DELTAIC AND SHELF DEPOSITS IN THE CRETACEOUS BLACKHAWK FORMATION AND MANCOS SHALE, GRAND COUNTY, UTAH

by

Marjorie A. Chan, Stephen L. Newman, and Fred E. May

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DELTAIC AND SHELF DEPOSITS IN THE CRETACEOUS BLACKHAWK FORMATION AND MANCOS SHALE, GRAND COUNTY, EAST-CENTRAL, UTAH

by

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ABSTRACT

Continuous, well-preserved clastic depositional units south of the Book Cliffs escarpment of east-central Utah offer exceptional exposures of ancient deltaic, shoreline, shelf and offshore rocks. A stratigraphic and sedimentologic context for these Cretaceous units is an important tool in exploration for coal, oil, and gas, and for recognition of sand-body geometries in the subsurface. This study concentrates on the genetic relationships of litho- and depositional facies in the Upper Cretaceous Blackhawk Formation and Mancos Shale located in Grand County, Utah. Some sandstone and siltstone portions of the study section are correlative to the gas-productive Mancos B interval of the Mancos Shale in western Colorado. Both vertical and lateral facies relationships contribute to models for shelf deposition and sequence stratigraphy, which can be applied to other portions of the Western Interior seaway. Detailed stratigraphic sections establish important correlations for interpreting depositional sequences and controls on shelf sedimentation. These sections will also serve as a significant reference for geologists in both industry and academia, who commonly visit and study these areas of the Book Cliffs.

Attempts to date anomalous offshore sand bodies yielded the discovery of new species of dinoflagellates and palynomorphs that have not been previously described for the study portion of the Cretaceous Western Interior.

INTRODUCTION

The Book Cliffs of east-central Utah contain spectacular and extensive exposures of non-marine to offshore marine facies in several cyclic packages. Exposures in the Book Cliffs and including the study area (Figs. 1 and 2) are recognized as classic examples for training in clastic facies relationships, depositional models and for establishing standards in sequence stratigraphy.

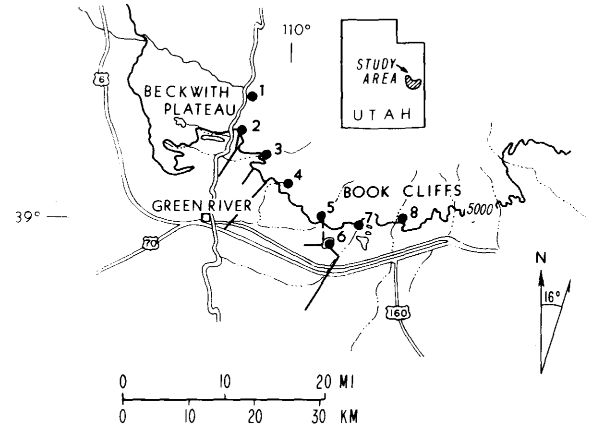

Fig. 1. Study area location in east-central Utah. Measured sections of Plate 1 are labeled 1 through 8.

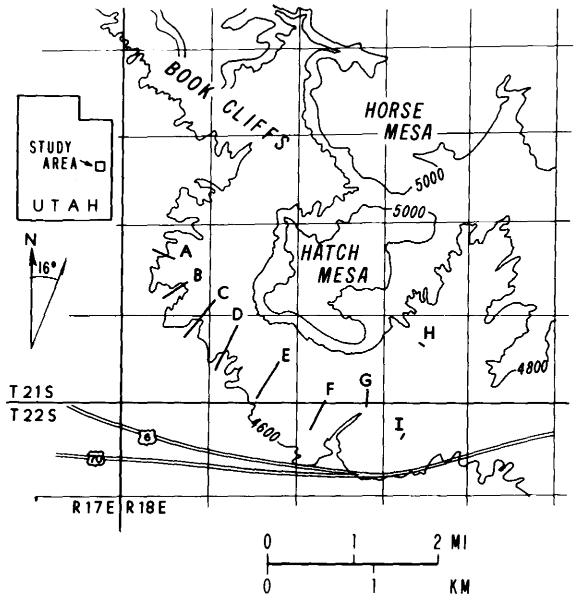

Fig. 2. Location of Hatch Mesa measured sections of Plate 2, labeled A through H.

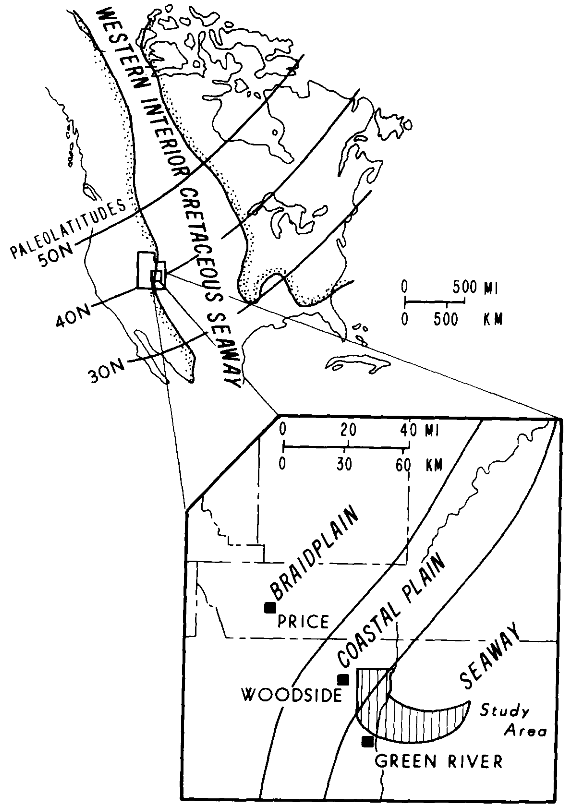

Fig. 3. Cretaceous Western Interior seaway (modified from Gill and Cobban, 1973) with shoreline orientation of Western Interior seaway relative to study area (modified after Fouch and others, 1983).

