected with leaves of that species. A. T. Cross (personal communication, 1975) has said that these fruits were oval, fleshy, drupe-like fruits about 7.6 cm long and found in the same bedding plane as the leaves.

Several ferns and gymnosperms yielded large numbers of individual specimens at single sites, but for various reasons they are thought not to have been deciduous, among them are: *Cyathea pinnata, Onoclea hebridica, Araucarites* sp., *Brachyphyllum macrocarpum*, *Protophyllocladus* sp. 2 and *Sequoia cuneata*. Both ferns may have been buried *in situ* or at least before the foliage dried and curled up. The fossils of *C. pinnata* were mentioned in the discussion of the Cox Swale swamp. All the conifers except *Protophyllocladus* sp. 2 are represented by leafy branches which do not appear to be deciduous, since they vary in size and often have numerous lateral branches. The phyllodes of *Protophyllocladus* sp. 2 have been discussed earlier in the description of the bottomlands at Taylor Flat. They may have come from a single slowly-dying tree which had its base buried.

EVIDENCE OF ANIMALS

Several fossil leaf compressions show pre-burial damage of the blade or lamina from which irregular patches are missing. Much of this damage is seemingly due to invertebrate parasitism during the growing season perhaps before the leaves were shed.

My personal observations of the attached leaves from the ground level to a height of about 12 feet (4 m) in forests of central Michigan and southern Indiana during the first week of October, 1973, and Shelford's observations (Shelford, 1963), indicate that by the end of a growing season virtually all the leaves of herbaceous plants and a significant percentage of the leaves of woody plants to a height of about 12 feet (4 m) under the canopy are nipped, skeletonized, perforated, or otherwise deformed. Recognition of taxonomic characteristics requisite for identification is often impossible for some leaves because of this type of damage. Leaves of the canopy layer at heights up to 80 feet (25 m) were not examined directly, but observation of the detached leaves on the forest floor, which were assumed to come from the upper canopy layer, was made. Fewer of these leaves appeared to be damaged, but still, a large proportion had been grazed. Smith-Davidson (1930) has estimated that the population of invertebrates in the canopy layer of a modern deciduous forest is about 15,000 individuals per ten square meters. Of these, there are about 60 species which cause serious damage to the leaves of climax trees (Shelford, 1963).

Because of the damage of Blackhawk leaves, there was, in all probability, a large population of invertebrates in the Blackhawk forests. However, since relatively few Blackhawk fossil leaves seem to have been insect-damaged (compared to the undamaged ones), there may not have been as many invertebrates in these Cretaceous forests as today. In addition, some of the recent host-predator relationships apparently had not developed in the Cretaceous, such as Lepidopteran leaf-mining activities. Hickey and Hodges (1975) report that the earliest evidence of leaf mining Lepidopteran larva is in the Eocene. They suggest an earlier evolution of this activity since it is obviously well developed by that time. However, since it is not identified in the Blackhawk flora it may have originated after the Campanian.

Certain holes or spots on leaves examined by Lesquereux (1874), Knowlton (1930), Brown (1962), and others, have been thought to be the result of parasitic or saprophytic fungi because there seem to be fungal remains present. However, no fungal hyphae or fruiting bodies have been isolated from Blackhawk leaves.

Although many kinds of terrestrial vertebrate animals undoubtedly lived on the Blackhawk floodplain, none have been collected. The only direct evidence that they existed are several large dinosaur footprint casts 1 to 4 feet long (0.3 to 1.2 m), collected in various coal mines. Several of these casts may be seen in permanent display at the Carbon County Museum in Price, Utah and at the Utah Museum of Natural History at the University of Utah. Additional specimens may be seen in various rock shops in the area. To my knowledge, no vertebrate skeletal remains have been collected in the Blackhawk Formation. This appears to be difficult to explain since the fossil plant localities are so abundant and represent various types of preservation.

Fresh water gastropod remains have been collected by me at the Water Hollow collection locality (Figure 1) and marine pelecypod and gastropod remains were collected from two horizons at the Ivie Creek collection locality (Figure 1).

THE WESTERN HIGHLANDS, FLOODPLAIN AND RIVER SYSTEM

Highlands and Floodplain

Armstrong (1968) indicates that the Sevier Orogenic belt in western Utah and eastern Nevada was the source of clastics for the Blackhawk and other related sedimentary formations. The approximate eastern boundary of the highland formed by this north-south trending belt is near the present location of Sevier Lake, Utah, about 100 miles (160 km) from the closest Blackhawk exposure. McGookey (1972) indicates that the coastal plain during sedimentation of the Blackhawk, during Telegraph Creek and Eagle time, was on the order of 50 to 100 miles (80 to 160 km) wide in Central Utah. Since the entire floodplain or coastal plain environment at this time extended several hundred miles northward and southward, there were unquestionably many major rivers meandering eastward across this floodplain. The length of the rivers which were in central Utah were on the order of 100 to 150 miles (160 to 240 km) if they originated near the axis of the Sevier Orogenic belt near the recent Confusion Range in western Utah and extended to the shore approximately in the Castle Valley area (McGookey, 1972).

The Rivers

One of these major Cretaceous floodplain rivers was the Ferron River, which deposited a portion of the Ferron Sandstone, 5 miles (8 km) south of Ferron, see Figure 1. This river existed during Carlile time (Turonian) but had the same general relationship to the Sevier Orogenic belt and Western Interior Cretaceous seaway as younger Blackhawk rivers but the delta buildup was further southwest than those of the younger rivers. In addition the climatic conditions under which the Blackhawk Formation and Ferron Sandstone were deposited were similar inasmuch as thick accumulations of coal are found in each (Doelling, 1971).

Cotter (1971) calculated several paleoflow characteristics of the Ferron River by applying formula derived from recent rivers to fluvial sedimentary features he measured in the Ferron Sandstone. These measurements included the thickness and width of point bars and the type of sediment which composed them. He indicated that the river was roughly 300 feet (90 m) wide, 25 feet (7.6 m) deep and highly sinuous. It drained an area of about 7000 square miles (18130 km^2) with a mean annual discharge of about 6,500 cubic feet (184 kl) per second, and an annual flood of about 22,000 cubic feet (623 kl) per second.

Inasmuch as several Blackhawk point bars are the same dimensions and sediment type as those in the Ferron, they probably were deposited by a river with similar proportions to those of the Ferron River. It should be noted, however, that most of the Blackhawk point bars referred to in the sections in Salina and Straight Canyons are much thinner (than those in the Ferron), probably representing many individual channels developed in the wide meander belt up stream from the delta or at least further up stream on the delta plain than the channels of the Ferron where studied by Cotter.

Cotter's calculations of river flow are also significant in climatic interpretations. Since he indicated both annual river discharge and drainage area, an approximate annual precipitation can be calculated. If the river discharged 6,500 cubic feet (184 kl) per second for 11 months and flooded 22,000 cubic feet (623 kl) per second for one month each year, which is about the average flooding period for most rivers (Chebotorev, 1962), then 2.45×10^{11} cubic feet (6.9×10^{9} kl) of water was discharged by the river annually. This is equivalent to 15 inches (38 cm) of runoff from the total drainage area (see calculations, Appendix III). Since water runoff in low-elevation, humid, forested areas of the world today is roughly 20% of the total precipitation (Morisawa, 1968), then the precipitation might have been about 75 inches (190 cm) annually. However, a factor that undoubtedly influences the accuracy of this calculation is the difference in vegetative cover in Cretaceous and modern forests. As pointed out earlier, the Cretaceous soil apparently lacked much herbaceous covering, particularly grasses. As a result, more water would be expected to run down-slope to streams as it does in modern experimental plots which are barren of plant cover (Sokolovskii, 1971). If this runoff were as high as 25 to 30% of the total precipitation for Cretaceous forests, rainfall would have been roughly 50 to 65 inches (127 to 165 cm) annually, and this may be a more realistic estimate.

Cotter (1971) advised caution in the use of his paleoflow data because of many untested generalizations, but it is intriguing to attempt to use such information that has resulted in an approximation of annual precipitation which is generally consistent with the climatic factors determined from other types of evidence within the period when this flora was extant.

Schumm (1968) suggests that before soil stabilization by modern vegetation (presumably grasses and herbaceous dicots), the hydrologic situation in ancient valleys resembled that of modern semiarid regions. Thus it is possible that the paleoflow relations in humid regions in late Cretaceous time were relatively closer to those of semiarid and subhumid climatic areas where runoff is often less than 5% of the total precipitation (Morisawa, 1968). This may well have been the situation in the piedmont and western (upper) coastal plains of the Blackhawk River drainage areas but probably was not the case on the lower floodplain. Sokolovskii (1971) indicated that calculations of annual precipitation using modern river runoff data are not consistently reliable. However, he was attempting to develop equations which correlate, within a few millimeters, modern precipitation and runoff, whereas a more generalized statement of paleoprecipitation is satisfactory in this study.

The Periodicity of Flooding

Wolman and Leopold (1951) examined flooding records of 37 rivers of various sizes in the United States and India. For 26 of these rivers, those which had formed a well-defined flood plain, the recurrence interval of overbank flooding was 1.6 years. The other rivers often had much longer intervals between flooding which varied from 2 to 200 years. However, some of these were identified as "mountain torrents" in northwest Wyoming and their floodplains were difficult to define.

In more recent work, Leopold, Wolman and Miller (1964) indicate that river flooding on a world-wide basis occurs at an average interval of 2.33 years. Therefore, it seems clear that flooding and resulting overbank deposition is a characteristic feature of all existing rivers and must have been a near-annual feature of Blackhawk rivers also.

This regular flooding allowed overbank sedimentation and subsequent leaf burial so important to this study.

THE COASTAL NON-FLUVIAL SWAMPS

A small florule of about 75 fossil plant specimens has recently been collected at a single site by J. K. Balsley in what he identified as deltaic sediment between the Castlegate A and B coal beds of the Aberdeen Member in Price Canyon. It is composed of several species of dicotyledons and one conifer. My preliminary examination suggests that it appears to be dominated by the large peltate leaves of *Manihotites georgiana* and the leafy twigs of the conifer *Moriconia cyclotoxon*, with several unidentified dicotyledons as apparent subordinates. The abundance of both *Manihotites georgiana* and *Moriconia cyclotoxon* and their well-preserved condition suggest that they had not been transported, but were probably members of the local deltaic plant community.

This florule, although small, is unique since *Manihotites georgiana* and *Moriconia cyclotoxon* did not occur together in any of the fluvial swamps or bottomland communities (see Table 1) and the subordinate plants are species which are apparently not even present (or at least are not common) in the floodplain communities. In addition, no fluvial swamp dominant plant is present such as *Sequoia cuneata* or *Rhamnites eminens*, nor are any other conifers although they were in great abundance in the fluvial swamps. Therefore, based upon the flora of this single site, it appears that there is a major floristic difference between the plant communities on the Blackhawk floodplain and the Blackhawk delta.

These deltaic plants probably are among those which contributed to the great amount of peat which accumulated at times to make the economically important coals of the lower and eastern portions of the Blackhawk Formation. Some of these coals are greater than 15 feet (3 m) in thickness (Doelling, 1972) and therefore represent great amounts of time.

In a petrographic analysis of the sunnyside coals, Thiessen and Sprunk (1937) reported that the coal was partly made up of the wood, leaves, and seeds of coniferous plants. The fact that *Moriconia cyclotoxon* has been found to be an apparent member of the deltaic community suggests that it was one of these coniferous plants. Recently, Maberry (1971) indicates that this coal was chiefly composed of plant debris including abundant spores, pollen and waxes, rather than a great amount of woody material.

Because modern deltaic environments are commonly brackish or are at times brackish, it may be assumed that the Blackhawk deltas were also occasionally saline. This may have been the factor which limited or restricted the fluvial swamp communities and kept them from inhabiting the delta. Modern cypress-tupelo forests can survive mildly brackish water, but are killed when the salinity reaches 0.6% (Penfound, 1952). Interestingly, when recent cypress-tupelo forests are killed with brackish water, they are usually replaced by grasses or other monocots which eventually form a marsh (Penfound, 1952), unlike the apparent woody plant community which existed on the Blackhawk delta.

In the discussion of both *Manihotites georgiana* and *Moriconia cyclotoxon* in the fluvial floodplain swamps and bottomlands above, it was assumed that these plants were subordinate members of these communities. However, because they are now known to have existed on the delta, the specimens collected in floodplain communities may represent infrequent invaders from a larger population on the adjacent delta.

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PALEOCLIMATIC INTERPRETATION

Fossil Leaf Physiognomy

Bailey and Sinnott (1915, 1916) and Sinnott and Bailey (1916) recognized that a rough estimate of paleoclimate might be determined by assuming that fossil dicotyledon leaves which exhibit certain morphological features probably existed in past climates similar to those in which modern dicotyledons with the same leaf features live. Preliminary data was collected by them which indicated that leaves of many woody dicotyledons have entire margins in tropical, artic and xeric regions, while taxa in temperate regions have a high proportion of leaves which are non-entire. Leaf margins and other aspects of foliar physiognomy have been used by several workers in the examination of Cretaceous and Tertiary paleoclimates. These include Bailey and Sinnott, 1915; Endo, 1934; Chaney and Sanborn, 1933; MacGinitie, 1937, 1969; Dorf, 1938, 1942; Edwards, 1955; and Bell, 1957. Recent renewed interest in the refinement of leaf physiognomy as a tool in determining past climates has been undertaken by Wolfe (1969, 1971) and Dilcher (1973). Both authors present information indicating that the relationship between physiognomy of modern leaves and climatic zones is unquestionable, but more complicated than at first suggested.

Entire leaf margins. -- Although more investigation is necessary to determine all factors involved, Dilcher (1973) points out that a fairly direct correlation exists between climates with certain tempera

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temperature and rainfall ranges, and entire-margined dicotyledon leaves. He shows that leaves with entire margins range from 86% in tropical rain forests of Malaya to 10% in mixed northern hardwood forests of Manchuria. My own studies of the leaf margins of 84 species of woody dicotyledons in Sanford Natural Area on the Michigan State University campus in Central Michigan indicate that 15% have entire margins (see Appendix V).

After analyzing available information on temperature, rainfall and leaf margins, Dilcher (1973) wrote:

> ... the percentage of entire-margined leaves decreases as the climate cools, dries or cools and dries. In paleoclimates it is often impossible to distinguish between the part temperature and moisture played in producing types of leaf margins since both factors have similar effects. Those zones having 55-100% entire margins have either high levels of temperature and varying moisture or high levels of moisture and varying temperature. Only those zones which have both reduced levels of temperature and moisture have lower percentages, 10-50%, of entire-margined leaves.

The number of entire leaves in the Blackhawk flora are listed in Table 7 and Appendix VI, and will be discussed subsequently.

Leaf nervation, thickness, drip points, vein patterns and epidermal features. -- Observations of extant floras indicate that other features of leaf morphology probably are a response or adaptation to climate. These include leaf size, which will be discussed in detail below, leaf nervation (pinnate or palmate), leaf organization (simple or compound), mesophyll thickness, and the presence of dripping points or attenuated apicies. The proportion of these features in the Blackhawk leaves is shown in Table 7 and Appendix VI.

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It is thought that high proportions of compound leaves with pinnate nervation, thick mesophyll, and drip points are most abundant in tropical lowlands and decrease proportionately toward subtropical and temperate regions (Chaney and Sanborn, 1933; Dorf, 1942). However, little or no quantitative data of leaves in extant forests has been obtained, and until it is, the true relation of these features to climate is unknown.

Microscopic features such as the size of marginal areolae formed in the ultimate venation, number of stomata, morphology of the stomatal apparatus (e.g., the presence of cuticular lips, sunken guard cells, stomatal crypts, etc.), multiple epidermal layers, thick cuticle and the presence of numerous epidermal trichomes or scales, may also be adaptations to specific climatic factors (Esau, 1952; Dilcher, 1973). But again, no quantitative data have been collected on the relationship of microscopic leaf features and climatic factors.

Most of these features could not be observed in the Blackhawk leaves, due to the apparent lack of cuticular and cellular preservation, and therefore have not been used in climatic analysis.

Leaf-size analysis. -- Several workers have shown that the wet tropics are characterized by a high percentage of large leaves but the percentage of large leaves decreases toward cooler or drier climates (Chaney and Sanborn, 1933; Dorf, 1942; Webb, 1959; Richards, 1966). Therefore, leaf size is also, in a general way, a measure of climate. Dilcher (1973) recently has summarized most of the available information on the relationship between leaf size and climate. He says that the same

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the same problem exists in the use of leaf size classes, to determine ancient climates, as with the use of leaf margins, that is, trying to separate the influence of temperature and moisture on leaf morphology.

Raunkiaer (1934) established several leaf size classes according to surface area in his studies of modern European forests. Later Webb (1959) modified them into a more workable form for studies in the tropics. They are as follows:

Leptophyll	0.0	to	.25	cm^2
Nanophyll	0.26	to	2.25	cm^2
Microphyll	2.26	to	20.25	cm^2
Notophyll	20.26	to	45.0	cm^2
Mesophyll	45.1	to	182.25	cm^2
Macrophyll	182.26	to	1640.25	cm^2
Megaphyll	1640.26 cm^2 up			

Dilcher (1973) demonstrates quite clearly the reduction of leaves in the smaller size classes in response to reduced levels of temperature and/or moisture. He also shows a larger proportion of leaves in larger size classes as temperature and/or moisture are increased. His figure 5 (p. 31) can be used as an index of paleoclimate when leaf size classes of fossil plants are compared to it. (Note, there is an error in the caption of Dilcher's figure 5, which should read, "... the average per cent of each leaf-size class is given from <u>right</u> to <u>left</u>.")