The Upper Cretaceous Mesaverde Group of Utah contains regressive sandstone tongues, partially derivived from western sources such as the Sevier orogenic belt. These clastic tongues were deposited along the western shoreline of an epieric sea (Fig. 3) and interfinger with transgressive units. Within the Mesaverde Group and Mancos Shale, several formations have been distinguished (Figs. 4 and 5). The interval of this study (Fig. 4) is the Campanian Blackhawk Formation and portions of the Santonian to Campanian Mancos Shale, in the Book Cliffs area of Green River, Utah to Crescent Junction, Utah. This particular interval demonstrates a variety of wave-dominated to fluvial-influenced deltaic facies and shelf facies. Some of the shelf facies are unique and have important sedimentologic implications.

The purpose of this paper is to present detailed stratigraphic and sedimentologic information on a well-exposed and variable portion of the Upper Cretaceous section in Grand County, east-central Utah. This study describes a 35 mile (56.3 km.) section north of Green River, Utah, to a section north of Crescent Junction, Utah (Figs. 1 and 2). Cliffs in the study area are steep to nearly vertical, and range in height from 800 to 1200 ft (243 to 365 m) (Fig. 5). Semi-regularly spaced canyons (averaging from 1 to 4 mi; 1.6 to 6.5 km.) apart permit access to the exposures along the entire 200 to 220 mi (323 to 355 km) extent of the Book Cliffs from central Utah to western Colorado. The detailed correlations and sedimentology presented here also complement mapping work of the Crescent Junction quadrangle area (J. Chitwood, 1989 pers. comm.).

An additional objective of this study was to specifically age date samples from the Mancos Shale, to tie isolated sandstone bodies to the named shoreline units. Age dates using palynological analyses on samples from beneath or above the isolated sandstone bodies would help determine whether or not these bodies occur at sequence (and/or stage) boundaries. Although the Blackhawk Formation is dated as Campanian (about 80-83 my), there have been no definitive dates in this area for the Cretaceous Mancos section between the Blackhawk Formation and Dakota Sandstone; an interval spanning the Santonian, Coniancian, Turonian, and Cenomanian.

The genetic relationships of these facies can yield important information about paleogeography, the location and geometry of sand bodies (potential reservoirs), and the intra- or extra-basinal controls on deposition. Mitchum and others (1977) emphasized the importance of depositional sequences (any succession of genetically related strata) and their corresponding sequence boundaries or unconformities (which can be distinguished in the field). Such studies on "sequence stratigraphy" (e.g., Van Wagoner and others, 1988; Van Wagoner and others, 1990) can lead to interpretations of the magnitude and effect of sea-level change on local and/or global scales. This study utilizes some of the sequence stratigraphic concepts and attempts to recognize Cretaceous boundaries and unconformities exposed in the study section of east-central Utah.

A significant portion of this study is based on the M.S. thesis work (Newman, 1985) completed at the University of Utah, with additional sampling and synthesis by the senior author. The stratigraphic measurements of this study are summarized in two plates:

(1) A detailed measured stratigraphic section and correlation chart (Plate 1) of the Cretaceous Blackhawk Formation (Desert, Grassy and Kenilworth Members) and Mancos Shale (Bluegate Member, Emery Sandstone, Ferron Sandstone, Tununk Member) between the Green River and Crescent Canyon, east-central Utah, (over a distance of about 40 km (25 mi), including

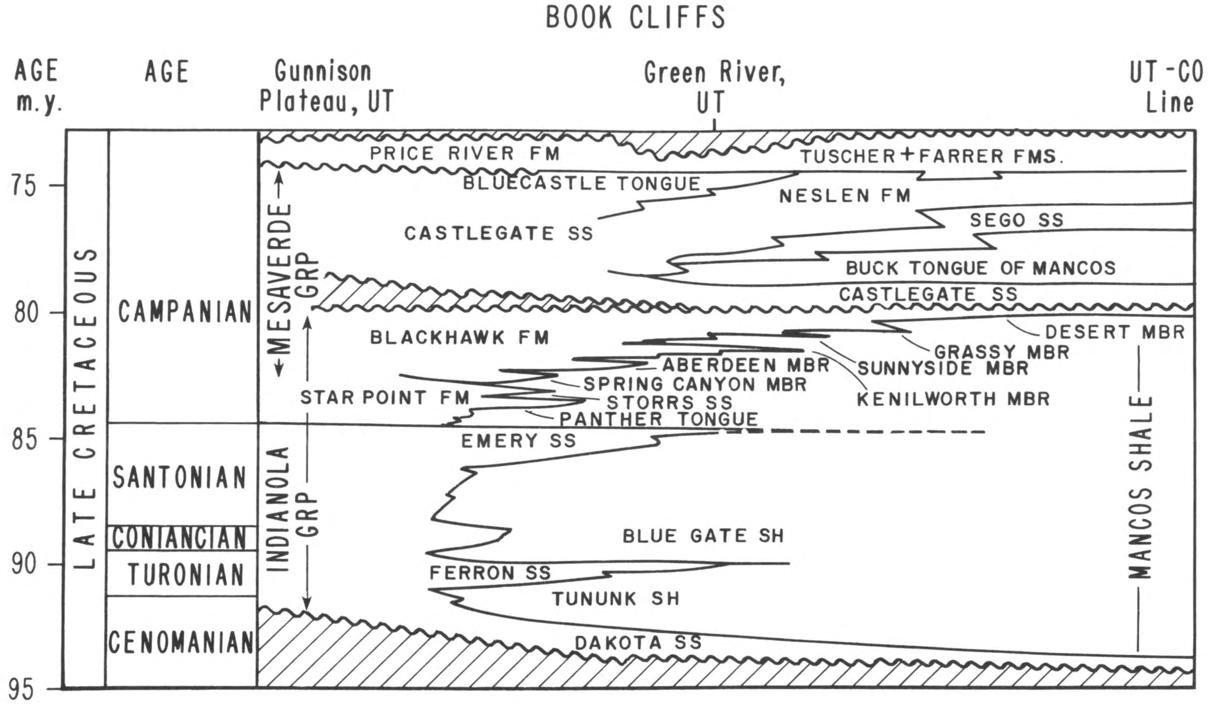

Fig. 4. Generalized cross-section of stratigraphic units (modified after Fouch and others, 1983).