Table 7 summarizes the percentage of Blackhawk leaves in each of the Raunkiaer leaf size classes. See also Appendix VI. No fossil leaves were found in the smallest are largest classes (leptophyll and megaphyll), therefore they have been omitted.

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Table 7. Percentages of all 82 Blackhawk species of dicotyledons showing selected aspects of physiognomy including size. (This information is taken from Appendix VI.)

Entire Margins	Pinnate Nervation	Coriaceous Texture	Drip Points
72%	78%	45%	33%

Leaf Size Classes				
Nanophyll	Microphyll	Notophyll	Mesophyll	Macrophyll
9	41 to 53	20 to 32	15 to 17	1

Problems associated with using leaf physiognomy. -- Wolfe (1971) and Dilcher (1973) have discussed several problems and inconsistencies seen in the use of certain features of leaf morphology in the determination of paleoclimates. Such factors as probable under-representation of large fossil leaves due to fragmentation before burial, possible over-representation of leaves from stream-side plants, the relationship of leaf physiognomy to high altitude temperate areas in low-latitude tropics, and variations of leaf size classes within small sampling areas of extant forests. Although certain problems might remain unsolved, both workers are convinced that leaf physiognomy is important as an independent method of determining paleoclimate. Dilcher (1973) concludes:

> As the relationships of leaf form to the physiology of the plants and the variability in climate, solar radiation, and other factors become known, foliar physiognomy will become an increasingly important tool for paleoclimatic analysis.

Application to this flora. -- The Upper Cretaceous Blackhawk flora has a fairly high proportion of leaves which have pinnate nervation, an evident coriaceous texture, and dripping points (see Table 7). Since no standards of thickness have been established, the determination of texture was arbitrarily based upon my own judgment. Similarly, any leaf which exhibited a reasonably long, acute apex was considered a drip tip. (This feature was often impossible to determine because many leaves were preserved without the apex. These plants are indicated with a question mark, Appendix VI.)

The above features all suggest that the climate was probably warm and moist. However, since none have been critically evaluated in living forests, no quantitative comparisons can be made in order to determine a more detailed description of the paleoclimate.

The Blackhawk flora is also characterized by a fairly high proportion of leaves with entire margins, 72% (Table 7). In comparison to Dilcher's latest summary of the physiognomy of leaves of living plants (Dilcher, 1973, table 1, and figure 4), floras with 72% entire leaves exist only in very warm climates which range from "warm temperate-rain", to "tropical-rain", and "tropical-seasonally dry." Included, of course, are "subtropical" climates, and probably include "subtropical-seasonally dry" although he gives no leaf margin data for this climate type (Dilcher, 1973, figure 4).

The percentages of Blackhawk leaves in various leaf size classes similarly indicate a warm climate. They most nearly approximate the leaf size classes in "subtropical-seasonally dry" climates but clearly are no

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are not like floras in any other subtropical, tropical, or warm temperate climate (Dilcher, 1973, figure 5).

As a summary of the use of leaf morphology in the determination of ancient climates, Dilcher (1973) says:

> ... none of the techniques used in this analysis are yet sufficiently developed to provide an absolute basis for an exact description of the paleoclimate. The state-of-the-art in interpretation of paleoclimates from plants fossil material is at a level to provide good approximations only, with the expectations that our ability to interpret past climates will improve as more precise data on the nature of fossil and modern vegetation becomes available.

A comparison of the physiognomy of swamp and bottomland leaves. -- Penfound (1952) indicated that certain deep swamps of the southeastern United States were characterized by woody plants with sclerophyllous leaves. Furthermore, he states that swamp forests cannot be considered normal climax communities because they are controlled by water depth rather than any climatic factors. If this is true, then the Blackhawk swamps might have had a different proportion of leaves in the several Raunkaier leaf size-classes than the bottomlands. At this time, no information is available on possible differences between leaf size classes of existing forests in swamps and adjacent bottomlands in any climatic zone.

Therefore, in order to determine differences which might exist between the fossil swamp and bottomland forests, the plants which seem to be most characteristic of these environments were identified (Table 12, Appendix IV). The total number of plants with entire margins, the leaf size classes, and other features were determined and are listed in Table 8.

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Table 8. Percentages of dicotyledon species in Blackhawk Swamp, Bottomland and Point Bar environments having the same leaf characteristics as those in Table 7.

	No. Species	Entire Margins	Pinnate Nervation	Coriaceous Texture	Drip Points
Swamp plants	60	77	78	50	37
Bottomland plants	49	67	77	51	41
Point bar plants	13	50	64	64	43

		Leaf Size Classes				
	No. Sp.	Nano-phylls	Micro-phylls	Noto-phylls	Meso-phylls	Macro-phylls
Swamp plants	60	2	43 to 58	17 to 33	17 to 23	2
Bottomland plants	49	12	33 to 47	20 to 38	14 to 18	2
Point bar plants	13	0	35	29	7	0

Rather than there being any obvious differences in the leaf physiognomy of the two environments, they are surprisingly similar. The largest differences were 10% fewer plants with entire margins and about 10 to 20% more plants with small leaves (nanophylls and microphylls) in bottomlands than in swamps. These differences are apparently not significant in the identification of ancient climates and therefore separating the Blackhawk plants into environmental groups did not aid in the climatic analysis. Even when certain plants from one habitat were eliminated because they seemed to be slightly more significant in the other habitat, all the values for entire margins and leaf size classes remained nearly the same.

This may indicate that the climate on this coastal plain during the later Cretaceous was not a significant factor operating in the control of swamp vegetation. It may have been a factor, however, in the control of the leaf morphology of the plants of the several local environments.

Climatic Requirements of Living Relatives

A few studies of Cretaceous floras have based paleoclimatic determinations upon the climates of the supposed closest living relatives of the fossil plants (Dorf, 1938, 1942; Parker, 1968). This technique assumes that the fossil plants are correctly identified and have living relatives to which they can directly be compared. However, Dilcher (1973) mentions that in the Puryear Eocene flora which he has been examining in critical detail, 60% of the fossil leaves which had been previously named had been referred to incorrect extant genera or apparently belong to taxa which are extinct. If this is true for Eocene plants in general, then it is undoubtedly also true of the older Cretaceous plants. Dilcher (1973) says, "In any floristic study in which the climatic interpretations are based mainly upon modern affinities the reliability of the interpretations depends on the accuracy of the identification."

Dilcher (1974) presents an excellent discussion of the problems involved in the identification of Cretaceous and Tertiary plants, chiefly dicotyledons. He also proposes methods for determining the true

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true identity of fossil plants chiefly through a systematic examination of leaf venation and epidermal features.

Because the generic names previously given to many of the fossil angiosperms of the Blackhawk Formation may erroneously indicate that the fossil is related to extant genera, I feel that it is inappropriate to make paleoclimatic conclusions based upon the climatic requirements of the supposed nearest living relatives. Other Cretaceous studies in which paleoclimate is determined in a similar way should be viewed with caution.

Reference has been made earlier to several plants in the environmental interpretations of swamps and bottomlands. These genera include: *Cercidiphyllum, Cissus, Cyathea, Menispermum, Metasequoia, Nymphaeites, Onoclea, Platanus, Protophyllocladus, Sequoia, Trapa.*

It is my opinion that these plants in particular, plus certain others not listed here, are identified correctly and do have affinities to extant genera.

Seasonality of the Blackhawk Climate

A single specimen of lignitized gymnosperm wood collected by me at Water Hollow Road (the "Base of Road Cut" site) and several pieces of petrified gymnosperm wood collected by others in Tommy Hollow (W. D. Tidwell, personal communication, 1970) show distinct growth rings. A. T. Cross (personal communication, 1975) indicates that vitrinized wood in the Blackhawk coals also show periodicity of growth. These Blackhawk woods were either growing in the loose alluvial soils of the upper floodplain and interfluves or on the poorly-drained or saturat

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saturated soils of the bottomland or swamps. It is conceivable that dry seasons could cause the water table on the higher ground to become low enough to allow formation of growth rings in the trees. Similarly, the water level of the swamps and the water table of the bottomlands could be lowered sufficiently for seasonal dry periods and result in differential growth of xylem. It has been established earlier that the Blackhawk swamp trees probably had very shallow but broad root systems, not deeper than 2 to 3 feet (1 m). Since water levels of existing swamps in seasonally dry regions fluctuate at least 3 feet (1 m), it is probable that the Blackhawk trees could have been affected by an annual water drop and therefore had periods of growth and dormancy. Since none of the wood was collected in place, it is possible that it originated in or nearer the mountains where a cool-warm season might be more significant in effecting growth than on the low-lying floodplain.

Leaf "mats" discussed earlier, which seem to be composed of large quantities of shed leaves, also indicate a seasonal climate.

Another study of Mesozoic sediments in the Rocky Mountain area also indicate a definitely seasonal climate. Moberly's (1960) study of the Upper Jurassic Morrison and Lower Cretaceous Cloverly Formations in Wyoming and Montana suggest that the climate was hot with a fairly high annual rainfall interrupted by brief (2 to 3 month), but pronounced, dry seasons. This interpretation is based upon numerous layers of lacustrine carbonates present in these formations. No such carbonates exist in any of the Upper Cretaceous Mesaverde formations.

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Thayne (1973) has examined three species of petrified dicotyledonous wood from the Lower Cretaceous (Aptian or Albian) Cedar Mountain Formation near Castle Dale and Ferron, Utah. Since there were no growth rings in any of the specimens and since the size of the xylem vessels was consistent throughout individual specimens, he suggested that the climate was relatively constant and probably tropical.

It appears from these studies that the climate of the late Mesozoic in the Montana-Wyoming-Utah area fluctuated from warm-seasonally dry in the late Jurassic, to a warm-nonseasonal climate in the early Cretaceous, and then back to a warm-seasonal period by the Upper Cretaceous.

Climate Suggested by Other Cretaceous Floral Studies

Based upon the physiognomy of fossil leaves collected in the Upper Cretaceous (Maestrichtian) Fox Hills, Lower Medicine Bow and Lance Formations of Wyoming and Colorado, Dorf (1938, 1942) concluded that the climate was subtropical to warm temperate. Ostrom (1964) used Dorf's studies and several other Upper Cretaceous floras in a summary of vegetation types. He concurred that the climate was most likely warm and seasonal.

By the Paleocene, Brown (1962) was of the opinion that the leaf floras he examined were controlled by a warm, temperate climate, but he accumulated no data to support this, other than the observation that a seemingly large proportion of the living correlatives of the fossil plants are restricted to warm, temperate areas today.

For comparative purposes, leaf size classes of selected Upper Cretaceous, Early Tertiary, Late Tertiary and extant floras were determi

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determined, Table 11. These compilations indicate a general decrease in leaf size from the Campanian (Late Cretaceous) to the Miocene (Late Tertiary), thus supporting the gradual cooling trend suggested by Dorf in a series of studies of paleoclimates (Dorf, 1959, 1960, 1964, 1969).

Summary of Paleoclimatic Information

Several independent methods have been used to suggest that the Blackhawk paleoclimate was warm and seasonal, most likely subtropical seasonally dry. It seems that the most significant method in the determination of the climate is the large proportion of leaves in microphyll and notophyll leaf size classes. Living floras with similar proportions of leaves in these classes occur only in subtropical, seasonally dry climates. The large number of species of plants having leaves with entire margins also suggest a very warm climate during the Campanian stage.

Several plants which probably can be considered to be living relatives of the Blackhawk plants currently live in very warm regions with seasonal changes, supporting the conclusions given above.

Differential growth in lignified, coalified, and petrified Blackhawk woods are undoubtedly annual growth rings which indicate a definite seasonality to the climate, unlike trees which live in tropical moist climates today which generally show no growth rings. Accumulations of apparent seasonally-shed leaves as "mats" also imply seasonal changes of temperature, moisture or both.

As indicated earlier in the discussion of the Blackhawk river system, p. 121, the average annual local rainfall may have been from

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50 to 65 inches (1650 to 1900 mm) in order to form the fluvial sedimentary features which can be seen in the Ferron Sandstone Formation and the Blackhawk Formation. Although all of the factors necessary have not been determined to calculate more accurately the rainfall by the nature of fluvial sedimentary features (i.e., amount of runoff, evapo-transpiration, etc.) it is interesting that such evidence has been compiled which completely supports that given above from analysis of fossil plant remains for estimating some of the principal climatic features of the Upper Cretaceous in this area.

It should be emphasized that the studies of the Blackhawk flora confirm and supplement those paleoclimatic examinations which have been made by Dorf (1959, 1960, 1964, 1969), Wolfe and Hopkins (1967), Axelrod and Bailey (1969) and Wolfe (1971).

Table 9. A comparison of percentages of leaves in the leaf size classes of selected Cretaceous, Tertiary and extant floras. All measurements were made by the author from published photographs except those of the late Tertiary floras which were measured by Ralph E. Taggart.

FLORAS (References cited)	Number of Species	Percentage of Leaves in Size Classes				
		Leptophyll and Nanophyll	Microphyll	Notophyll	Mesophyll	Macrophyll and Megaphyll
Cretaceous Floras						
Blackhawk (this report)	82	9	41 to 53	20 to 32	15 to 17	1
Fox Hills, etc. (Dorf, 1938)	47	2	28	53	15	2
Lance (Dorf, 1942)	40	3	60	25	13	0
Denver (Knowlton, 1930)	72	0	50	31	18	1
Early Tertiary Floras						
Dawson (Knowlton, 1930)	72	3	35	36	26	0
Goshen (Chaney & Sanborn, 1933)	52	0	27	48	25	0
Green River (MacGinitie, 1969)	66	12	71	12	5	0
Late Tertiary Floras						
Mascal (Chaney & Axelrod, 1959)	?	0	55	40	5	0
Blue Mountain (Chaney & Axelrod, 1959)	?	3	45	47	5	0
Stinking Water (Chaney & Axelrod, 1959)	?	3	71	22	4	0
Sucker Creek (Chaney & Axelrod, 1959)	?	4	56	40	0	0
Extant Floras						
Central Michigan (See Appendix V)	84	4	31	33	31	0
Northern Puerto Rico (Little & Wadsworth, 1964)	46	0	28	41	22	9

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SYSTEMATIC PALEOBOTANY

Description and a discussion of each of the ecologically important non-angiospermous plants follows. They are grouped in alphabetical order within the broad categories of ferns and gymnosperms.

The systematics of the Cretaceous and early Tertiary angiospermous plants has been recently reevaluated (Dilcher, 1974). In the past nearly 150 years, most fossil angiosperms, particularly dicotyledons, have been referred either directly or indirectly, to extant genera. But as Dilcher (1973, 1974) has shown, several other extant taxa might just as well have been chosen for reference to the fossils. For example, in the Eocene, Puryear, Tennessee flora described by Berry (1916a, 1924, 1930b, 1941) a majority of the dicotyledons have been given modern generic names or are described as being probably related or at least similar. Dilcher (1974) now has evidence that at least 60% of these generic names have been incorrectly applied to the fossils. If this is true for the Eocene, then it must be true for the much older Upper Cretaceous floras. To compound the problem, leaf morphology of extant plants, including secondary, tertiary, and fine venation and epidermal cells, is only now being studied in a way which would allow the discovery of probable consistent patterns within groups such as families or genera (Dilcher, 1974; Hickey, 1973). Therefore, at the present time, and until much more work is done with living plant leaves, further comparison of fossil dicotyledons to extant genera seems futile.

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Because of the unsettled condition of the systematic position and nomenclature of fossil angiosperm leaves, they have been omitted from the descriptions of the fossil plants here, with the exception of the palm, *Geonomites imperialis*.

Asplenium dicksonianum Heer

(Plate 3, Figure 2)

Asplenium dicksonianum, Newberry, 1895, p. 39, pl. 1, figs. 6, 7; pl. 2, figs. 1-8; pl. 3, fig. 3.

Description of the Blackhawk specimens:

Several poorly preserved fragments of this fern were collected at the Water Hollow site, 8/24/70. The incomplete pinnules vary from 1 cm long and 0.3 cm wide to 4 cm long and 1 cm wide. Total size and shape of the complete fronds is unknown. The ultimate pinnules are lanceolate and attached to a thin, foliate rachis. The margin is entire to shallowly lobed and appears to be thickened or perhaps slightly revolute at the margin. A single midvein can be seen in each ultimate pinnule, but secondary venation is entirely obscure. The foliage of this plant seems to have been somewhat thin but coriaceous and heavily cutinized. Newberry (1895, p. 40) used the term "polished" to describe the leaf surface, indicating its thick cuticle. No cuticle with epidermal cell impressions could be obtained from the Blackhawk fossils.

Because of its obscure venation and lack of color contrast with the rock matrix this specimen was difficult to photograph. Thus the drawing was prepared. As shown, there are few features to characterize the plant. Therefore, its relationship to other Cretaceous ferns and in the l

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to the living species of *Asplenium* may be questioned. Fern fragments similar to these were collected in abundance in the Amboy Clays of Woodbridge, New Jersey (Newberry, 1895).

Asplenium dicksonianum was a member of the swamp plant community and, as explained earlier, seems to have been an epiphyte on the conifer *Sequoia cuneata*.

Cyathea pinnata (MacGinitie) LaMotte

(Plate 3, Figure 1)

Cyathea pinnata, LaMotte, 1952, p. 140; Pabst, 1968, p. 36, pl. 2, 3, 4, 5.

Hemitelia pinnata, MacGinitie, 1941, p. 97, pl. 10, fig. 1.