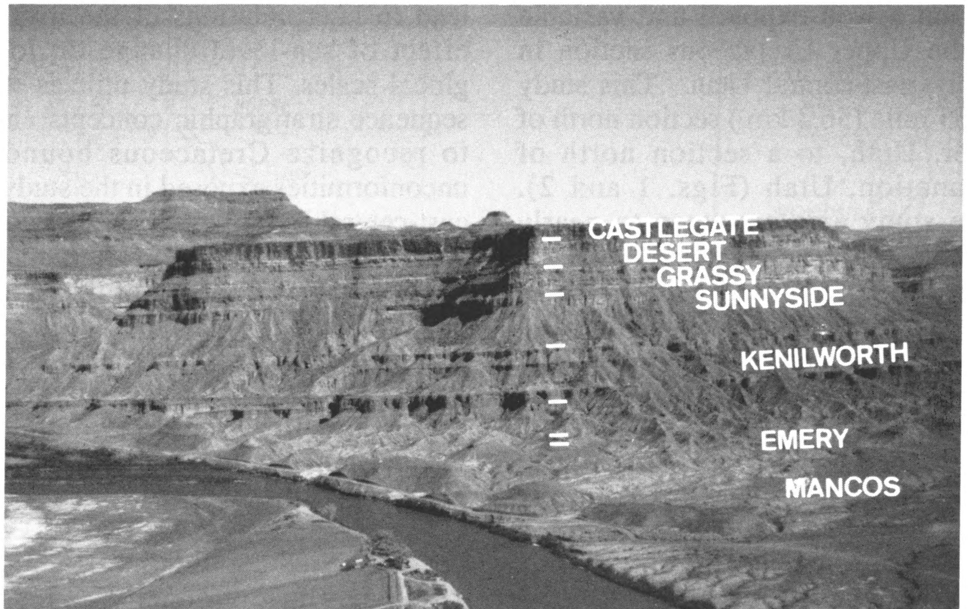

Fig. 5. Members of the Blackhawk Formation including the Desert, Grassy, Sunnyside, and Kenilworth. Location: Green River, Utah.

sections at Gray Canyon, Tuscher Canyon, Coal Canyon, Horse Canyon, Hatch Mesa, Floy Canyon, and Crescent Canyon).

(2) A detailed measured stratigraphic section and correlation chart (Plate 2) of the Cretaceous Mancos Shale (and Emery Sandstone?) from the Hatch Mesa area (Crescent Junction Quadrangle, Grand County), east-central Utah, (over a distance of about 5 km or 3 mi).

GEOLOGIC SETTING

Upper Cretaceous deposits of the Book Cliffs in east-central Utah are unique in exhibiting classic facies relationships, cyclicity (transgressions-regressions) and intertonguing of fluvial, deltaic, shoreline, shelf and offshore facies. Depositional models derived from these examples are significant to the understanding of deltaic and shoreline - shelf processes, and have important applicability to coal and hydrocarbon exploration (Rice and Gautier, 1983). These Cretaceous rocks have also been particularly instrumental in distinguishing eustatic events and in developing global sea-level curves (e.g., Haq and others, 1987; 1988).

The Cretaceous epicontinental sea (Kauffman, 1977) was a broad, N-S trending foreland basin which formed during subduction of the Farallon plate beneath the North American plate. Stratigraphic sequences are largely the result of interactions between tectonism (associated with eastward thrusting), eustasy, and sedimentation. Pulses of the Sevier Orogeny provided the western margin of the basin with a large volume of terrigenous clastics.

The overall style of sedimentation in this area of the Book Cliffs was dominated by clastic shoreline deposition (associated with a wave-dominated deltaic and interdeltaic systems, Fig. 6). Stacked strand-plain packages are common with major coal seams inferred to have accumulated in coastal-plain and lagoonal-swamp environments. The western shoreline of the epicontinental sea (Fig. 3) vacillated within the Book Cliffs area during the Late Cretaceous, although the dominant trend was NE-SW (Fouch and others, 1983). The climate is inferred to have been warm temperate to sub-tropical, as evidenced by the types and abundance of plants (Balsley, 1982).

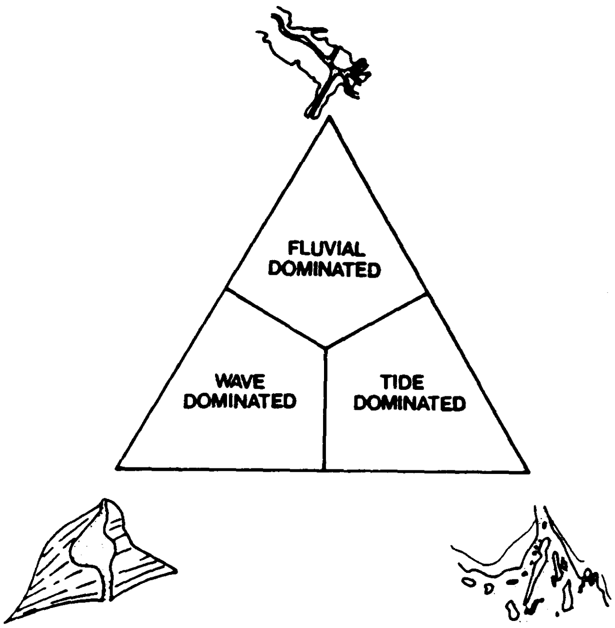

Fig. 6. Classification of deltaic systems (modified after Galloway, 1975).

Structural features in the study area include deformation during the latest Cretaceous to early Cenozoic Laramide Orogeny (Kauffman, 1977), as well as uplift of the Colorado Plateau (Stokes, 1986). Small-scale faulting, especially at the northern end of the

Salt Valley deformational trend (Fig. 1), presents minor, but localized complications. The Laramide Orogeny (Late Cretaceous-Early Cenozoic) provided gentle regional and intense local uplift of Cretaceous basin-fill, and contributed to the final regression of the Western Interior seaway (Kauffman, 1977). Late Cenozoic structures are related to uplift of the Colorado Plateau, within about the last 2 milion years (Frazier and Schwimmer, 1987). Average strike of units within the study area is approximately N70E, and maximum dip is 5^{o} or 6^{o} to the north.

STRATIGRAPHY

Early studies of the general stratigraphy of the region include studies by Clark (1928) (ref. Hudleson, 1984), and Spieker and Reeside (1925). Spieker (1949) and Young (1955; 1957) described the cyclic nature of the deposits and proposed criteria for their recognition, as well as depositional environment interpretations. Balsley (1982) compiled a field guide on wave-dominated delta systems within the Book Cliffs, which summarized much of the previous work and added new lithofacies interpretations.

The generalized Cretaceous stratigraphic section depicts the intertonguing nature of the intertonguing sandstone and shale in central Utah (Fig. 4). The formations of this study include the Upper Cretaceous Blackhawk Formation and intertonguing Mancos Shale. Mappable units within the study area include the Ferron Sandstone (Turonian) and Emery Sandstone (Santonian) Members of the Mancos Shale, and the Kenilworth, Sunnyside, Grassy, and Desert Members (Campanian) of the Blackhawk Formation. Clastic tongues higher in the Mesaverde Group "pinch out" further east, thus displaying an overall progradational character with superimposed, relatively minor fluctuations of strandline position (Fig. 4). Much of the stratigraphic section in the study area between the Kenilworth Member and the Dakota Sandstone is a shaly interval. However, farther west, time-equivalent Campanian deposits to this shaly interval consist of the Star Point Sandstone (the Panther Tongue and Storrs Member) and the lowest two Members of the Blackhawk Formation (the Spring Canyon and Aberdeen Members), which pinch out west of the study area. Some sandstone bodies (Hatch Mesa Sandstone and "Mancos B" interval of Mancos Shale) occur isolated within the Mancos Shale, and are difficult to physically correlate. Stratigraphic correlations of these bodies are attempted in this study. Other workers propose that this section of isolated bodies is part of the Upper Blue Gate depositional sequence (Cole and Young, in press).

Fouch and others (1983) determined an average northeast-southwest paleoshoreline trend from outcrop and drillhole data (Fig. 3) across the Book Cliffs region. Within the study area, the cliffs trend northwest-southeast, so this stratigraphic cross-section view is approximately normal to paleoshoreline and permits examination of the nature of local shelf deposition and basin fill.

A brief summary of each of the stratigraphic units included in this study (Fig. 5) is given below (also see Plates 1 and 2).

Mancos Shale

The Mancos Shale is a widespread unit found in western Colorado, northwestern New Mexico, northeastern Arizona, and eastern Utah (Cross, 1899; Young, 1955). In this section of the Book Cliffs, it is a dark grey to steel-blue shale which forms much of the valley floor south of the escarpment (Figs. 4 and 5). The Mancos Shale is divided into four distinguishable members. In ascending order, these are the Tununk Shale, Ferron Sandstone, Bluegate Shale, and Emery Sandstone (Plates 1 and 2).

Tununk Shale Member

The Tununk Shale lies above fluvial and shallow-marine deposits of the Dakota Sandstone (Cenomanian) and ranges from 161 ft (49 m) to 171 ft (52 m) in the study area. It is recognized by its stratigraphic position and the occurrence of *Gryphaea newberryi* (now *Pycondonte* aff. *P. Kellumi*; ref. Walters and others, 1987) lying directly upon underlying Dakota Sandstone (see Sections 4 and 6; Plate 1). Pyrite concretions are abundant in the basal Tununk Shale.

Ferron Sandstone Member

The Tununk Shale is overlain by cuesta-forming Ferron Sandstone, which has an average thickness of 58 ft (18 m) in the study area. The Ferron Sandstone (see Section 4 of Plate 1) is composed of a thin (8 in; 21cm), well-sorted, medium-grained sandstone with numerous fish teeth, sole markings, burrows, and high-angle cross-stratification. Two thin medium-grained fishtooth-bearing sandstones with high-angle trough cross strata are recognized. These medium-grained sandstone beds vary in thickness over short distances, and bioturbation (*Ophiomorpha*) is restricted to the top portions of beds. The uppermost 53 ft (16 m) of the Ferron Sandstone at Section 4, and the uppermost 52 ft (16 m) at Section 6 (Plate 1) consists of interbedded shale and siltstone. These siltstones typically contain pelecypod molds, cephalopod molds, and sole marks. West of the study area, the Ferron Sandstone is divisible into two portions: the upper Ferron and the lower Ferron. The upper part of the Ferron is largely deltaic (e.g., Ryer, 1981a, b; Tripp, 1989; Gardner, 1989, pers. comm.) and the lower part of the Ferron contains shelf deposits (e.g., Cotter, 1975; Riemersma, 1987; Riemersma and Chan, in press).