Description of the Blackhawk specimens:

Complete fronds of this fern have not been collected in Blackhawk sediments but fragments consist of an unbranched axis 3 to 7 cm long. These axes are most likely the secondary or tertiary pinnules of a much larger frond. They are covered with small, alternate or opposite, ultimate pinnules, 0.7 to 1.7 cm in length which vary in shape from deltoid to linear. All are inclined or curved such that their apices point to the anterior (proximal) end of the axis to which they are attached. A few pinnules are narrowly attached to the rachis but most are broadly attached (decurrent) and some are even joined to one another at their bases because of an incomplete cleft between pinnules. The apex of most pinnules is acute, but a few are rounded. The venation in the ultimate pinnules consists of a central midrib which extends nearly to the apex. The open, dichotomous secondary veins diverge from the

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from the midrib at an acute angle and curve toward the margins. They are not decurrent. Some veins are unbranched, others are once-branched, and a few are twice-branched; none have three orders of branching. These veins do not anastomose. A few veins in the base of some of the ultimate pinnules arise directly from the main rachis rather than from the midrib of the pinnules.

Fertile specimens have not been collected in the Blackhawk Formation.

This Cretaceous collection apparently represents the earliest occurrence of this plant, but it seems indistinguishable from Tertiary specimens found in the middle Eocene Ione Formation (?) (MacGinitie, 1941), and the Paleocene Chuckanut Formation (Pabst, 1968). It is also much like *Cladophlebis fisheri* collected in the Lower Cretaceous Kootanie Series (Knowlton, 1907).

This fossil species is thought to be related to species in the extant genus of "tree ferns", *Cyathea*. This plant was discussed as an apparent member of the herbaceous understory of a Blackhawk swamp.

Onoclea hebridica (?) (Forbes) Bell

(Plate 4, Figures 1, 2)

Onoclea hebridica, Bell, 1949, p. 40, pl. 20, fig. 5; pl. 24, fig. 3, 5; pl. 25, fig. 2.

Description of the Blackhawk specimens:

Fragments of this species consist of small axes 4 to 10 cm long, probably 15 cm or more long when complete, with opposite or alternate ultimate pinnules. They are obovate to spatulate in outline and appear to be the complete frond of this species. The ultimate pinnules are linear to ovate with margins which are broadly crenate to coarsely serrate. Venation consists of a broad, 2 mm wide, midvein in both the main and secondary axes which is characterized by a parallel striation on either side. In some specimens it appears that these lateral and parallel striations are secondary veins while in other specimens they look like ridges or channels in the mesophyll. All the major midribs in the pinnules including those which extend into some of the lobes of the ultimate pinnules have these striations. The fine venation is evident in only one specimen, but it is apparent that the veins branch and anastomose, forming numerous, small aerola, about 2 mm long and 0.5 mm wide, before they reach the margin.

Fertile fronds have not been collected in the Blackhawk Formation.

This fern seems to range into the Paleocene where it has been collected by Bell (1949). He considered his species to be conspecific with those of *Onoclea sensibilis fossilis* collected by Newberry (1898) in the Fort Union Formation. Newberry considered his specimens to be very much like the living sensitive fern *O. sensibilis* but the diagnostic fertile fronds of this fossil plant have not yet been collected.

Two small fragments of a fern of similar appearance, *Woodwardia crenata* have been collected by Knowlton (1900) (1917) and Dorf (1942) in Cretaceous sediments. However, all fragments are too small to characterize or to compare adequately with the Blackhawk specimens.

In the Blackhawk Formation, this species was collected chiefly in swamp sediments. At one locality, 7/11/70 II, it was found preserved

in growth position, apparently buried as it grew on the surface of peaty swamp soil.

Osmunda hollicki Knowlton

(Plate 3, Figure 6)

Osmunda hollicki, Knowlton, 1917, p. 246, p. 30, fig. 6.

Sphenopteris hollicki, Bell, 1957, p. 23, pl. 4, figs. 1, 5.

Description of the Blackhawk specimens:

Complete fronds of this fern have not been reported in any Cretaceous flora, but the Blackhawk specimens indicate that they were bipinnate, probably broadly ovate in shape, 3 dm or more in length and 1.5 dm broad. Apparently, only the apical portions of the compound fronds have been collected during this study, but these specimens indicate that there were at least 3 secondary and probably 5 to 7 secondary pinna on the complete frond. These pinna (which are that portion of the plant most often collected) are borne suboppositely along the main rachis and are in turn divided into 8 to 15 ultimate pinnules. The ultimate pinnules are lanceolate to oblong in shape and range from 1 to 3 cm long. They are borne alternately along the secondary rachis. Margins of the ultimate pinnules are deeply lobed near the base, undulate in the mid portion and entire near the apex. The apex is rounded. The open, dichotomous venation of the ultimate pinnules consists of a distinct midvein which extends to near the apex, and secondary veins which diverge from the midvein at an acute angle. They are slightly decurrent to the midvein. The secondary veins are typically forked 1 to 4 times as they extend to the margin.

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They do not anastomose. No fertile fronds have been collected in the Blackhawk or other formations.

Bell, 1957, says specimens collected from Vancouver Island are undoubtedly the same species that Knowlton (1917b) collected from Colorado and New Mexico, but places them in the form genus *Sphenopteris*. Because he gives no justification for this and because illustrations of his specimens do not show critical details, it is best to leave the systematics of this plant as Knowlton established them. The Blackhawk specimens are apparently only the third collection of this species reported to date. It ranges from the Campanian to the Maestrichtian.

As indicated earlier in this report, *Osmunda hollicki* seemed to prefer bottomland habitats where it apparently made up most of the herbaceous understory. Chaney (1925) infers that any fern foliage which is commonly found as fossils probably was very abundant in the living forest.

Unknown Fern 1

(Plate 3, Figures 3,4,5)

Description of the Blackhawk specimens:

The specimens collected in the Blackhawk Formation consist of three equal sized pinnules attached in palmate, trifoliate organization to the end of a 2 cm long rachis. Five specimens clearly show this unusual type of pinnule arrangement, suggesting that it is not the transport-damaged condition of a single specimen, but was the actual organization of at least a portion of the frond. Individual pinnules range

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range in size from 1.5 to 3.5 cm in length and from 1.3 to 1.8 cm wide. They are oval to slightly ovate in shape with obtuse bases and broadly rounded apicies. The margin is entire to slightly undulate and is marked by a distinct, dark, vein-like line which could be the remains of a marginal vein, marginal sclerenchyma tissue, a slightly revolute margin or immature marginal sporangia. The midvein is distinct and extends nearly to the apex of the pinnule. Secondary veins are not decurrent to the midvein, but diverge at an acute angle and run parallel to one another to the margins. They are open and dichotomous, branching at least once, typically near the midvein, but commonly branching again midway or near the margin.

Discussion:

Associated with all the trifoliate specimens and many isolated pinnules is a thin, longitudinally striated stem, 1.5 to 3 mm wide. In three of the complete specimens it passes directly through or near the axis of the trifoliate organization. Because no other plant remains are directly associated with these fern fronds, and because of the interesting symmetry of these stems to the pinnules, this may have been the main rachis of a much larger compound leaf or it may have been the thin stem of a climbing fern.

This fern is very similar to two other Cretaceous ferns previously described, *Asplenium occidentale* (Knowlton, 1917b, p. 84, pl. 31, figs. 2-5; Brown, 1933, p. 3, pl. 1, fig. 5) and *Pteris*? sp. (Knowlton, 1917a, p. 245, pl. 30, fig. 3). It is similar to several species of the living genus *Pellea*, which have marginal sporangia. It also bears a superficial resemblance to certain large-leafed clover species, particularly *Trifolium amoenum*, *T. flavulum* and *T. repens*.

This species seems to have been restricted to bottomland environments where it was part of the herbaceous understory.

Araucarites sp.

(Plate 4, Figures 4 to 8)

Araucarites, Presl. 1838, p. 204 (in Sternberg, 1838)

Description of the Blackhawk specimens:

Many leafy twigs of this plant have been collected in sandy, apparently point bar sediment, at 3 localities. These specimens have been preserved as casts of the stems and leaves, often with a carbonaceous residue remaining inside. Most are the apical areas of thin twigs, 1 to 3 mm in diameter, but a few are of older, thicker stems, 2 cm wide. All specimens are fairly short, the longest being 11 cm, and none are branched. Leaves are narrowly awl-shaped, 1.5 to 2 cm long, and recurved toward the stem apex. All have an accuminate apex and a slightly expanded base, 1 to 2 mm broad. Some leaves, particularly on older, larger twigs are slightly decurrent. The leaves remain attached even as the stem increases in circumference, but the leaves do not increase much in lateral dimension, as do those in certain living evergreen conifers. This has the effect of moving individual leaves apart from one another or making them less dense on older twigs. Stomatal bands, other epidermal features and venation have not been preserved.

In some specimens the rock matrix has broken at right angles to an embedded twig revealing the appearance of the twigs in cross section. In all cases, the leaves are equally distributed around the circumference of the twig in a "bottle-brush" fashion. It seems possible to imbed and cut one of these specimens in serial section and thus determine its phyllotaxy. This has not yet been done.

Several rhombohedral to triangular shaped cone scales, similar to those Dorf (1942) considered to have belonged to foliage he called *Araucarites longifolia*, were collected in the Blackhawk Formation. However, since none of the specimens were collected in association with the foliage, and since all scales were collected in several swamp, rather than point bar localities, it is unreasonable to believe they are part of the same plant.

Although I consider the Blackhawk species to be much like the foliage of extant species of the genus *Araucaria*, there is no other basis for believing it to be related. Several plants have similar foliage including species in the extant genera *Cryptomeria*, *Cunninghamia*, *Dammara*, *Glyptostrobus*, *Juniperus*, and *Sequoiadendron*, plus extinct species in the genera *Cunninghamites*, *Elatides*, *Geinitzia*, and *Sequoia*. Perhaps with more efforts directed toward the determination of phylotaxy and epidermal features, a better estimate of its true relationship to living plants can be made.

Many other large Upper Cretaceous floras illustrate foliage which is similar in appearance. However, there remains a considerable amount of confusion in the nomenclature and systematics of this foliage even though the first specimens were collected more than a century ago.

Some of the plants which look very similar to the Blackhawk are the following:

Araucarites longifolia (Bell, 1965, p. 24, pl. 11, fig. 8)

Dammara sp. (Knowlton, 1922, p. 114, pl. 2, fig. 4)

Elatocladus albertaensis (Bell, 1965, p. 16, pl. 7, fig. 4)

Geinitzia formosa (Newberry, 1895, p. 51, pl. 9, fig. 9; Knowlton, 1900, p. 28, pl. 5, figs. 1, 2; Knowlton, 1917b, p. 251, pl. 31, figs. 1-3; Bell, 1965, p. 14, pl. 6, fig. 5)

Sequoia acuminata (Lesquereux, 1878, p. 80, pl. 7, figs. 15-16a; Knowlton, 1922, p. 114, pl. 2, figs. 7-8)

Sequoia biformis (Ward, 1885, pl. 31, figs. 7, 8)

Sequoia longifolia (Lesquereux, 1878, p. 79, pl. 7, figs. 14, 14a; pl. 61, figs. 28, 29)

Sequoia reichenbachi (Berry, 1903, p. 59, pl. 48, figs. 14, 20; Hollick, 1906, p. 42, pl. 3, figs. 4, 5)

The Blackhawk specimens have leaves which are generally shorter and much thinner than the variable-sized leaves of:

Araucarites longifolia (Dorf, 1942, p. 130, pl. 4, figs. 9, 12, 13; pl. 5, figs. 1-6)

Cunninghamites ? sp. (Knowlton, 1900, p. 29, pl. 5, fig. 3)

Sequoia longifolia (Knowlton, 1922, p. 115, pl. 3, fig. 3; pl. 4, fig. 2)

Elatocladus was proposed as a comprehensive form genus for sterile coniferous shoots that cannot otherwise satisfactorily be assigned to other groups of plants or when it is undesirable to imply relationship to other plants (Arnold, 1942). It may be best to eventually include the Blackhawk araucarites-like foliage in this form genus, as Bell (1965) has done.

This plant may have been a member of the piedmont community above the Blackhawk floodplain.

Brachyphyllum macrocarpum Newberry

(Plate 4, Figure 9; Plate 5, Figure 1)

Brachyphyllum crassicaule, Fontaine, 1889, p. 211, pl. 100, fig. 4; pl. 109, fig. 1-7; pl. 110, figs. 1-3; pl. 111, figs. 6, 7; pl. 112, figs. 6-8; pl. 158, fig. 9; Brown, 1950, p. 50, pl. 9, fig. 5, 6.

Brachyphyllum crassum, Lesquereux, 1892, p. 32, pl. 2, fig. 5; Newberry, 1896, p. 51 (see his footnote), pl. 7, figs. 1,2,5,7.

Brachyphyllum macrocarpum, Newberry, 1895, p. 51, pl. figs. 1-7; Knowlton, 1900, p. 29, pl. 4, figs. 5, 6; Hollick, 1904, p. 406, pl. 70, figs. 4, 5; Berry, 1905, p. 44, pl. 2, fig. 9; Berry, 1906, p. 168, pl. 9; Hollick, 1906, p. 44, pl. 3, figs. 9, 10; Hollick & Jeffrey, 1906, p. 200; Berry, 1910, p. 420; Berry, 1910, p. 183; Berry, 1912, p. 392, pl. 30; Berry, 1912, p. 106; Berry, 1914, p. 106; Berry, 1914, p. 21, pl. 3, fig. 2; Knowlton, 1917b, p. 249, pl. 31, fig. 4; Berry, 1919, p. 59, pl. 5, fig. 9; Berry, 1922, p. 160, pl. 36, fig. 1; MacNeal, 1958, p. 54.

Thuites crassus, Lesquereux, 1883, p. 32.

Description of the Blackhawk specimens:

The Blackhawk specimens are composed of the leafy, much-branched portions of woody stems. They vary in width from 2.3 cm to about 0.3 to 0.5 cm in the youngest branches. The youngest branches range from 1 to 4 cm in length. All branches are subopposite and distichously arranged. The ultimate branchlets were apparently pendulous and flattened, forming frond-like horizontal sprays. The largest axis collected is 19 cm long, 15 cm wide, has 4 orders of branching, and at least 10 flat sprays or branchlets. It was used as the basis for the reconstruction. The accuracy of the reconstruction was improved by examining all 155 Blackhawk specimens and included aspects of stem size, branching pattern, branch shape, number of branches, leaf size, leaf shape and leaf markings. Not indicated in the reconstruction is the range in size of the lateral branchlets, representing the latest season's growth. One such specimen, with only 1 order of branching, was 18 cm in length and 3.5 cm in width, about twice the size of those illustrated in the reconstruction.

The stems are covered with spirally arranged scale-like, rhomboidal leaves which range in width from less than 1 mm on the youngest stems to about 5.5 mm on the oldest. They are appressed to the stem along the whole adaxial surface. On older leaves there are numerous thin ridges which radiate from the apex toward the base. Most leaves have small, 0.01 mm diameter, irregularly spaced glands near the base. Stomatal bands or other epidermal features could not be determined.

No cones or other reproductive structures of this plant were collected in the Blackhawk Formation.

Many Blackhawk specimens exhibited an interesting transition from the typically poorly preserved youngest branches with obscure or indistinct leaf patterns to the better preserved lower or older portions where the leaves were very well defined. Almost all the above listed workers either comment on the poor preservation of the ultimate branches of their specimens, or illustrate this with drawings or photographs. A reasonable explanation of this observation is that the living plant produced succulent or very soft branch and leaf tissue the first year, but as the branches aged and thus increased in girth, the leaves also grew in width and breadth producing much more sclerenchymous tissue. This is not unusual and can be observed in existing genera such as *Cupressus*, *Juniperus*, *Sequoiadendron*, and others. This development of leaf and stem hardness is probably also related to the growth and branching pattern of the plant. After examining many specimens, it appears that the youngest stems have a determinate growth pattern which allows them to reach a limited size with a certain number of leaves. These branches remain small (1-2 cm in length) the first season but begin increasing in length and diameter the second or perhaps third season when they also produce lateral stems. This explains the difference in the size of the leaves and stems and is in keeping with the typical long shoot-spur shoot growth pattern of many living conifers.

Brachyphyllum is chiefly a genus of Jurassic and Lower Cretaceous plants although several Upper Cretaceous species have been described. However, methods for distinguishing them have not been clearly established (Brown, 1950). *B. macrocarpum* seems to be the only species remaining through the Santonian and Campanian, and it seems to have become extinct in the Maestrichtian.

Plants in the genus *Brachyphyllum* are known to have been among those which produced the common Mesozoic pollen genus *Classopollis* spp., although gymnosperms of other types were also probably involved (Chaloner, 1969).

The numerous species of this plant have not been critically examined since Berry's (1911, 1914) work 50 years ago. This genus could be reexamined with recent knowledge of new collections, the stratigraphic and geographic range of the apparent palynomorphs, its Mesozoic origin and distribution as it was affected by continental movements and its ecological requirements examined in this report. No anatomical studies have been done on petrifactions of wood or cones since near the turn of the century (Hollick and Jeffery, 1906; Jeffery, 1906) and these studies might also need reevaluation or commentary.

The Blackhawk specimens were restricted to swampy environments, where apparent clusters of trees were only of local importance. It is thought that these swamps were entirely fluvial floodplain in origin, some distance from the coastal strand. One small florule collected in probable brackish water sediments on the delta had no specimens of *Brachyphyllum*, suggesting that it was restricted by brackish water. All other North American collections in which it is possible to determine rock matrix type indicate that this species was collected in clay (Newberry, 1896; Hollick, 1906; Berry, 1914a, 1914b) or black clay (Brown, 1950) also suggesting swampy or quiet-water environments.

Wieland (1916) misidentified several specimens of a Jurassic (Liassic) species of *Brachyphyllum* in Mexico when he considered several leafy twigs to be the remains of a cycad *Williamsonia* sp. He apparently thought that the rhomboidal leaves were leaf base scars of the much larger compound cycad leaves which were found in associated rocks. However, these specimens seem to be unquestionable branching stems of a species much like those of *B. macrocarpum*, including such features as leaf size, arrangement, and vertical striations (Wieland, 1916, pl. 4, fig. 1; pl. 33, figs. 1, 2, 4; pl. 34, figs. 1-5; pl. 35, figs. 1-3; pl. 36, fig. 4 in part).

Moriconia cyclotoxon Debey and Ettingshausen

(Plate 6, Figures 3,4; Plate 7, Figure 1)

Moriconia cyclotoxon, Debey and Ettingshausen, 1859, p. 59, 64, pl. 7, figs. 23-27; Heer, 1882, p. 49, pl. 33, figs. 1-9b; Heer, 1883, p. 53, fig. 10; Newberry, 1895, p. 55, pl. 10, figs. 11-22; Hollick, 1898, p. 57, pl. 3, fig. 10; Hollick, 1907, p. 46, pl. 3, figs. 16, 17; Berry, 1903, p. 65, pl. 48, figs. 1-4; Berry, 1911, p. 86, pl. 8, figs. 3-6; Berry, 1925, p. 30, pl. 3, figs. 1, 2

Pecopteris kudlisentensis, Heer, 1874, p. 97, pl. 26, fig. 18.

Description of the Blackhawk specimens:

The specimens of this plant are leaf covered, decussate, branchlets which formed flattened sprays similar to those of several extant species in the family Cupressaceae, particularly *Libocedrus* spp. They consist of a flattened central axis with numerous decussate secondary or ultimate branches. The outline of the entire branchlet is distinctly wedge shaped, widest at the base and tapering toward the apex. They range in size from specimens 1-2 cm wide and 6 cm long to those which are 4 cm wide and 20 cm long. The apex of most branchlets is acuminate, the base being acute to obtuse and typically forming a thin, flattened petiole-like structure 3 mm wide and 5 mm long. The secondary or ultimate branches are 1 to 3 cm in length, lanceolate in shape with an acute to round apex, broadly attached to the main axis at the base. All are inclined at about a 45° angle toward the apex.

The leaves are scale-like and closely appressed to the stems. Two kinds are evident, those which occur over the midrib areas of the main axis and ultimate branches. These are dorsal-ventrally flattened, have broadly attached bases and broad, semicircular apicies. Most of them are slightly keeled. The second type of leaves occur lateral to the first, in opposite pairs on the margins of the main and ultimate branches. They are narrower than the other leaves and are compressed transversely (or laterally) over the edges of the main and secondary stems. They have acute apicies but broad bases. Ultimate branches arise in axes of the lateral leaves on the main stem. Both types of leaves become smaller toward the apex of the branches. These branchlets appear to have been deciduous units. This possibility has been mentioned by Berry (1914). The main vascular strand is 1-2 mm wide at the base. In some specimens a vein can be seen to diverge from the main strand and enter an ultimate branch. Leaves show no veins.

A single Blackhawk specimen is apparently a fertile branch, with a small single staminate strobilus sunken in the acute apex of the ultimate branches. These are carbonized and spherical in shape, 0.5 to 0.75 mm in diameter. No structure or organization was preserved such as scales, bracts or sporangia. Significantly these are the first strobili described (Berry, 1925). They are very similar in size, shape and position to the stament strobili of certain members of the family Cupressaceae, and support the proposal that *Moriconia* was a member of that family (Berry, 1925).

A single strobulus was carefully chipped from the rock matrix in which it was imbedded and macerated in standard polynologic methods for analysis of fossil polynomorphs (Cross, 1968). It was hoped that possible *Moriconia* pollen could be isolated and thus characterized, but the strobili yielded numerous trilete spores and angiosperm pollen grains. Apparently all the pollen the plant produced had been shed, leaving an empty cone as a potential trap for wind blown polynomorphs of other types. Cross (personal communication, 1973) said that entrapment of foreign pollen and spores in empty cones and anthers is fairly common in extant plants.

In general outline the flattened sprays of *Moriconia* spp. have the appearance of a once-pinnate fern frond with narrow, pointed pinna. The first European and Greenland specimens were considered ferns of the genus *Pecopteris* and it was not known to be a coniferophyte until much later (Berry, 1925).

Berry (1925) has discussed the stratigraphic and geographic distribution of *Moriconia* spp. At that time he considered it one of the "most characteristic fossil plants" in stratigraphic determinations of strata of Cenomanian to Santonian age. The Blackhawk specimens therefore increase the geologic range into the Campanian and the distribution into Western North America.

Two species of *Moriconia* have been previously described, *M. cyclotoxon* and *M. americana*. Berry, 1925, says that they are probably the same biological species but because *M. americana* differs in size and stratigraphic distribution, he suggests that they remain as separate forms. References to this second species are: Berry, 1910, p. 20, 186; Berry, 1914, p. 26, pl. 7, figs. 1-4; Berry, 1916, p. 802, pl. 56, fig. 1; Berry, 1925, p. 31, pl. 3, figs. 3, 4.

Moriconia cyclotoxon seems to have been a common plant of the floodplain and brackish delta swamps of the Blackhawk coastal strand. Other specimens of the genus were also collected in swamp or coastal strand sediments (Berry, 1914, 1925) and suggest that this plant was a consistent member of fresh water and brackish water swamp communities.

Nageiopsis sp.

(Plate 6, Figures 1,2,5,8)

Nageiopsis, Fontaine, 1889, p. 194.

Description of the Blackhawk specimens:

Thirteen leafy twigs and more than 1,000 isolated leaves of an apparently new species of *Nageiopsis* were collected at site 8/19/70 at Pipe Springs. Individual leaves are typically cuneate, but range from suborbicular to lanceolate in shape. They also vary in size from leaves 5 mm long and 4 mm wide to 24 mm long and 6 mm wide. The apex of all specimens is acute and the base is always round. Margins are entire. Venation consists of 10 unbranching, parallel veins of equal thickness which diverge at the base and converge at the apex. No major midvein is present. All leaves were thin, but seem to have been sclerified or rigid. Attachment to the twigs is distichous and opposite, by a short, decurrent petiole up to 1.5 mm long. Leaves occur only on ultimate twigs which appear to be the latest season's growth. Older stems have no leaves, suggesting, with the abundance of isolated leaves in the sediment, that the plant was annually deciduous. Ultimate twigs, which are up to 7 cm long, thin and uncurving, and have the appearance of also being erect. Branches also arise in opposite, distichous pairs. A single specimen exhibits 3 orders of branching, while the other twigs show only 2 orders of branching or were ultimate twigs. Twigs typically exhibit leaf scars consisting of the decurrent petiole bases; these scars are less evident on the larger twigs.

One twig 5 mm in diameter was collected. Although the Blackhawk specimens represent only the terminal branches of the plant, the short ultimate branches and the opposite or often dichotomous branching pattern suggest that the entire plant was probably shrub-like in appearance. Because all the specimens of *Nageiopsis* sp. were collected within a 10 cm thick horizon in a single block which was .75 m wide and 1 m long, it seems probable that they were produced by a single plant.

The presence of *Nageiopsis* in this study is significant because it has heretofore been considered an exclusively Lower Cretaceous genus. It was originally described by Fontaine (1889) from the Lower Cretaceous (no younger than Albian) Potomiac series of Virginia. Fontaine (1889) so named this group of plants because of their close resemblance to living plants of the *Nageia* section (tribe?) of the genus *Podocarpus*.

The true relationship of these plants to any members of the Podocarpaceae has been questioned by Berry (1910) and Arnold (1947).

Arnold (1947) reported that no fructifications of this plant had been collected. However, several fragments of small, apparently staminate conifer cones were observed in the rock matrix of the *Nageiopsis* site (8/19/70). One of these was removed and macerated according to standard palynological techniques (Cross, 1968). Several hundred pollen grains were isolated, supporting the thought that it had indeed been the remains of a staminate cone. Cross (personal communication, 1972) tentatively identified the pollen as being similar to some of the earlier "Podocarpus types." These cones and pollen grains, although not showing organic connection to the foliage of the Blackhawk *Nageiopsis* sp., may have been produced by it.

Nageiopsis sp. was collected in sediment of swamp origin and because of the numerous leaflets collected, unquestionably grew in the immediate vicinity.

Podozamites sp.

(Plate 6, Figures 6,7)

Podozamites (Brongniart) Braun, 1843, p. 28 (in Munster, 1843)

Description of the Blackhawk specimens:

Fragments and a few complete specimens of this plant were collected in several Blackhawk sites. They are elongate, linear-lanceolate to ovate in outline with entire margins and range in size from specimens which are 0.7 cm wide and 4 cm long to those which are 1 cm wide and 8 cm long. The base is acute with a short petiole; the apex is typically acute but in some specimens it is slightly rounded. No midvein is present in these specimens; all veins are of equal size, are parallel with one another and are straight and unbranched. They do not converge at the tip, but gradually stop as they are encroached upon the narrowing margins.

None of the specimens were attached to a stem or rachis and no epidermal or other cellular features could be determined. No reproductive structure was collected in association with these specimens which could be considered part of this plant.

The *Podozamites* fossils found in the Blackhawk strata may be derived from two or more species. Those found at the bottomland sites, 7/30/70 and 8/25/70, were much smaller and more oval than those collected in the swamp sites, 8/14/70, 8/18/70, and 8/19/70.

Many species of *Podozamites* have been described from Europe, Russia, and North America in rocks ranging from Triassic (Daugherty, 1941) to the lower Tertiary (Brown, 1962). The genus was originally proposed for leaves believed to belong to cycadophytes because the leaves, when attached to a rachis, are similar in appearance to a pinnate cycad frond. Later it was observed that the supposed pinnae of some species are spirally arranged on the twigs, indicating that it is a leafy shoot. In addition, the leaves of some species seem to have been deciduous (Arnold, 1947) and are often found detached like those of the Blackhawk flora.

Protophyllocladus polymorpha (Lesq.) Berry

(Plate 6, Figures 9,10; Plate 8, Figures 3,5)

Adiantites praelongus, Dawson, 1893, p. 25, pl. 5, fig. 19; Dawson, 1894, p. 55, pl. 6, fig. 6.

Proteoides major, Dawson, 1893, p. 61. pl. 12, fig. 54.

P. obesus, Hollick, 1930.

P. polymorpha, Lesquereux, 1895, p. 362; Berry, 1903, p. 438-445; Bell, 1957, p. 35, pl. 19, fig. 5; pl. 20, figs. 1, 2, 4; pl. 21, figs. 1, 3, 5; pl. 25, fig. 4; Bell, 1963, p. 31, pl. 9, fig. 5.

P. subintegrifolius, Lesquereux, 1874, pl. 1, fig. 12; Lesquereux, 1892, pl. 2, figs. 1-5; Hollick, 1906, p. 36, pl. 5, figs. 1-6; MacNeal, 1958, p. 51, pl. 31, fig. 3.

Salisburia baynesiana, Dawson, 1883, p. 25, pl. 5, fig. 21.

S. polymorpha (nomen nudum), Lesquereux, 1895, p. 362.

Thinfeldia lesquereuxiana, Heer, 1882, pl. 46, figs. 1-126; pl. 49, figs. 9, 10.

T. montana, Knowlton, 1900, p. 11, pl. 1, figs. 1-3.

Description of the Blackhawk specimens:

Several complete phyllodes (phylloclades) of this plant have been collected in the Blackhawk Formation ranging in size of from 6 to 15 cm long, and from 1.5 to 7 cm broad. Fragments of some specimens suggest that they were often nearly twice that size. They are generally obovate in outline but are variable and include oblanceolate, spatulate, and obcordate forms. The apex is typically acute or round but in some it is emarginate or otherwise deeply cleft. This apical cleft is often as de

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as deep as 1/3 the length of the leaf, giving these specimens an appearance similar to the leaves of the extant *Ginkgo biloba*. The base is attenuate or wedge shaped, forming a thick, 0.5 cm wide, petiole-like structure often 1-2 cm long, where it attaches to the plant. Margins are also variable including forms which are entire, undulate, irregularly lobed, and irregularly cleft or divided to the midrib. In some specimens the lobing is similar to that of *Protophyllocladus lobatus* (Berry, 1914, pl. 2, figs. 9-13) only the individual lobes are broader and less frequent than those of that species. Occasional small, 0.5 mm long, teeth have been observed on a few specimens. When present, the teeth are either located at the apex of small lobes or are irregularly spaced, at least 2 mm apart, along otherwise entire margins. The main axis of each phyllode has a more or less distinct midvein or vascular system which is typically the width of the "petiole" at the base of the phyllode, becoming less and less distinct toward the apex. Judging from the vertical depth of the impression it usually formed in the rock matrix, this midrib was 2 to 3 mm thick in life. The lateral veins or vascular bundles diverge at an acute angle to the midrib and curve to the margin. They remain parallel with one another but may or may not bifurcate once or rarely twice. They never anastomose. These lateral veins are numerous and lie close to one another with roughly 20 to 25 veins per cm, similar to the veins in *Ginkgo biloba* leaves. The phyllodes of this plant are simple, and often crowded together at the tip of small, 0.5 cm wide branches. The thickness of the carbonaceous remains of certain specimens was nearly 1 mm thick, suggesting that they were very thick structures, probably coriaceous in life. No cuticular remains could be isolated from the Blackhawk phyllodes.

As pointed out earlier in this report, *Protophyllocladus polymorpha* preferred swampy or otherwise saturated floodplain soils and was an abundant member of the fluvial swamp community. It is not found in a small florule collected in the apparent brackish waters of the Blackhawk delta. It seems to have been evergreen.

This plant is abundant in several floras of both North America and Europe where it has been known for more than a century. It apparently ranges from the Albian through the Maestrichtian and into the Paleocene; however, it is interesting that it is absent in several major Upper Cretaceous floras. Undoubtedly, its geographical distribution was strongly controlled by environmental factors. More specimens have been collected in the Blackhawk Formation (124 specimens) than in any other flora, perhaps suggesting that it was entirely restricted to fresh water conditions similar to those of the Blackhawk floodplain.

It probably is related to the living genus *Phyllocladus* (Podocarpaceae) with at least 7 species which are all currently restricted to the Southern Hemisphere. Other species of this genus have been collected in Cretaceous and Early Tertiary strata, but problems still exist in the systematics of *Protophyllocladus* spp. and *Thinfeldia* spp. which should be resolved before the limits of this genus can be defined.

Protophyllocladus sp. 2

(Plate 8, Figure 2)

Description of the Blackhawk specimens:

The collection site 7/28/70 II at the Taylor Flat locality yielded nearly 50 phyllodes of an obvious member of the genus *Protophyllocladus*. They were generally similar to those of *P. polymorpha*, but differ enough to isolate them from that species, at least until all the possible ecotypes of *P. polymorpha* are known. Earlier, in the discussion of the stratigraphy of Taylor Flat, it was mentioned that these odd specimens may have been produced and shed from one *P. polymorpha* tree which was in poor health because of burial of the trunk base by overbank sediment.

Phylloclades of this plant are typically much wider than those of *P. polymorpha*, and are very broadly obovate. At least one specimen (7/78/70 II, 22-41) is reniform in outline with a crenate to serrate anterior margin, measuring 5 cm long and 5 cm broad. It is very unlike the wedge-shaped phylloclades of the *P. polymorpha*. These specimens also differ in having much shorter "petioles", fewer marginal lobes and an apparent membranous texture rather than being thicker or coriaceous.

About 8 very small, 0.5 cm wide and 0.5 cm long, apparently immature phyllodes were among those collected at this site. Since they are the only immature phyllodes of any species collected, they may support the proposal of being shed from a dying tree, perhaps early in a growing season.

Sequoia cuneata Newberry

(Plate 8, Fig. 4; Plate 9, Figs. 1-13; Plate 10, Fig. 1; Plate 11, Fig. 4)

Foliage:

Metasequoia cuneata, Chaney, 1950, p. 229, pl. 11, figs. 1-6; Bell, 1957, p. 31, pl. 11, figs. 3, 5, 6; pl. 13, fig. 2; pl. 17, figs. 1, 7; Bell, 1963, p. 29, fig. 1, only.

Sequoia affinis, Parker, 1968, p. 27, pl. 2, figs. 4-7.

Sequoia brevifolia, Lesquereux, 1874, U. S. Geol. Survey Terr., Ann. Rept., p. 298 (no illustrations); Lesquereux, 1878, U. S. Geol. Survey Terr., vol. 7, p. 78, pl. 61, figs. 25-27; Knowlton, 1900, U. S. Geol. Survey Bull. 163, p. 27, pl. 4, figs. 1-4.

Sequoia cuneata, Newberry, 1898, U. S. Geol. Survey Mono. 35, p. 18, pl. 14, figs. 3, 4a.

Sequoia dakotensis, Brown, 1939, U.S. Geol. Survey Prof. Paper 189, p. 247, pl. 48, fig. 10; Dorf, 1942, Carnegie Inst. Wash. Pub. 508, 129, pl. 6, fig. 4-6 (not figs. 8-11 as Chaney, 1950, believed).