Bluegate Shale Member

The Bluegate Shale Member consists of several major westward-extending tongues of shale (Plate 1) which lie between the Ferron and Emery Sandstone, and intertongue with sandstones of the Blackhawk Formation. The Bluegate Shale is grey to bluish-grey with common Inoceramus fragments and calcite veins. Septarian concretions of calcareous shale and fracture-filling calcite range from 4 in (11 cm) to 6 ft (1.8 m) in diameter, and are found at various stratigraphic intervals. Internal molds of Baculites are present in many shale hillocks supported by concretionary caps. The Bluegate Shale also contains numerous laterally continuous, thin sheets of calcareous siltstone averaging 8 in (21 cm) in thickness (Plate 1). These siltstones are structureless or display parallel laminae. Laminations may be deflected around randomly oriented Inoceramus fragments.

Emery Sandstone Member

Fouch and others (1983) report exposures of the Emery Sandstone Member of the Mancos Shale within the Green River area, which Fouch and Cashion (1979) also be correlated across the southern Unita basin. At a stratigraphic level believed to be correlative with Fouch's Emery Sandstone is a unit of interlaminated siltstone- and shale-filled channels isolated in the Bluegate Shale (Plate 1). Large shale hillocks in the Mancos badlands at the foot of the cliffs are sheltered by these channel fills. Channels range in width from approximately 10 to 120 ft (3 to 37 m), are 1 to 30 ft (0.3 to 9 m) deep, and are rarely exposed or preserved for more than a few tens of feet parallel to their axial direction. These trough-shaped channels have an axial orientation approximately normal to the average paleoshoreline trend determined by Fouch and others (1983). Angular discordances occur within fissile, and normally horizontally laminated shale. The channels are filled with current-rippled siltstones interstratified with silty shale. These siltstone beds commonly appear structureless, and may grade upwards to current ripples and rib-and-furrow structures exposed along bedding planes. Crawling traces are also present on bedding planes and numerous well-developed groove and prod marks are preserved along the soles of many beds.

Overlying the channelized strata, the Bluegate Shale thickens from west to east. The lower portion of this shale interval is fissile and shale laminae are distinct. The upper 2 to 3 ft (0.6 to 0.9 m), however, are typically burrowed and silty. Intense burrowing in the uppermost portion of this interval gives the shale a structureless appearance in outcrop.

Blackhawk Formation

The Blackhawk Formation was named by Spieker and Reeside (1925) for the coal-bearing rocks in the Book Cliffs and Wasatch Plateau. The formation consists of six members (Young, 1955), each of which contain cyclic progradational packages. In ascending order, these members are: Spring Canyon, Aberdeen, Kenilworth, Sunnyside, Grassy, and Desert (Fig. 5). This formation records a major eastward regression into the epeiric sea in Utah, with the eastward-extending tongues pinching out in the Bluegate Shale Member of the Mancos Shale Many of the facies (Table 1) are exemplified in the outcrop exposures within the Price area.

Within the Book Cliffs coal field, the Blackhawk strata have a total production of about 225 million tons, with an estimated 1 billion tons of recoverable coal still remaining (Stokes, 1986). In the Wasatch Plateau field, recoverable reserves are estimated at more than 3.2 billion tons. Multi-colored clinker beds are a result of burning coal, and oxidized iron in surrounding beds.

Although the bulk of the Blackhawk members contain non-marine coals (after which the formation is named), many of those coals pinch out, and/or decrease in abundance in the eastern part of the study area. Thus, much of the lithologic discussion focuses on the marine sections which make up the majority of the sand bodies in this study.

Other studies which deal with the Blackhawk Formation include: Clark (1928); Erdmann (1934); Fisher (1936); Fisher and others (1960); Spieker (1931); Young (1955, 1966); Balsley (1982); Newman (1985); Kamola and Howard (1985); Swift and others (1987); Cole (1987); and Cole and Friberg (1989).

Kenilworth Member

The Kenilworth Member of the Blackhawk Formation consists of four distinct tongues, each of which is an upward-coarsening package of interbedded shale and siltstone to very fine-grained sandstone. Each package coarsens upward in grain size, and bed thicknesses correspondingly increase upward. These features indicating shoaling in the packages.

The four Kenilworth tongues range in thickness from 5 ft (1.74 m) to 37 ft (11 m) (Section 2, Plate 1), to a feather edge eastward. Each tongue displays rippled-to-parallel-laminated siltstone (Bouma C-D sequences), and sandstone beds of current ripples and parallel laminae superimposed on one another. Hummocky cross-stratification and wave ripples occur in upper portions of the third highest tongue. *Thalassinoides* and *Ophiomorpha* burrow traces are particularly abundant.

Sunnyside Member

The Sunnyside Member is lithologically and morphologically similar to the Kenilworth Member. The Sunnyside Member has a gradational lower contact with the Bluegate Shale, and pinches out eastward from a thickness of 77 feet (23.5 m) (Section 2, Plate 1), to a feather edge (Sections 4 and 5, Plate 1).

The Sunnyside Member consists of

alternating siltstone and very fine-grained sandstone, and silty shale. Sandstone beds range in thickness from 6 in (15 cm) to 3 ft (0.9 m), and generally increase in thickness with higher stratigraphic position. Sedimentary structures in the lower sandstone beds include: load casts on siltstone bases, and structureless to parallel-laminated to rippled beds (Bouma A-B and Bouma A-C). Uppermost very fine-grained to fine-grained sandstone beds contain hummocky cross-stratification and wave ripples.