Sequoia heterophylla ?, Knowlton, 1905, U. S. Geol. Survey Bull. 257, p. 132, pl. 16, fig. 5.

Sequoia langdorfi, Lesquereux, 1878, U. S. Geol. Survey Terr., vol. 7, p. 76.

Sequoia macrolepis ?, Heer, 1883, vol. 7, p. 16, pl. 51, fig. 13.

Sequoia nordenskioldi, Dorf, 1938, Carnegie Inst. Wash. Pub. 508, p. 45, pl. 1, fig. 10.

Sequoia obovata, Knowlton, 1916, p. 333; Knowlton, 1917, p. 250, pl. 30, fig. 7; Hollick, 1930, p. 58, pl. 25, figs. 10-12; pl. 29, fig. 2b; Capps, 1940, p. 201.

Sequoia winchelli, Lesquereux, 1895, p. 10, pl. A, fig. 1.

Sequoiites sp. cf. *Geinitzia formosa*, Bell, 1963, p. 28, pl. 12, fig. 4.

Taxodium cuneatum, Newberry, 1863, Boston Jour. Nat. Hist., vol. 7, p. 517; Dawson, 1893, Roy. Soc. Can. Trans., vol. 1, p. 25.

Tumion ? suspectum, Hollick, 1930, p. 55, pl. 19, figs. 4-6a; pl. 29, fig. 16.

Cones:

Geinitzie formosa, Bell, 1963, p. 28, pl. 12, figs. 2, 3, 4 only (note that fig. 2 shows foliar attachment).

Sequoia gracillima, Berry, 1903, p. 57, pl. 48, figs. 21, 22; Newberry, 1895, p. 50, pl. 9, figs. 1-3.

Description of the Blackhawk specimens:

This conifer, one of the most abundant plants collected in the Blackhawk flora, has been described by Chaney (1950). Although he considered this plant to be a species of *Metasequoia*, analysis of foliage, epidermal cells, and reproductive structures of the Blackhawk specimens indicate that it clearly falls within the description of the genus *Sequoia*. Information to support this conclusion will be subsequently presented, as will other aspects of morphology which are either new or are modifications of Chaney's (1950) descriptions.

The reconstruction of the leafy axis with staminate and pistillate cones, was based upon the specimen, 8/24/70, 013A-020A. All aspects of twig, leaf, and cone gross morphology were considered; however, the staminate cones were added.

Chaney's (1950) description of the foliage is as follows:

> Foliage shoots bearing monoporphic, acicular leaves except at base where they are scaly; of two types, long shoots which are persistent and develop into branches, and short shoots which are deciduous. Long shoots bearing needles up to 14 mm. long (some probably longer, but incomplete), and up to 3 mm. broad; needles decussately attached and rotated into flat sprays prior to the development of short shoots in their axils, at which stage they show a return toward diametrically opposed position, and become widely spaced as the shoot lengthens and short shoots develop; subtending needles commonly deciduous during or after shoot development; needles in whose axils no short shoots have developed may be persistent, including single needles on one side of the stem where a shoot has failed to develop or has been shed. Short shoots slender, straight or curving, up to 5 cm. long, bearing at maturity 15 to 20 closely spaced pairs of leaves, decussately attached but always rotated into distichous position, longest in lower half of shoot, and progressively shorter to its apex; commonly shed separately. Leaves typically slender-oblanceolate, abruptly rounded at the base, and narrowed to a very short petiole, much widened and rounded at apex with a mucronate tip which is seldom preserved, or more rarely of uniform breadth to apex; approximate average dimensions at middle of shoot 8 mm. by 1.8 mm.; closely spaced on shoot, branching off at angles under 90 degrees but seldom as low as 45 degrees; obliquely attached on decurrent bases which are fairly prominent and extend obliquely down shoot to next pair of needles; needles somewhat more persistent than those of *M. occidentalis*; midvein well defined.

Because more than 450 leafy twigs of *S. cuneata* were collected in the Blackhawk Formation, several modifications can be made to Chaney's description. First, short shoots, more than twice as long as those he described, up to 12 cm in length with at least 96 leaves, are in the Blackhawk collection. Typically, they are shorter with fewer leaves, 5 to 8 cm being average length. Second, the short shoots were not deciduous. More than one half of the specimens, 257, were long shoots.

The rest, 212 specimens, were isolated short shoots, some of which may have shown attachment to long shoots if the rock matrix had been excavated. Thus, the total number of long shoots was probably higher. This, therefore, does not support Chaney's suggestion that the plant was deciduous. Instead, it seems to have been an evergreen species which lost foliage because of external factors such as wind or animals. All the foliage of *S. cuneata* which was collected is apparently mature, rather than immature, and was therefore shed from the plant sometime after spring growth ended.

The shoots and growth of this fossil plant can be described in terms of short shoot-long shoot organization, similar to many extant and extinct conifers. The short shoots typically became long shoots after the first season by an increased length and thickness. As this transition occurred, the short shoot leaves lose their distichous organization and become more spiral. They also become more obviously decurrent, and are moved away from one another.

Although the foliage of this plant is generally like that of the living redwood, *S. sempervirens*, periodic growth or over-wintering features are not evident in the fossil plant as they are in the living redwood. *S. sempervirens* has obvious clusters of small, spirally arranged, awl-shaped leaves typically at the base of short shoots. These are the slightly enlarged and hardened protective leaves which enclosed the bud during the non-growing season. No such over-wintering bud scales or buds can be observed on any of the Blackhawk specimens. In this aspect, the fossil *S. cuneata* is more like *Sequoiadendron gigantea* which does not typically display over-wintering features or buds.

Older twigs, up to 1 cm thick, which Chaney (1950) did not describe have now been collected. They clearly show leaf scars.

Cuticular fragments were isolated from needle-like leaves of two specimens using the preparation techniques of Dilcher (1963). They are described below according to the format and terminology suggested by Dilcher (1974). Besides having impressions of numerous epidermal cells one specimen had remains of 3 stoma.

The epidermal cells are short-rectangular to isodiametric in shape and arranged in indistinct rows parallel with the long axis of the leaf. Most have square end walls; a few end walls are oblique. Neither the lateral or end walls have undulations or ornamentations. The stomatal complex is oriented with the long axis of the guard cells parallel with the long axis of the epidermal cells and leaf. Their position and organization on the leaf is unknown. The guard cells were apparently sunken, their impressions on the cuticle was not preserved. Subsidiary cells were tetracytic. See Plate 11, Figure 4.

Both staminate and pistillate cones were collected in the Blackhawk flora, some attached to foliage. The 2 staminate cones apparently had deciduous scales and seem to be incomplete. They are ovoid, 8 mm long and 4 mm wide, attached to the end of a leafy shoot. Cone scales are not clearly seen, but seem to have subtended the 8 or 10 globose sporangia, very similar in appearance to male cones of *S. sempervirens*. One cone was chipped from the rock matrix and macerated, using standard palynological techniques (Cross, 1968), but unfortunately no Taxodiaceous pollen could be isolated.

About 30 pistillate cones are in the Blackhawk collection, seven of them attached to foliage shoots of *S. cuneata*. They are narrowly oval to rectangular in shape and thus differ from the subglobose cones of *S. sempervirens*. They range from mature specimens 4 cm long and 1.2 cm wide to those which are 7.2 cm long and 1.8 cm wide. Fifteen to 20 scales may be seen in the fossil compressions, suggesting that 30 to 40 scales were present in complete cones. Scales are peltate with a hexagonal outer face, 4 to 5 mm tall and 7 mm wide. An umbo, 2 to 3 mm wide, which is in the center of each scale, terminates in a thin, erect spine about 0.5 mm long. Most scales showed shallow striations radiating outward from the umbo to near the margin. A narrow, 1 mm wide, rim is present around the hexagonal periphery. One cone had been preserved whole without distortion in the rock matrix and had subsequently been broken to allow a transverse view. It shows 5 scales attached to the axis in an apparent spiral fashion and is definitely not cruciform in organization as cones of *Metasequoia*. When mature all the scales presumably fit tightly together, but separated or shrank apart in dehiscence. This seed dispersal mechanism is similar to the living redwood and several other species in the families Taxodiaceae and Cupressaceae. Pistillate cones were borne on the end of a thick, 3-4 mm wide, leafy twig. One incomplete twig was 4.5 cm long and bore at least 15 awl-shaped leaves.

Six small ovulate cones in the flora are apparently immature. All were 2.4 cm or less in length, had exactly the same number of scales as the larger or mature cones, and were attached to the ends of leafy *S. cuneata* twigs. None of the scales have the thickened and scl

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and sclerified appearance of those of mature cones. Because all were directly associated with mature rather than immature foliage, they were dropped from the tree sometime after spring growth, perhaps as late as the end of the first growing season when strong winds could have torn them from the plant. This may suggest that two seasons were required for their maturity. Although the living *S. sempervirens* requires only one season for cone maturity, the closely related *Sequoiadendron gigantia* does require two.

Chaney (1950) supposed that certain Cretaceous pistillate cones which Dorf (1942) and Hollick (1930) collected were produced by this plant. However, all of them were attached to naked stalks. In light of the Blackhawk cone morphology and stem attachment it does not seem likely that these specimens belonged to *S. cuneata*.

A single *Sequoia*-like seed was recovered. It is 4 mm wide and 6 mm long with a wing or membrane which partially surrounds the embryo. Although it was not connected directly to a cone scale it is less than 0.5 cm away from the fragment of a seed cone and 0.5 cm away from a leafy twig of *S. cuneata*. It is nearly twice the size of seeds of *S. sempervirens* and *Sequoiadendron gigantea*, but is remarkably similar to them. It is thought that it is a seed of *S. cuneata*.

This fossil plant falls within the limits of the genus *Sequoia* as it has been defined and discussed by Buchhotz (1938, 1939), Chaney (1950) and Bierhorst (1971). Although it has at least 4 features similar to *Sequoiadendron* it seems clear that it is not a *Metasequoia* as Chaney (1950) believed after he examined a limited number of leafy specimens. The following indicate its relationship to the genus *Sequoia:*

1. Leaves of short shoots are subopposite or alternate rather than opposite as in *Metasequoia*.
2. Leaves are borne spirally and secondarily rotated into a distichous position whereas in *Metasequoia* leaves are borne distichously.
3. Branching is always alternate, never opposite as in *Metasequoia*.
4. Short shoots are normally persistent not deciduous as in *Metasequoia*.
5. Two types of leaves are present, needle-like and awl-like, whereas *Metasequoia* (and *Sequoiadendron*) produce only one leaf type.
6. Epidermal cell shapes, and stomatal orientation are like those of *Sequoia* (and *Sequoiadendron*) and are clearly unlike *Metasequoia*.
7. The peltate pistillate cone scales are *Sequoia*-like in general appearance. They resemble no other Taxodiaceous genera.
8. Staminate and pistillate cone stalks are covered with leaves like *S. sempervirens*, and are not naked like those of *Metasequoia*.
9. Cone scales are attached to the axis in a spiral manner, not cruciform or decussate as in *Metasequoia*.

The features of this plant which are somewhat similar to *Sequoiadendron* are:

1. The awl-like leaves present on the pistillate cone stalks.
2. The epidermal cell size which is normally smaller than in *Sequoia sempervirens*.
3. The lack of over-wintering bud scales and buds.
4. The apparent two-year period for pistillate cone development.

Recently, Eckenwalder (1976) has proposed that the families Taxodiaceae and Cupressaceae be combined because of numerous similarities which make them closely related. The recovery of *S. cuneata* with such obvious *Sequoia*-like features indicates that any divergence of the two families occurred much earlier than the Upper Cretaceous.

The foliage of *S. cuneata* has been collected widely in Western and Central North America during the last century. Localities include those in Alaska (Hollick, 1930); Fort St. John, Alberta (or perhaps British Columbia, it is unclear) (Bell, 1963); Kootenai, British Columbia (Dawson, 1893); Namaino, British Columbia (Newberry, 1863, 1898); Vancouver, British Columbia (Bell, 1957); Craig, Colorado (Dorf, 1938); Vermejo, Colorado and New Mexico (Knowlton, 1917b); Austin, Minnesota (Lesquereux, 1895); Marmarth, North Dakota (Brown, 1939); Fruitland, New Mexico (Knowlton, 1916); Black Buttes, Wyoming (Lesquereux, 1878); Lance Creek, Wyoming (Dorf, 1942); Point of Rocks, Wyoming (Lesquereux, 1874, 1878; Knowlton, 1900); and Judith River, state unknown (Knowlton, 1905). All are apparently Santonian to Lower Maestrichtian in age. The foliage of this plant seems to have been rare in all the localities. Although it has been called many different specific names, almost all authors have recognized its Taxodiaceous affinities.

The distinctive ovulate cones have also been widely collected. These range from an unidentified locality in Alberta (Bell, 1963); a single site at Vancouver, B. C. (Newberry, 1898) and three sites entirely disjunct from western cone and foliage sites in New Jersey. They are near Cliffwood (Berry, 1903; Jeffery, 1911) and Key Port (Newberry, 1895). It is interesting that while only six cones had previously been collected in the west, not counting those of the Blackhawk Formation, apparently hundreds were collected in New Jersey. The western cones including most of the Blackhawk specimens are compressions, while those in the east are preserved whole as lignified remains or are petrified. Jeffery (1911) examined the cellular structure of several petrified specimens. No *S. cuneata* foliage was collected in association with the New Jersey specimens.

Only 2 of the previously collected cones showed attachment to foliage twigs (Bell, 1963, pl. 12, fig. 2; Newberry, 1895, pl. 9, fig. 2), the rest were found unattached to twigs of any type. The significance of the leafy cone stalks as a means of distinguishing genera of Taxodiaceous plants had not been recognized in the reports of these previously collected cones.

The disjunct distribution of the cones, which were on either side of the Cretaceous epicontinental sea, suggests the possibility that at least 2 species existed which produced cones of similar appearance. Considering this and the large number of fossil species which have been referred to the family Taxodiaceae in the last 150 years, a major monograph of the family is probably in order. Although Chaney (1950) made significant contributions to certain Taxodiaceous genera, the systematics may be more complex than he has indicated.

S. cuneata clearly preferred the Blackhawk fluvial swamps where it was an apparent co-dominant tree. Several aspects of this plant, discussed earlier, indicate that it was an approximate ecological equivalent to the living bald cypress, *Taxodium distichum* of southeastern North America.

Widdringtonites reichii (Ettingshausen) Heer

(Plate 8, Figures 1,6)

Widdringtonites reichii, Heer, 1882, p. 51, pl. 28, fig. 5; Berry, 1914, p. 25, pl. 2, figs. 14-17; Berry, 1916, p. 793, pl. 55, fig. 1; Newberry, 1895, p. 57, pl. 10, figs. 2-4; Bell, 1963, p. 30, pl. 12, fig. 1, pl. 13, figs. 1,4.

Description of the Blackhawk specimens:

The specimens collected in the Blackhawk formation consist of the terminal portions of several much-branched axes. The largest specimen is 22 cm long, consisting of a main stem with numerous, alternate branches; three orders of branching are evident. The secondary branches arise on all sides of the main stem and thus do not form distichous, flattened sprays as in *Moriconia* spp. and *Brachyphyllum* spp. The main stem is about 16 cm long and 2.5 mm wide at the base. Smaller, ultimate branches are 0.5 cm to 4.5 cm long and very narrow, typically about 0.5 mm wide. The leaves are broadly awl-like to ovate, spirally arranged on the stem but very small, no longer than 1 to 2 mm. On ultimate branches where they are clearly observable, there are usually 6 to 8 leaves per cm. They are apparently much more appressed to older stems or are missing altogether. No cones or other reproductive structures have been collected in the Blackhawk Formation.

Both microsporangiate and megasporangiate cones have been collected in other Cretaceous collections in Europe, Greenland and North America. They are very similar to extant species of the genus *Widdringtonia* and, based upon both foliar and reproductive morphology, they have been referred to that extant genus (Berry, 1925). Two species of the fossil genus *Widdringtonites* have been collected, the other being *W. subtilis* also of Europe, Greenland and North America (Berry, 1914). They are very similar in appearance.

The stratigraphic range of this species seems to be Cenomanian to Campanian. Its occurrence in the Blackhawk Formation is only the second time it has been collected in Western North America (Bell, 1963).

W. reichii appears to have been an infrequent or relatively unimportant member of the Blackhawk fluvial swamp communities.

Geonomites imperialis (Dawson) Bell

(Plate 11, Figures 1 to 3)

Geonomites imperialis, Bell, 1957, p. 37, pl. 22, fig. 5; pl. 23, fig. 2; pl. 24, fig. 3.

Description of the Blackhawk specimens:

No complete leaves of this species have been collected in any Cretaceous flora, however, by piecing together several large Blackhawk fragments, it is now known that they are 2 m or more in length and about 0.5 to 0.8 m wide. The leaves are simple, pinnate, and oblong to oblong-obovate. The apex is rounded in outline and the base is acute to slightly attenuate. The blade was at least 1.0 to 1.5 m in length and attached to the end of a 0.5 to 0.8 m long petiole. The leaf blades are plicate or folded into lamina or rays, typical of all palms. These plications are reduplicate or Λ-shaped in cross-section with the midrib prominent on the upperside, characteristic of most extant pinnate genera (palmate genera with some exceptions are induplicate) (Corner, 1966). The orientation of these plications in the fossil palms is therefore a convenient means of determining the adaxial or abaxial surface of these leaves as they are preserved in the rock. Each ray or fold is about 8 to 25 mm broad and are united by their edges except near the leaf margins where they normally split apart. Each contains about 5 to 10 parallel veins, 0.3 to 0.8 mm apart with 3 or 4 intermediate striae between and parallel with them. The rays diverge from the rachis at broad angles from the base of the blade, while near the center of the blade they diverge at about 30° and near the apex they diverge at 10 to 15°. These plicae normally are decurrent to the rachis for 1 to 2 cm. The margins of all the leaves examined is made of the distal splitting of the plicae to a distance of from 15 to 30 cm toward the rachis. These splits only reach the rachis in the most weathered or perhaps transport-damaged specimens. The major portion of the blade of these leaves is therefore solid, and not divided or split into leaflets. The rachis extends from the petiole to near the apex of the blade. At the base of the blade it is about 3 cm wide and tapers gradually to near the apex where it is only a few mm wide. It is longitudinally striated. The petiole is unarmed. Throughout most of its length it is 3 to 6 cm wide, but widens abruptly at the base into a wedge-shaped structure, 17 to 20 cm broad. This expanded portion attaches to the stem as a decurrent, short sheath. *In situ* trunk casts (described on p. 69) had several of these wedge-shaped petiole bases attached to them. Both the petiole and the widened base are also longitudinally striated. The depth of the impressions of a few leaf fragments indicate that the petiole at the base of the blade was 1 to 2 cm thick.

Apparently based upon incomplete specimens, Brown (1962) considered *Geonomites imperialis* and several other species to be of the genus *Sabal*, a group of palmate or fan-leaved palms. However, the large specimens (although also incomplete) collected in the Blackhawk Formation clearly indicate that this species has a rachis which extends throughout the length of the blade making it pinnate in organization. One such specimen was recovered from Unit O at the Water Hollow locality. It is composed of a 0.6 m long petiole with the wedge-shaped base and a portion of the leaf blade. The petiole extends into the blade as a gradually tapering rachis, rather than the abruptly tapering or wedge-shaped rachis (hastula) of the fan palms. On the same rock slab several leaf apicies are present and clearly show the narrow, tapering rachis near the apex. In addition, the rays of this plant are clearly decurrent, leaving little doubt that this species is a pinnate rather than a palmate palm.

A group of these palms described earlier in this report (p. 69) were growing on a peaty substrate of a Water Hollow swamp as close as 1.5 to 2 m to one another. Since the leaves were longer than the distance between the trunks, a tight palm thicket must have been formed. In other localities, isolated leaves were recovered in coarser bottomland and point bar sediments, but all the leaf "mats" were associated with swamps. This suggests that although many plants extended into adjacent environments, they grew most abundantly in swamps or near swamp margins.

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The restoration of *Geonomites visianii* by Berry (1914, p. 38, fig. 4) is somewhat similar to that of *G. imperialis* in the Blackhawk flora, except I have reason to believe that the leaves of the Blackhawk specimens remained attached to the base of the plants after they died, that the leaves occurred much closer together, vertically, along the stem, and that the leaf margins were normally split at the plications.

Recently, Read and Hickey (1972) have proposed a classification of Mesozoic and Cenozoic palm foliage. They emphasize that because it is very difficult to identify specimens of modern palms accurately from leaves alone, attempts to place fossil palm fragments in genera of modern palms probably gives a confused picture of the floristics of the geologic record. For example, leaves of the extant genera *Geonoma* and *Manicaria* are almost impossible to distinguish without seeing flowers or fruit. It is therefore questionable that the fossil *Geonomites imperialis* bears any relationship to the extant genus *Geonoma*, and only has a superficial foliar resemblance to it. Perhaps, as Read and Hickey (1972) suggest, fossil leaves of this species should be placed in the form genus *Phoenicites* A. Brongniart.

This species seems to have been restricted to sediments of Campanian age.

APPENDICES

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APPENDIX I

COLLECTION LOCALITIES

Several areas in the Wasatch Plateau were examined in order to determine the most feasible collection localities. Fossil plants were found at a large number of places but only six were selected for major collection. All six localities are within 200 yards (180 m) of either Utah State Highway 29 in Straight Canyon, west of Orangeville, Utah, or Interstate 70 in Salina Canyon, east of Salina, Utah (Figure 1). Most localities include three or more specific plant-bearing horizons or sites. These localities and sites are identified and described below.

1. Cox Swale collection locality in Straight Canyon is in SW 1/4 sec. 2, T. 17 S, R. 6 E and in the adjacent NW 1/4 sec. 11, T. 17 S, R. 6 E, Hiawatha, Utah Quadrangle. It is in a road cut on the north side of Utah State Highway 29, opposite and northwest of Cox Swale, about 300 yards (275 m). It is 14.2 miles (22.9 km) from Orangeville, Utah.

One site was excavated in the above road cut, 7/11/70 II. A second site, 7/11/70 I, was excavated approximately 200 meters west on Utah 29 in a small amphitheatre-like wash (see Figure 4).

2. Black Diamond Mine collection locality in Straight Canyon is in NW 1/4 sec. 12, T. 17 S, R. 6 E, Hiawatha, Utah Quadrangle. It is southwest of the abandoned mine entrances about 200 yards (180 m), and on the east-facing slope of the small amphitheatre-like canyon. This

locality is 12.9 miles (20.8 km) west from Orangeville, Utah and 1.4 miles (2.3 km) east of the Cox Swale locality.

Collection sites excavated here were: 7/23/70 I, 8/28/70 I, 8/28/70 II, 8/28/70 III (See Figure 4).

3. Knight Mine collection locality in Salina Canyon is in SW 1/4 sec. 34, T. 23 S, R. 4 E, Acord Lakes, Utah Quadrangle. The collection sites here are adjacent to the abandoned mine road about 50 yards (45 m) west and below the mine entrance. This locality is 31.0 miles (50 km) from Salina, Utah, on Utah State Highway 10 (being replaced by Interstate 70).

Collection sites excavated here were: 7/22/70, 8/26/70 I, 8/26/70 II, 8/26/70 III (see Figure 4).

4. Taylor Flat collection locality in Salina Canyon is in NW 1/4 sec. 21, T. 22 S, R. 6 E, Water Hollow Ridge, Utah, Quadrangle. It is 30 yards (27 m) north of Interstate 70 at the point where the highway enters (from the west) the down-faulted graben at Taylor Flat. It is 18.6 miles (29.9 km) from Salina, Utah.

The sites excavated here were: 7/8/70 I(1), 7/12/70, 7/18/70 I(1), 7/28/70 I(2), 7/28/70 I(5), 7/28/70 II, 7/30/70 I, 7/30/70 II, 7/30/70 III (see Figure 4). This is at the same position as that section measured by Spieker and Baker (1928).

5. Pipe Springs collection locality in Salina Canyon is in NW 1/4 sec. 20, T. 22 S, R. 3 E, Water Hollow Ridge, Utah, Quadrangle. It is 200 yards (180 m) north of Interstate 70 in a small unnamed canyon, herein called Pipe Springs Canyon. (Before the construction of Interstate 70, there existed a roadside water fountain, piped out

of this canyon from a small spring.) This locality is 17.5 miles (28.2 km) east of Salina, Utah. The collection sites are 165 feet (50.3 m) above the canyon floor.

The sites excavated here were: 6/1/68, 7/9/70 I(1), 7/9/70 I(2), 7/9/70 I(3), 7/17/70 I(1), 7/18/70 I(2), 8/13/70, 8/14/70, 8/15/70, 8/18/70, 8/19/70, 8/20/70 (see Figure 4). Collection number 6/1/68 was collected entirely by W. D. Tidwell. This is the same section measured by Bachman (1958) and Baughman (1958).

6. Water Hollow collection locality in Salina Canyon is in NE 1/4 sec. 14, T. 22 S, R. 2 E, Steve's Mountain, Utah, Quadrangle. It is about 200 yards (180 m) northwest of where Interstate 70 crosses Salina Creek on a steep east-facing slope. Most of the collection sites were under the massive, overhanging sandstone, about 170 feet (52 m) above the road. It is 13.3 miles (21.4 km) east of Salina, Utah.

Sites excavated here were: 8/24/70, 8/25/70, 8/29/70, "Base of Road Cut", "Unit I", "Unit K", "Unit M", "Railroad cut" and "Above railroad cut" (see Figure 4).

In addition, several fragments of *Araucarites* sp. were collected in a large sandstone block which had been exposed in the construction of Interstate 70 about 2 miles east of the Taylor Flat locality. This site was termed "Road Construction." Its stratigraphic position is unknown, although it is probably within the middle 1/3 of the Blackhawk Formation.

APPENDIX II

OTHER FOSSIL LEAF IMPORTANCE INDEX CONSIDERATIONS

A second fossil plant Importance Index could be constructed to consider the large number of fossil leaves which were unidentifiable. Table 1 shows that of the dicotyledons collected, 2071 could be identified and 2928 were not identifiable out of the 4999 dicot leaves differentiated in the collection. This total is 2.4 times more than those actually identified. An Importance Index might be as follows:

$$\text{Fossil Leaf Importance Index} = \text{Relative frequency of dicots} + 2.4 \ \text{Relative density of dicots}$$

The index for the non-dicotyledonous plants would be calculated as in the Fossil Leaf Importance Index used earlier. The results of this calculation are interesting and are listed in Table 10, where they are compared with the Importance Index obtained using the first formula. It is my opinion that this index gives a more realistic idea of the true relationship among dominant plants in the living community, since it uses the total number of dicot leaves collected, instead of those that are identified.

At least one problem in using this third index is that the unidentifiable dicot remains might be from species other than those which are identified. However, it is my own opinion that if there are taxa which as yet have not been recognized among the dicotyledons, they are unimportant members of the communities statistically.

It is thought that because of the bias in various factors of preservation, a fossil species which is represented by a few specimens in a majority of collection sites is ecologically more significant than a species which might be found in great abundance at only one or few localities (R. Anstey, personal communication, 1972). Therefore, consideration has been given for the construction of a third possible Fossil Leaf Importance Index in which "frequency" is used instead of "relative frequency." Frequency is determined as follows:

$$\text{Fossil Plant Frequency} = \frac{\text{number of collection sites in which the species occurred}}{\text{number of collection sites}} \times 100$$

This third Fossil Plant Importance Index using frequency could be calculated as follows:

Fossil Plant Importance Index = Frequency + Relative Density

When this is used for the 43 important Blackhawk species, the plants are listed in almost exactly the same order as when the first Importance Index (using Relative Frequency and Relative Density) is used.

Unfortunately, none of these Importance Indicies can be compared directly to Importance Indicies calculated from plants in living communities. A method to determine the number of individual plants in the Blackhawk communities has not been found and probably will have to await the completion of studies correlating the number of leaves on the forest floor with the number of parent plants in several types of living communities.

Table 10. A comparison of the values from the two Importance Indices.

Taxa	Swamps I.I. #1	Swamps I.I. #2	Bottomlands I.I. #1	Bottomlands I.I. #2	Point Bars I.I. #1	Point Bars I.I. #2
Asplenium dicksonianum	1.8	1.8	0	0	0	0
Cyathea pinnata	3.2	3.2	0	0	0	0
Onoclea hebridica	3.4	3.4	1.1	1.1	0	0
Osmunda hollicki	2.4	2.4	6.9	6.9	0	0
Unknown Fern 1	0	0	1.7	1.7	0	0
Araucarites sp.	0	0	0	0	31.6	31.6
Brachyphyllum macrocarpum	13.8	13.8	0	0	0	0
Moriconia cyclotoxon	6.4	6.4	1.0	1.0	0	0
Nageiopsis sp.	1.4	1.4	0	0	0	0
Podozamites sp.	3.5	3.5	0	0	47.9	47.9
Protophyllocladus polymorpha	15.0	15.0	6.0	6.0	11.4	11.4
Protophyllocladus sp. 2	0	0	5.4	5.4	0	0
Sequoia cuneata	43.4	43.4	7.1	7.1	7.7	7.7
Widdringtonites reichii	1.5	1.5	0	0	0	0
Cyperacites sp.	4.1	4.1	1.2	1.2	0	0
Geonomites imperialis	9.2	9.2	4.3	4.3	15.9	15.9
Anona robusta	1.4	2.4	0	0	0	0
Apocynophyllum giganteum	3.1	3.5	4.3	6.4	0	0
Cercidiphyllum arcticum	1.2	1.9	27.3	60.3	9.5	13.4
Cissus marginata	7.0	11.9	9.2	13.0	4.3	5.7
Cornus denverensis	3.9	5.4	2.5	3.3	0	0
Cornus praeimpressa	4.1	6.9	5.7	7.2	3.6	4.0
Dryophyllum subfalcatum	5.5	7.3	19.0	35.2	13.3	22.5
Dryophyllum whitmani	0	0	3.9	6.7	0	0
Ficus laurophylla	2.7	3.5	3.1	3.5	0	0
Ficus planicostata	2.1	3.1	2.1	2.4	5.0	7.4
Laurophyllum coloradensis	0	0	7.5	12.8	0	0
Manihotites georgiana	2.4	2.8	7.4	13.8	3.5	4.0
Menispermum dauricumoides	0	0	2.5	3.3	4.0	5.0
Myrtophyllum torreyi	4.7	6.4	9.4	16.1	0	0
Phyllites vermejoensis	3.2	4.7	7.3	11.1	0	0
Platanus alata	1.9	2.6	3.1	4.8	0	0
Platanus raynoldsii	10.8	18.1	21.2	36.6	16.1	20.0
Rhamnites eminens	18.1	31.7	4.7	6.1	9.1	12.5
Salix gardneri	2.4	3.8	1.3	1.9	0	0
Salix proteaefolia	2.8	3.8	0	0	0	0
Salix stantoni	0.8	0.9	3.7	5.0	0	0
Viburnum antiguum	2.3	2.6	3.7	6.2	3.6	4.0
Unknown Dicot 2	0	0	13.4	29.5	0	0
Unknown Dicot 13	3.7	6.9	2.2	2.6	0	0
Unknown Dicot 19	1.9	2.6	1.0	1.1	13.0	21.8
Unknown Dicot 25	2.8	5.7	0	0	0	0
Unknown Dicot 32	1.5	2.6	0	0	0	0

APPENDIX III

RAINFALL CALCULATIONS

Calculations to determine the total precipitation in the drainage basin of the Cretaceous Ferron River described by Cotter (1971).

$$6{,}500\ ft^3/sec \text{ for 11 months} = 1.88 \times 10^{11}\ ft^3$$

$$22{,}000\ ft^3/sec \text{ for 1 month} = \underline{5.70 \times 10^{10}\ ft^3}$$

$$\text{Total} = 2.45 \times 10^{11}\ ft^3/year$$

$$7{,}000 \text{ sq miles} = 1.95 \times 10^{11}\ ft^2$$

$$\frac{2.45 \times 10^{11}\ ft^3}{1.95 \times 10^{11}\ ft^2} = 1.25 \text{ feet} = 15'' \text{ runoff}$$

$$15'' = 20\% \text{ of Precipitation}$$

$$\frac{15}{.20} = \text{Precipitation}$$

$$75'' \text{ (190 cm)} = \text{Precipitation}$$

APPENDIX IV

DICOTYLEDONS IN EACH OF THE FLOODPLAIN ENVIRONMENTS

Table 11. Dicotyledons in each of the floodplain environments.