Grassy Member

The Grassy Member is composed of two prominent coarsening-upward tongues which have the greatest eastern extent in the study area. The lowest coarsening-upward tongue is composed of siltstones and fine-grained sandstones interbedded with organic-rich shale or silty shale. The predominant sedimentary structure is hummocky cross-stratification (Fig. 7). Other typical features in the sandstones are: load casts; flame structures; wave ripples; *Ophiomorpha* burrows (restricted to the tops of hummocky cross-stratified beds); and a few sole marks. The uppermost beds in the lower tongue are very fine-grained sandstones with some sandstone clasts, pelecypod fragments, and fish teeth.

The upper tongue is similar to the lower one, but is capped by coarser-grained sandstone and bituminous coal (up to 9.2 ft or 2.8 m thick). A light-grey to white, fine- to medium-grained sandstone with abundant plant fragments and trough cross-stratification overlies the hummocky cross-stratified beds. Interspersed with the trough cross-stratification is parallel- to low-angle lamination with abundant organic fragments and root casts in the upper 1.5 to 2 in (4 to 5 cm). This white to light grey sandstone is locally referred to as a whitecap (Young,

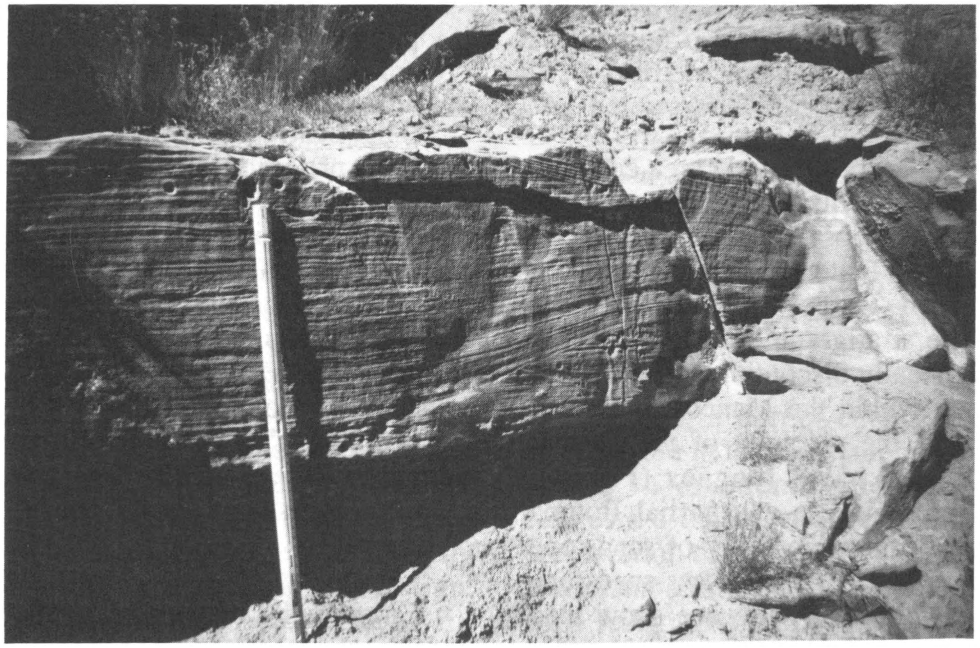

Fig. 7. Hummocky cross-stratification and *Ophiomorpha* burrows in the lower shoreface facies, Grassy Member of the Blackhawk Formation. Bed is ~2.2 ft (0.7 m) thick. Location: Section 1, Plate 1.

1955; Balsley, 1982).

Desert Member

The Desert Member is the youngest member of the Blackhawk Formation, and like the other members it coarsens upward. Lower beds are siltstone to very fine-grained sandstone. The sandstones typically contain hummocky cross-stratification. Bed thicknesses increase upward to an interval of trough cross-stratification within thick sandstone beds. At several localities in the study area, this trough cross-stratified portion of the Desert Member is incised by large channels approximately 150 ft (46 m) in width. The uppermost whitecap sandstone was chosen as the datum for Plate 1. The Desert Member displays load casts and numerous *Thalassinoides* and *Ophiomorpha* in lower to middle portions of the sequence, whereas the upper beds lack bioturbation and have an abundance of organic debris. Thin coals and channel-filling sandstones with trough cross-stratification characterize upper portions of the member, just beneath the overlying Castlegate Sandstone.

Hatch Mesa Sequence

The eastern part of the study area contains a thick sequence of siltstones and sandstones isolated in the Mancos Shale beneath Hatch Mesa (Fig. 2 and Plate 2). This interval is herein referred to as the Hatch Mesa sequence. The stratigraphic position of this interval is physically discontinuous because it occurs isolated within the Mancos Shale and lies eastward of the pinchout of the Ferron, Emery, and Blackhawk tongues (Fig. 4). Well-developed complete and partial Bouma sequences are common in many of sandstone beds. Some relatively structureless sandstone beds of the Hatch Mesa sequence show load casts, pinch and swells, large flame structures, and ball and pillow features. Dating studies (to be discussed later) on the shale intervals were used to try to bracket the age of the Hatch Mesa sequence.

Laterally discontinuous sequences of siltstone to fine-grained sandstone beds are exposed beneath Hatch Mesa. There is also an anomalous medium-grained, hematitic, oolitic ironstone, with fishteeth (Chan and others, 1987). These anomalous deposits encased in Mancos Shale are of particular interest because their origins are not well understood. The discontinuous oolitic ironstone (approximately 37 ft or 11 m below Sections D, E, F, G, and I; Plate 2) displays some high-angle cross-stratification, with numerous fishteeth, fish bones, internal molds of *Baculites*, bivalves, plant fragments, and hematite-stained mudstone laminae. Immediately beneath, and adjacent to these strata are scattered *Inoceramus* mounds in sandy micrites.