NUMBER	TAXA	Swamps																			Bottomlands															Point Bars							
		6/1/68	7/11/70 II	7/12/70	7/18/70 I-1	7/18/70 I-2	7/28/70 I-2	7/28/70 I-5	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/28/70 I	Unit I	Unit K	Unit M	TOTAL	7/9/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/23/70 I	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/25/70	8/28/70 II	8/28/70 III	8/29/70	Rail Road Cut	TOTAL	7/17/70 I-1	7/22/70	8/26/70 I	8/26/70 II	8/26/70 III	Above R. R. Cut	Road Construction	TOTAL
1	*Anona? robusta*																10			10															0								0
2	*Acer cretaceum*		6																	6															0								0
3	*Apocynophyllum giganteum*				1						1		2	1						5							14	4	3						21								0
4	*Celastprophyllum carolinensis*		1																	1					2										2								0
5	*Celastrophyllum cretaceum*																			0							1								1								0
6	*Celastrophyllum undulatum*		8																	3															0								0
7	*Cercidiphyllum arcticum*												8							8							146	142	47		3				338				5	3			8
8	*Cinnamomum intermedium*								2											2															0								0
9	*Cinnamomum sezannense*																		8	8															0								0
10	*Cissus marginata*		43						1						1	6	1			52	1					2	3	1	1	24			6		38					3			3
11	*Cornus denverensis*						2				5			2					7	16										4			5		9								0
12	*Cornus praeimpressa*										10		5	15						30	1	5	7							1			2		16				1				1
13	*Dombeyopsis obtusa*		1																	1									1						1								0
14	*Dryophyllum subfalcatum*		12								3	1	1			1			2	20	4		1	1			5	9	89	54			3		166		18			1			19
15	*Dryophyllum whitmani*																			0										3			26		29								0
16	*Fagus cretacea*													4						4															0								0
17	*Ficus glasscorea*		2										1				1			4															0								0
18	*Ficus laurophylla*		4	1												4				9							1	1		2					4								0
19	*Ficus planicostata*								2				9							11										2				1	3				5				5
20	*Ficus post-trinervis*										1	1								2															0								0
21	*Ficus puryearensis*														1		6			7															0								0
22	*Laurophyllum coloradensis*																			0					3		17		10		25				55								0
23	*Laurophyllum meeki*		4																	4									3						3								0
24	*Lirodendron alatum*		6																	6															0								0
25	*Magnolia amphifolia*				2		2	1									2			7															0	1							1
26	*Magnoliophyllum cordatum*		2						2											4			4												4								0
27	*Manihotites georgiana*				2											1		1		4					24						6	36			66			1					1
28	*Menispermum dauricumoides*																			0								1	8						9					2			2
29	*Myrtophyllum torreyi*		6									1		3		7		1		18			2	2	3				3		59				69								0
30	*Nymphaeites dawsoni*																	1		1															0								0
31	*Pararymphaea crassifolia*																			0			1												1								0
32	*Phyllites craigensis*																			0										4					4								0
33	*Phyllites wilderi*				1														2	3															0								0
34	*Phyllites vermejoensis*		13								3		1							17							5	5	12	2	14				38								0
35	*Platanus alata*													7			1			8				7									10		17								0
36	*Platanus raynoldsii*	4	3					4	5	9		1				51		1		78	9		3		6	12	28	15	52	15	8		9	1	158	2	4	1	1				8
37	*Pterospermites undulatus*																			0										2					2								0
38	*Populus? apiculata*																			0										1					1								0
39	*Quercus stantoni*										7									7															0								0
40	*Ranunculus (?) sp.*					1														1															0								0
41	*Rhamnites eminens*		22	1	11		11	9	31	14	13	3	15	15		1				146		3							2			7		3	15	5				2			7
42	*Rhamnus salicifolius*															1				1										1					1								0

Table 11. (con't)

NUMBER	TAXA	Swamps																			Bottomlands															Point Bars							
		6/1/68	7/11/70 II	7/12/70	7/18/70 I-1	7/18/70 I-2	7/28/70 I-2	7/28/70 I-5	8/13/70	8/14/70	8/15/70	8/18/70	8/19/70	8/20/70	8/24/70	8/28/70 I	Unit I	Unit K	Unit M	TOTAL	7/8/70 I-1	7/9/70 I-2	7/9/70 I-3	7/11/70 I	7/23/70 I	7/28/70 II	7/30/70 I	7/30/70 II	7/30/70 III	8/25/70	8/28/70 II	8/28/70 III	8/29/70	Rail Road Cut	TOTAL	7/17/70 I-1	7/22/70	8/26/70 I	8/26/70 II	8/26/70 III	Above R. R. Cut	Road Construction	TOTAL
43	*Salix gardneri*		3													12				15													6		6								0
44	*Salix lancensis*																1			1							1			4			1		6								0
45	*Salix proteaefolia*		2												6		3			11															0								0
46	*Salix stantoni*																1			1						5				7				1	13								0
47	*Sapindus morrisoni*											2								2															0								0
48	*Trapa paulula*																	1		1														1	1								0
49	*Trapa* sp.																1			1															0								0
50	*Viburnum antiguum*												1			1	1			3			3										23		26	1							1
51	Unknown dicotyledon 2																			0										162				2	164								0
52	" " 9		1																	1															0								0
53	" " 13										9								25	35													3	1	4								0
54	" " - 14																			0										2					2								0
55	" " 15																			0										2					2								0
56	" " 16								1											1											2				2								0
57	" " 17		5																	5															0								0
58	" " 18			2												3				5														2	2								0
59	" " 19								6	2										8											1				1		6		12				18
60	" " 20																			0															0			1					1
61	" " 24																			0											1				1								0
62	" " 25		31																	31															0								0
63	" " 26		2										1				1			4								1							1								0
64	" " 27																			0					4			1	2						7								0
65	" " 30		1																	1															0								0
66	" " 32												12							12															0								0
67	" " 33																			0								1	2		3				6								0
68	" " 35											1								1							2								2	2							2
69	" " 36													1						1															0								0
70	" " 37																			0										1					1								0
71	" " 40																	1		1										5					5								0
72	" " 41																			0										1					1								0
73	" " 44											1								1															0								0
74	" " 46														6					6															0								0
75	" " 47																			0											2				2								0
76	" " 49																2			2															0								0
77	" " 50																1		1	2															0								0
78	" " 53																			C							1								1								0
79	" " 54														4					4															0								0
80	" " 55															1				1															0								0
81	" " 56													1						1															0								0
82	" " 57																			0						1									1								0

Table 12. A summary of the dicotyledons which appear to be characteristic of each of the environments. The taxa numbers refer to those listed in Table 11.

Swamps (60 species)					Bottomlands (49 species)			
Taxa Numbers					Taxa Numbers			
1	14(?)	29	45	65	3	22	38	56(?)
2	16	30	46(?)	66	4	23	41(?)	59(?)
3	17	33	47	68	5	26	42	61(?)
4	18	34	49	69	7	27	43	63
6	19	35	50	71	10	28	44	64
7(?)	20	36	52	73	11	29	46	67
8	21	39	53	74	12	31	48	68
9	23	40	57	76	13	32	50	70
10	24	41	58	77	14	34	51	71
11	25	42	59	79	15	35	53	72
12	26	43	62	80(?)	18	36	54	75(?)
13	27(?)	44(?)	63	81	19(?)	37	55	78
								82

APPENDIX V

PHYSIOGNOMY OF LEAVES FROM A MICHIGAN FOREST

Table 13. Leaf margins and Raunkiaer leaf size classes of the woody dicotyledons of Sanford Natural Area, Michigan State University, East Lansing, Michigan. The species have been determined by Beaman (1970) and all measurements were made by me from herbarium specimens.

Taxa	Entire Leaf Margins	Size Class
Acer negundo		Notophyll
A. nigrum		Mesophyll
A. platanoides		Mesophyll
A. rubrum		Mesophyll
A. saccharinum		Notophyll
A. saccharum		Mesophyll
Amelanchier laevis		Microphyll
Asimina triloba	X	Mesophyll
Berberis thunbergii	X	Nanophyll
Carpinus caroliniana		Notophyll
Carya cordiformis		Notophyll
C. ovata		Mesophyll
Celastrus scandens		Microphyll
Celtis occidentalis		Notophyll
Cephalanthus occidentalis		Mesophyll
Cornus alternifolia	X	Microphyll
C. amomum		Microphyll
C. florida	X	Microphyll
C. foemina	X	Microphyll
C. stolonifera	X	Microphyll
Crataegus macrosperma		Notophyll
C. mollis		Notophyll
C. punctata		Microphyll
C. succulenta		Notophyll
Dirca palustris		Microphyll
Euonymus atropurpureus		Notophyll
E. obovatus		Microphyll
Fagus grandifolia		Notophyll
Fraxinus americana		Mesophyll
F. nigra		Notophyll
F. quadrangulata		Notophyll
Gleditsia triacanthos	X	Nanophyll
Gymnocladus dioica	X	Microphyll
Hamamelis virginiana		Microphyll
Ilex verticillata		Microphyll

APPENDIX V (Cont.)

Taxa (Cont.)	Entire Leaf Margins	Size Class
Juglans cinerea		Microphyll
J. nigra		Microphyll
Lindera benzoin	X	Notophyll
Liriodendron tulipifera	X	Mesophyll
Menispermum canadense		Mesophyll
Morus alba		Mesophyll
M. rubra		Mesophyll
Ostrya virginiana		Notophyll
Parthenocissus quinquefolia		Notophyll
Platanus occidentalis		Macrophyll
Populus deltoides		Mesophyll
P. grandidentata		Notophyll
P. tremuloides		Mesophyll
Prunus serotina		Microphyll
P. virginiana		Notophyll
Ptelea trifoliata	X	Notophyll
Quercus alba		Mesophyll
Q. bicolor		Mesophyll
Q. macrocarpa		Mesophyll
Q. muhlenbergii		Mesophyll
Q. rubra		Mesophyll
Q. velutina		Mesophyll
Rhus typhina		Microphyll
Ribes cynosbati		Microphyll
R. sativum		Mesophyll
Rubus allegheniensis		Microphyll
R. occidentalis		Notophyll
R. strigosus		Microphyll
Salix amygdaloides		Notophyll
S. discolor	X	Microphyll
S. fragilis		Microphyll
S. interior		Microphyll
S. rigida		Notophyll
Sambucus canadensis		Notophyll
S. pubens		Microphyll
Sassafras albidum	X	Mesophyll
Staphylea trifolia		Notophyll
Tilia americana		Mesophyll
Toxicodendron radicans		Notophyll
T. vernix	X	Microphyll
Ulmus americana		Notophyll
U. rubra		Notophyll
U. thomasi		Mesophyll
Viburnum acerifolium		Notophyll
V. lentago		Mesophyll
V. recognitum		Notophyll
V. trilobum		Microphyll
Vitis riparia		Mesophyll
Zanthoxylum americanum		Nanophyll

APPENDIX VI

PHYSIOGNOMY OF LEAVES IN THE BLACKHAWK FLORA

Table 14. Those dicotyledons of the Blackhawk Formation which have entire margins, pinnate nervation, coriaceous texture, and drip points. The average size of the leaves in cm^2 and Raunkiaer leaf size class is also indicated. When there was a possibility that the average size of the leaves could be larger if more had been measured, the leaf size class indicates a range from one class to another.

	TAXA	Entire Margin	Pinnate Nervation	Coriaceous Texture	Drip Point	cm^2	Size Class
1	*Anona? robusta*	X	X		?	14	Microphyll
2	*Acer cretaceum*					37	Notophyll
3	*Apocynophyllum giganteum*	X	X	X	X	68	Mesophyll
4	*Celastrophyllum carolinensis*		X		?	34	Notophyll
5	*Celastrophyllum cretaceum*	X	X		?	1	Nanophyll
6	*Celastrophyllum undulatum*		X	X		29+	Microphyll-Mesophyll
7	*Cercidiphyllum arcticum*					9	Microphyll
8	*Cinnamomum intermedium*	X	X		?	13+	Microphyll-Notophyll
9	*Cinnamomum sezannense*	X	X	X		8	Microphyll
10	*Cissus marginata*		X			11	Microphyll
11	*Cornus denverensis*	X	X		X	21+	Microphyll-Notophyll
12	*Cornus praeimpressa*	X	X	X	X	9	Microphyll-Notophyll
13	*Dombeyopsis obtusa*	X		X		24	Notophyll
14	*Dryophyllum subfalcatum*		X	X	X	15	Microphyll-Notophyll
15	*Dryophyllum whitmani*		X	X	?	27	Notophyll
16	*Fagus cretacea*	X	X			11	Microphyll
17	*Ficus glassconea*	X	X	X	?	60	Mesophyll
18	*Ficus laurophylla*	X	X	X	?	34	Microphyll-Notophyll
19	*Ficus planicostata*	X		X	X	70	Mesophyll
20	*Ficus post-trinervis*	X	?		X	19	Microphyll
21	*Ficus puryearensis*	X	X	X	?	28	Notophyll
22	*Laurophyllum coloradensis*	X	X	X	X	14	Microphyll
23	*Laurophyllum meeki*	X	X		X	44	Notophyll
24	*Liriodendron alatum*	X	X	X	?	21	Notophyll
25	*Magnolia amphifolia*	X	X	X	X	40+	Notophyll-Mesophyll
26	*Magnoliophyllum cordatum*	X	X	X	X	77	Mesophyll
27	*Manihotites georgiana*	X		X		400	Macrophyll
28	*Menispermum dauricumoides*					30	Notophyll
29	*Myrtophyllum torreyi*		X		X	17	Microphyll
30	*Nymphaeites dawsoni*	X				4	Microphyll
31	*Pararymphaea crassifolia*			X	X	69	Mesophyll
32	*Phyllites craigensis*		X		?	47	Mesophyll
33	*Phyllites wilderi*	X	X		?	28	Notophyll
34	*Phyllites vermejoensis*	X	X	X	X	14	Microphyll
35	*Platanus alata*	X		X		218	Mesophyll

APPENDIX VI (Cont.)

	Taxa (Cont.)	Entire Margin	Pinnate Nervation	Coriaceous Texture	Drip Point	cm^2	Size Class
36	*Platanus raynoldsii*			X		58+	Notophyll-Mesophyll
37	*Pterospermites undulatus*	X	X	X		23	Notophyll
38	*Populus? apiculata*	X	X		X	26	Notophyll
39	*Quercus stantoni*		X		?	74	Mesophyll
40	*Ranunculus (?)* sp.		X			8	Microphyll
41	*Rhamnites eminens*	X	X	X	X	16	Microphyll
42	*Rhamnus salicifolius*	X	X		X	10	Microphyll
43	*Salix gardneri*	X	X		X	4	Microphyll
44	*Salix lancensis*	X	X		X	6	Microphyll
45	*Salix proteaefolia*	X	X		X	4	Microphyll
46	*Salix stantoni*	X	X		X	11	Microphyll
47	*Sapindus morrisoni**	X	X		?	12	Microphyll
48	*Trapa paulula*				?	1	Nanophyll
49	*Trapa* sp.					1?	Microphyll
50	*Viburnum antiguum*		X	X		42	Notophyll
51	Unknown dicotyledon 2		X		X	12	Microphyll
52	" " 9	X	X		?	20	Microphyll
53	" " 13	X	X	X	X	33	Notophyll-Mesophyll
54	" " 14	X	X			2+	Nanophyll
55	" " 15	X	X			12	Microphyll
56	" " 16		X			1	Nanophyll
57	" " 17	X	X	X		10	Microphyll
58	" " 18	X	X	X		36	Notophyll
59	" " 19	X	X	X	?	25	Microphyll-Notophyll
60	" " 20	X	X		X	10	Microphyll
61	" " 24	X	X			6	Microphyll
62	" " 25	X	X	X	X	11	Microphyll
63	" " 26	X				21	Microphyll-Notophyll
64	" " 27	X	X		X	7	Microphyll
65	" " 30	X	X	X	?	8	Microphyll
66	" " 32	X	X		X	33	Notophyll
67	" " 33	X	X	X		31	Notophyll
68	" " 35		X	X	?	46	Mesophyll
69	" " 36	X		X		36	Mesophyll
70	" " 37	X	X			15	Microphyll
71	" " 40	X	X			22	Microphyll-Notophyll
72	" " 41	X		X	?	21	Notophyll
73	" " 44	X	X		X	13	Microphyll
74	" " 46	X	X		?	10	Microphyll
75	" " 47		X		?	17	Microphyll
76	" " 49		X	X	?	55	Mesophyll
77	" " 50	X	X		?	1	Nanophyll
78	" " 53	X	X	X	?	1	Nanophyll
79	" " 54	X	X	X	?	18	Microphyll
80	" " 55	X	?		?	18	Microphyll
81	" " 56	?	?		?	70	Mesophyll
82	" " 57	X	X	X		2	Nanophyll

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PLATES

Plate 1

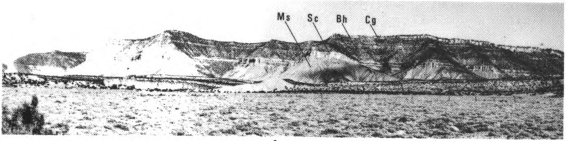
Figure

1. The southern end of the Wasatch Plateau viewed toward the west from near Emery, Utah. The Mancos Shale (Ms) forms the lower slopes of the Plateau while the Star Point Sandstone Formation (not distinguished on the photograph) and the Spring Canyon Member (Sc) of the Blackhawk Formation are resistant cliff forming units midway up the face of the Plateau. The Blackhawk Formation (Bh) extends from the base of the Spring Canyon Member to the base of the resistant sandstone cliff at the top of the Plateau formed from the Castlegate Sandstone (Cg) of the Price River Formation. The fossil plants discussed in this study were collected in the middle and lower portions of the Blackhawk Formation.

2. The collection locality at Water Hollow Road in Salina Canyon viewed toward the northwest from Interstate 70. Several major fossil plant collections (Fp) were made in the alternating fluvial swamp sediments seen here. Numerous palm leaves and other fossils can be seen on lower surfaces of the overhanging ledges including those discussed in Units M and O, see text Figure 7 and Plate 11, Figure 2. A massive in-channel point bar (P) capped the swamp. Load casts and cross bedding in the point bar indicate that the river was flowing in a southwest direction in this particular meander.

3. The collection locality at the Knight Mine in the Ivie Creek area of eastern Salina Canyon looking north. The Spring Canyon Member (Sc) of the Blackhawk Formation is the massive, white sandstone. Fossil plant collections (Fp) were made in fluvial sandstones and siltstones of floodplain origin above the littoral marine Spring Canyon sandstones. The entrance to the abandoned Knight Mine (K) and three coal dumps can be seen.

PLATE 1



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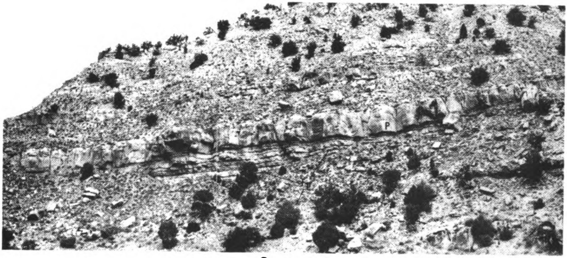

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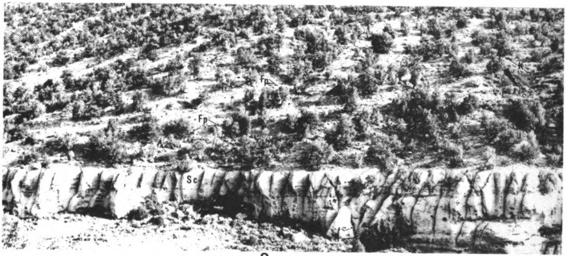


3

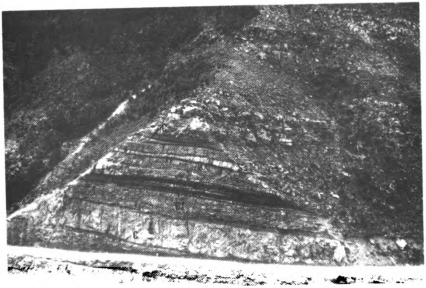
Plate 2

Figure

1. A recent roadcut opposite (southeast) the Water Hollow Road collection locality seen in Plate 1, Figure 2. The alternating fluvial sandstones, siltstones, shales and coals indicate the local extent of the peat forming swamps near an actively meandering river. Note the several thinning coals (C) wedge-shaped sandstones (Ss) and particularly the three thin lenticular channel fills (Cf) within the coal in the middle of the roadcut.