All sections of the Hatch Mesa sequence have much the same lithologies and trends (Plate 2); however, beds thin progressively eastward and large (20 to 30 ft; 6 to 9 m wide) scours occur within a thick bed in Section E (Plate 2).

Castlegate Sandstone

The Castlegate Sandstone records the eastward progradation of a fluvial-deltaic complex shed off the Sevier orogenic belt. Lateral changes in the sandstone occur from its type section located at Price Canyon, eastward to Green River, Utah where it can be subdivided into other formations/members (Lawton, 1983, 1986; Fouch and others, 1983; Franczyk and others, 1989). Although the cliff-forming Castlegate Sandstone was not measured in the study area, it forms a prominent marker above the Blackhawk exposures.

Early studies of the Castlegate Sandstone include: Forrester (1918), Clark (1928); Spieker and Reeside (1925); and Spieker (1931, 1946, 1949) who described lithologies and stratigraphic relationships. More recent studies are Fisher and others (1960) who assigned formational status to the Sandstone, Van de Graaf (1972) who described some of the lateral facies changes, and Lawton (1985; 1986), Pfaff (1985), and Cole and Friberg (1989) who detail sedimentology of fluvial facies within the formation.

DEPOSITIONAL FACIES

Major traceable sandstone and siltstone bodies within the study area are tongues which pinch out eastward (Plate 1), and are interbedded with opposed westward-thinning tongues of marine Mancos Shale. Each sandstone/siltstone tongue generally coarsens upward with respect to grain size and bed thickness, and individual sandstone beds thin in an easterly direction. Several workers have previously reported the deposits as being deltaic, interdeltaic beach, or barrier-island in origin (Young, 1955; Balsley, 1982; and Hudleson, 1984).

A wide variety of lithologies and facies ranging from non-marine to offshore marine are present in the Cretaceous deposits and are briefly summarized in Table 1. The majority of the deposits are "shoreface-attached", meaning that they can be traced laterally and are genetically linked to shoreline deposition. These facies include: offshore; transitional offshore; lower shoreface; middle shoreface; upper shoreface; foreshore; and backshore. The described shoreface deposits could also be considered delta front deposits, but due to the nature of wave-dominated deltaic and interdeltaic deposition (Fig. 6), much of the sand is redistributed by marine processes (thus the usage of shoreface terminology). Other facies are grouped in a category of shelf deposits that are "non-shoreface attached", and cannot be laterally traced or directly linked to shoreline or deltaic deposition. These shelf deposits include: channel fill facies, and reworked facies (oolitic ironstone, and coarse-grained sandstone).

Shoreface-Attached Deposits

Shoreface-attached deposits are discussed from the seaward towards the landward direction as they would occur in lateral relationships, and as they commonly occur in coarsening-upward cycles.

Offshore Facies

The offshore facies is characterized by an abundance of shale, mudstone, and siltstone, with some thin, horizontal, parallel-laminated, very fine-grained sandstone beds. A high content of carbonaceous material and very finely crystalline pyrite (and other sulfides) contributes to the distinctive dark grey color (Coleman, 1976). Sparse macrofossil occurrence may be attributed to leaching, which is common in organic-rich muds. This facies ranges from normal offshore deposition, to episodic clastic delta input (prodelta environment).

The argillaceous offshore facies is largely indicative of a calm environment of mainly suspension deposition. The term offshore is used to imply an environment of shelf depths and below, where sediments were deposited below effective wave base from suspension in or onto a sloping area from the base of the delta front to the basin floor (Coleman, 1976). Although delta distributaries are not recognized in the study area, it is inferred that some clastic shelf sediment may have been derived from deltas.

A lack of abrupt changes in degree of bioturbation in the stratigraphically lowermost shales in coarsening-upward sequences suggests offshore environments with better preservation of relatively quiet-water deposits. *Thalassinoides*, *Scolicia*, and "smooth tubes" were recognized in this study, and in addition to the common offshore traces reported by Howard (1972): *Asterosoma*, *Arthrophycos*, *Teichichnus*, "chevron burrows," and "small white tubes".

TABLE 1 Summary of Upper Cretaceous facies and lithologies

FACIES/ENVIRONMENTS	GENERAL LITHOLOGY/STRUCTURES
fluvial *	channel sandstone, lateral accretion sets, upward-fining trends
delta plain	coals, lenticular sandstones, rooting
delta distributary *	channel medium- to coarse-grained sandstone, large-scale cross stratification, Teredolites-bored wood
lagoon	thinly laminated and rippled fine-grained sandstone, estuarine faunas (oysters), landward-dipping stratification (washovers)
tidal inlet *	fine- to medium-grained sandstone with bipolar trough cross-stratification, some planar stratification, *Ophiomorpha* burrows
barrier beach *	parallel fine-grained laminated sandstone position in front of lagoonal facies
foreshore	parallel fine-grained laminated sandstone, well sorted, some roots, secondary bleaching
upper shoreface	high-angle trough cross-stratification, medium- to coarse-grained sandstone, vertical (*Skolithos*-like) and *Ophiomorpha* burrows
middle shoreface	stacked beds of hummocky cross-stratification fine-grained sandstone, few burrows
lower shoreface	"rhythmic" hummocky cross-stratified beds, wave ripples, fine-grained sandstones interbedded with siltstone/mudstone, subhorizontal-horizontal, *Thalassinoides* burrows
offshore (+ transitional offshore)	thinly-laminated siltstones/mudstones (+ very-fine grained rippled sandstones), some channels
transitional turbidite	graded "turbidite" beds with sole marks (full and partial Bouma sequences), or isolated (fluvial influence) fine- to medium-grained burrowed sandstone encased in mudstone
channel fill	thinly-laminated very-fine grained rippled sandstones, (siltstones/mudstones) with channel form
transgressive lags	localized and thin, reworked medium- to coarse-grained (reworked) sandstone, some iron-coated oolites, fish teeth, phosphatic material, wood pieces, and rip-up clasts, some burrowing

* not discussed in this study, but present in Blackhawk Formation (see Balsley, 1982).