2. A roadcut at the Pipe Springs locality in Salina Canyon looking north from Interstate 70. Wedge-shaped sandstones (Ss) and split coals (Sc) are present. A 10 m thick point bar (P) has several interesting fluvial sedimentary features such as cross bedding and load casts. Also present are 5 dm diameter fossil log casts. Plant collections made here were about 1/4 of the way up the slope at the right of the roadcut. The Castlegate sandstone (Cg) is near the top of the mountain approximately 170 m above the road. The lenticular point bar sandstones seen in text Figure 11 are about 300 meters to the right of the roadcut.

PLATE 2



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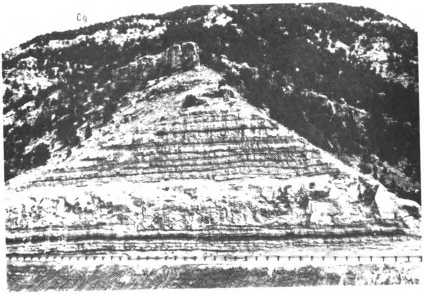

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Plate 3

Figure

1. *Cyathea pinnata* (MacGinitie) LaMotte. Portion of frond showing ultimate pinnules and veins. No. 6/1/68, 018-031. X 2.

2. *Asplenium dicksonianum* Heer. Portion of frond. Secondary veins in pinnules could not be seen. Drawn from specimen no. 8/24/70, 013-023.

3. Unknown fern 1. Tripinnate portion of a frond. Secondary veins can be seen. No. 8/28/70 II, 024-067.

4. Unknown fern 1. Tripinnate portion of a frond. No. 8/28/70 II, 028-091.

5. Unknown fern 1. Large ultimate pinnule. No. 8/28/70 II, 028-093.

6. *Osmunda hollicki* Knowlton. Portion of frond. No. 7/30/70 II, 027-061. X 2.

PLATE 3

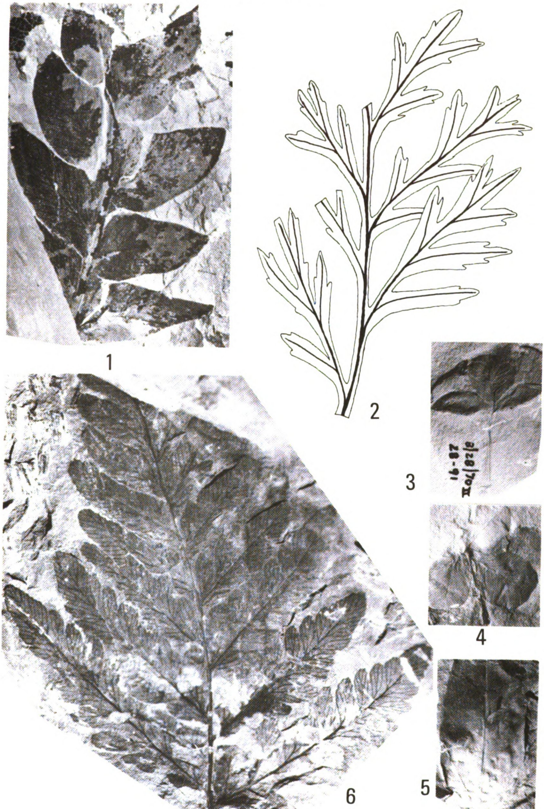

Plate 4

Figure

1. *Onoclea hebridica* (?) (Forbes) Bell. Portion of a frond. Note the small gastropod to the left. Nos. 7/11/70 II, 153-338; 7/11/70 II, 153-341.

2. *Onoclea hebridica* (?) (Forbes) Bell. Portion of a large frond. No. 7/11/70 II, 175-427.

3. *Brachyphyllum macrocarpum* Newberry. Fragment of an older stem. Casts of a scale-like rhombobedral leaves can be seen. No. 8/19/70, 068C-100.

4. *Araucarites* sp. Tip of leafy twig. No. 7/22/70, 050-083.

5. *Araucarites* sp. Transverse view of a leafy twig showing arrangement of leaves. No. 7/22/70, 018-033.

6. *Araucarites* sp. Portion of a leafy twig. No. 7/22/70, 062-097.

7. *Araucarites* sp. Branching twig. No. Above R. R. cut, 091.

8. *Araucarites* sp. Older leafy twig with leaf scars. Leaf length is no greater in this specimen than in younger ones. No. 7/22/70, 064-109.

9. *Brachyphyllum macrocarpum* Newberry. Branching stem. No. 8/19/70, 018-053.

PLATE 4

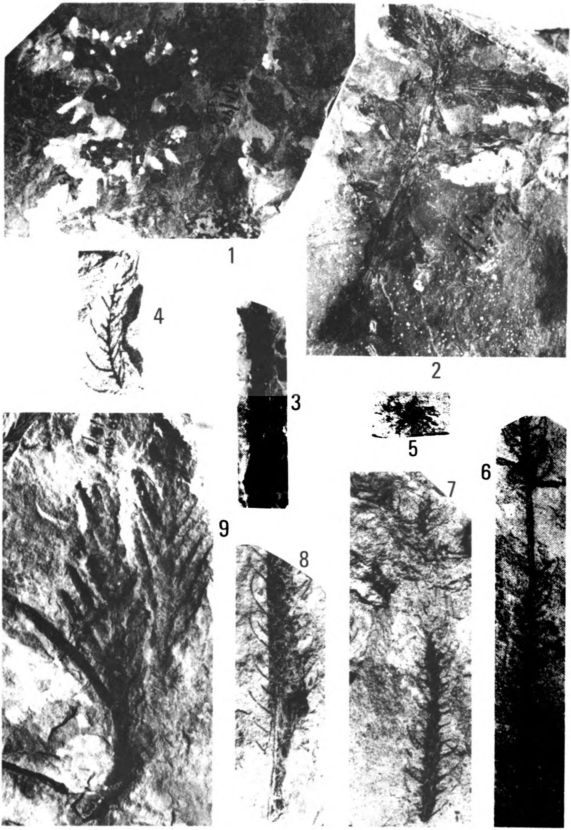

Plate 5

Figure

1. *Brachyphyllum macrocarpum* Newberry. Reconstruction of specimen no. 8/19/70, 054-119. X 1.

PLATE 5

1

Plate 6

Figure

1. *Nageiopsis* sp. Portion of a branching axis. No. 8/19/70, 068B-159.

2. *Nageiopsis* sp. Leafy twigs showing spiral origin of leaves. No. 8/19/70, 006-016.

3. *Moriconia cyclotoxon* Debey and Ettingshausen. Branching axis with impressions of the scale-like leaves. No. 7/11/70 II, 084-240.

4. *Moriconia cyclotoxon* Debey and Ettingshausen. Branching axis with male strobili (Ms) at the end of the ultimate branches. No. 8/15/70, 031-091. X 2.

5. *Nageiopsis* sp. Leaves with parallel venation. No. 8/19/70, 053-117. X 2.

6. *Podozamites* sp. Leaf. No. 8/19/70, 059-125.

7. *Podozamites* sp. Leaf with parallel venation. No. 8/13/70, 008-027.

8. *Nageiopsis* sp. Branching axis with 3 orders of branching. No. 8/19/70, 005-019.

9. *Protophyllocladus polymorpha* (Lesq.) Berry. Phyllode. No. Unit I, 699.

10. *Protophyllocladus polymorpha* (Lesq.) Berry. Phyllode. No. 8/24/70, 001-004.

PLATE 6

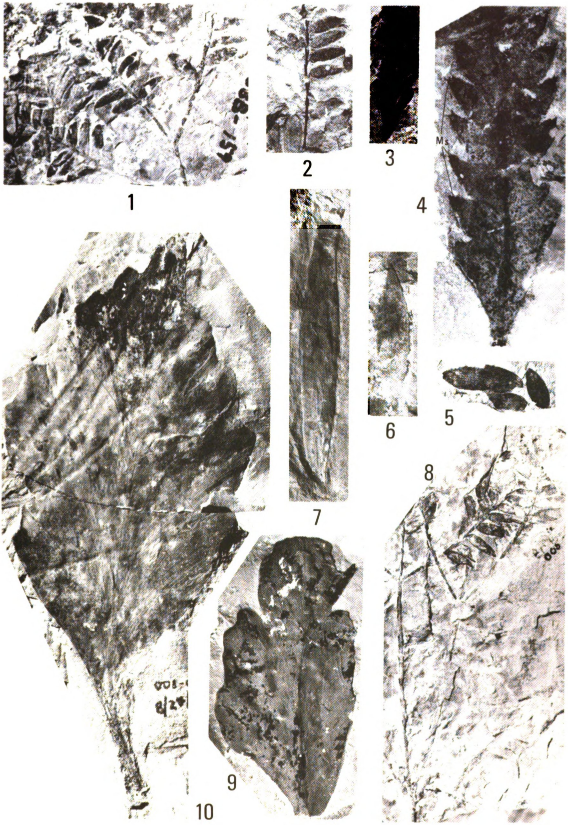

Plate 7

Figure

1. *Moriconia cyclotoxon* Debey and Ettingshausen. Reconstruction of specimen no. 8/20/70, 014-043.

PLATE 7

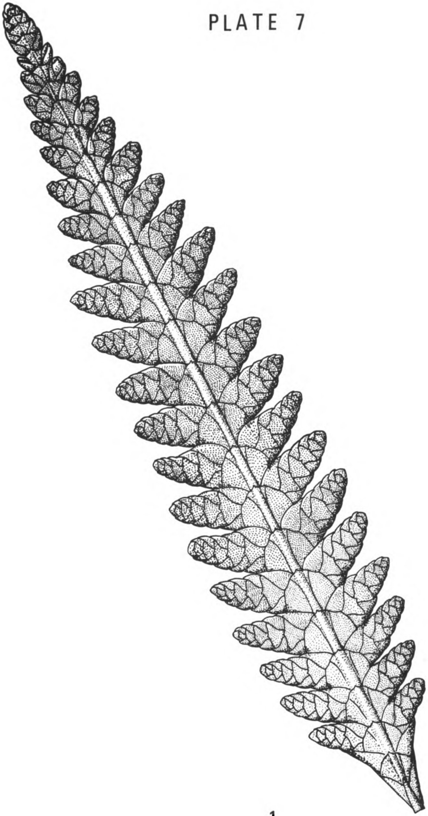

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Plate 8

Figure

1. *Widdringtonites reichii* (Ettingshausen) Heer. Twig with small leaves. No. 8/15/70, 004-007.

2. *Protophyllocladus* sp. 2. Reniform phyllode with serrate margin. No. 7/28/70 II, 022-041.

3. *Protophyllocladus polymorpha* (Lesq.) Berry. Phyllode with the bases of two others (Pb) diverging from the stem. No. 8/24/70, 015-024.

4. *Sequoia cuneata* Newberry. Short shoot. No. 7/11/70 II, 080-256.

5. *Protophyllocladus polymorpha* (Lesq.) Berry. Portion of a phyllode showing petiole-like base, midrib and venation. No. 8/24/70, 021-031.

6. *Widdringtonites reichii* (Ettingshausen) Heer. Branching stems. No. 8/15/70, 039-079.

PLATE 8

Plate 9

Figure

1. *Sequoia cuneata* Newberry. Long and short shoots. No. 7/11/70 II, 168-417.

2. *Sequoia cuneata* Newberry. Transverse view of a pistillate cone (probably immature) showing 5 peltate cone scales. No. 7/11/70 II, 058-186.

3. *Sequoia cuneata* Newberry. Immature pistillate cone. No. 8/14/70, 001-003.

4. *Sequoia cuneata* Newberry. Lower portion of a pistillate cone with attachment to a foliar stem. Cone scales have separated in dehiscence and have been preserved in an oblique angle. No. 8/24/70, 013-019. X 2.

5. *Sequoia cuneata* Newberry. Pistillate cone showing approximate shape before dehiscence. No. 7/11/70 II, 057-185.

6. *Sequoia cuneata* Newberry. Scales from pistillate cone. Note the features of the hexagonal scale at the top. No. 8/13/70, 016-059.

7. *Sequoia cuneata* Newberry. Seed(s). To its left is a short shoot and to its right is a portion of a pistillate cone. No. 8/13/70, 020-078.

8. *Sequoia cuneata* Newberry. Twig with awl-shaped leaves. No. 8/24/70, 002-006.

9. *Sequoia cuneata* Newberry. Older twig with leaf scars. No. 8/24/70, 003-008.

10. *Sequoia cuneata* Newberry. Shoots bearing staminate cones (Sc). No. 8/24/70, 004-009.

11. *Sequoia cuneata* Newberry. Short shoot. No. 8/24/70, 002-006.

12. *Sequoia cuneata* Newberry. Long shoot with short shoots. No. R. R. cut, 1526.

13. *Sequoia cuneata* Newberry. Long shoot with short shoots. No. 8/24/70, 006-010.

PLATE 9

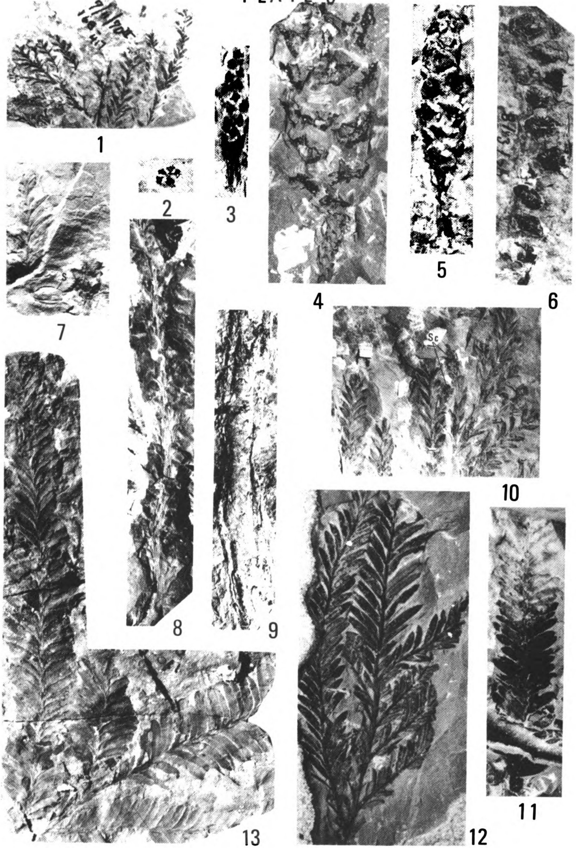

Plate 10

Figure

1. *Sequoia cuneata* Newberry. Reconstruction based upon specimen no. 8/24/70, 013A-020A. X 0.6.

PLATE 10

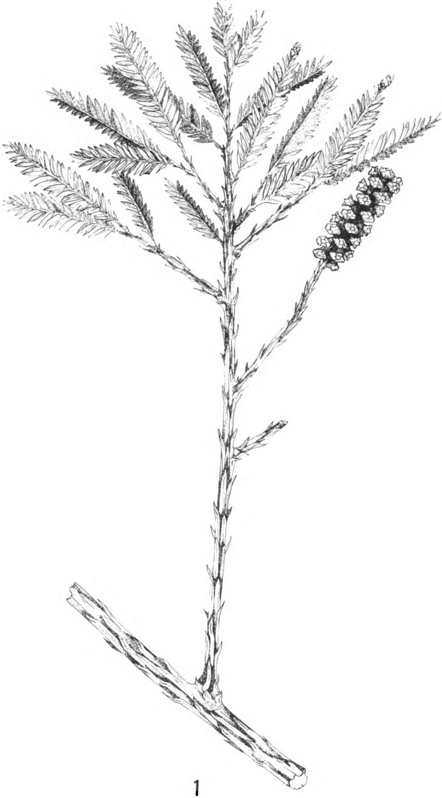

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Plate 11

Figure

1. *Geonomites imperialis* (Dawson) Bell. Portion of a leaf near the base of the blade. No. Unit I, 693. X 0.5.

2. *Geonomites imperialis* (Dawson) Bell. A leaf "mat" seen on the undersurface of an overhanging ledge of Unit O at the Water Hollow Road locality. An incomplete leaf (A) with its apex toward the left is 1.2 m in length. A portion of a second leaf (B) with its apex toward the right has an expanded petiole base (pb), an unarmed petiole (p), and the lower portion of the leaf blade (b). It is about 1 m in length. These specimens could not be removed from the site.

3. *Geonomites imperialis* (Dawson) Bell. Portion of a leaf. No. Unit I, 142.

4. *Sequoia cuneata* Newberry. Cuticle removed from a leaf of the specimen illustrated in Plate 9, Figure 11, showing impressions of epidermal cells including 3 stomata (s). The guard cells were apparently sunken and are therefore not seen. Scale as indicated.

PLATE 11