Some portions of the offshore facies show more clastic input and localized regions of storm current influence. Proximal silty shales are commonly burrowed to varying degrees according to the rate of sediment influx. Alternating non-burrowed to burrowed shales indicate episodic storm events punctuated by periods of quiet-water deposition. Non-burrowed sandstone sequences suggest high sediment input during storm periods, or deposition in regions directly offshore from river mouths. Intensely burrowed shales suggest deposition in areas of low sediment influx, or deposition during hydrologically quiet periods.

Transitional Offshore Facies

The transitional offshore facies of siltstones, shales, and some fine-grained sandstones lies in an intermediate position (gradational) between lower shoreface and offshore deposits (Balsley, 1982). Organic-rich siltstones to very fine-grained sandstones are generally structureless to parallel laminated or rippled (Bouma A-C). Sandstones commonly have sharp bases with numerous sole markings which include brush, prod, and groove casts. Bioturbation is restricted to the base and top of these sandstone beds.

Morphologic character of the transitional offshore facies suggests rapid emplacement of individual beds. Transitional offshore deposits may have formed by storm-generated density underflows, or by density flows generated by slumping in the delta-front environment. Some siltstone and sandstone beds contain repetitive scours distinguished by rip-up clasts, and indicate episodic deposition.

Numerous *Thalassinoides*, preserved in full relief within shaly beds, and in positive relief on sandstone bases are recognized in addition to *Ophiomorpha* and *Asterosoma*. *Rhizocorallium* are rare, yet are present at the tops of some sandstones. These burrow traces indicate deposit feeders working at the sandstone-shale interface between episodic events.

The prevailing current orientations for the transitional facies is approximately N71E. Previous investigators (e.g., Young, 1957; Balsley, 1982; and Fouch and others, 1983) interpret the trend of the Late Cretaceous strand line in this area to be approximately N30E to N45E (Fig. 3). Assuming that these interpretations of average paleoshoreline orientation are reasonable, these transitional offshore facies orientations suggest currents flowed obliquely to shoreline and thus record longshore current transport.

Lower Shoreface Facies

The lower shoreface facies is comprised of fine-grained sandstone dominated by hummocky cross-stratification (Fig. 7) and it commonly occurs just above the transitional offshore siltstones. Hummocks and swales range from 3 to 7 ft (1 to 2.1 m) in width, and average 15 in (38 cm) in thickess. Associated structures include common wave ripples, low-angle to plane laminae, and load casts. Mudstones typically cap beds of hummocky cross-stratified and wave-rippled fine-grained sandstones. These lower shoreface sandstones and mudstones were deposited below fair-weather wavebase and above storm wavebase. The abundance of hummocky cross stratification indicates the importance of episodic storm wave activity in reworking fine-grained material. The mudstones represent suspension deposition and fair-weather conditions.

The presence of *Ophiomorpha*, *Schaubcylindrichnus*, and unidentified smooth-walled vertical tubes in lower shoreface sandstones suggest a predominance of suspension feeders. This assemblage occurs only in uppermost portions of hummocky cross-stratified beds. Alternating nonburrowed hummocky sandstone and burrow-mottled siltstone to sandstone suggest that periodic storms scoured the inner shelf floor, resuspending, and later depositing entrained sediment. Burrowing organisms then were able to reoccupy the uppermost portion of the storm deposit.

Within this study area, no delta distributary channels are recognized. However, in the context of deltaic channels in the Blackhawk Formation recognized west of the study area (Balsley, 1982), the shoreface deposits are also considered to be wave-dominated delta front sands (interdeltaic) reworked and distributed by waves and longshore currents.

Middle Shoreface Facies

The middle shoreface facies is recognized by an increased proportion of sand to mud, thicker fine-grained sandstone beds, and larger hummocks and swales in the hummocky cross-stratification. Repeated beds of hummocky cross-stratification imply repeated scouring by storm events in a more proximal portion of the shoreface. Lower shoreface sandstones typically grade upward into thicker sandstone beds of the middle shoreface before the more abrupt transition into the upper shoreface sandstones.

Upper Shoreface Facies

The upper shoreface facies is characterized by medium-grained sandstone with abundant trough cross-stratification. Trough sets are generally about 0.7 m (2.4 ft) or less in thickness. Sparse burrows and rare *Ophiomorpha* and *Schaubcylindrichnus* in the upper shoreface sandstone contrast markedly with the abundance of trace fossils from previously described faces (lower shoreface and offshore). These sparse vertical to subvertical traces reflect high-energy conditions in the upper shoreface.

Trough cross-strata orientations from trough axes have an average down-trough azimuth orientation of 140^{o} (S50E). Assuming this reflects dune migration at nearly right angles to the paleoshoreline, the paleoshoreline orientation must have been at an azimuth of approximately 50^{o} (N50E). This estimate is close to estimates of paleoshoreline orientation of Balsley (1982) and Fouch and others (1983), as discussed in the transitional offshore facies.

Compositionally the sandstones appear to be mature, with abundant quartz, some chert and rare feldspar grains. The probable sediment source (Young, 1955; Balsley, 1982; Fouch and others 1983; and Hudleson, 1984) was Mesozoic and Paleozoic rocks eroded during the Sevier orogeny or early Laramide orogeny to the west. Outcrops samples of the upper shoreface, trough-cross stratified sandstones contain porosity values average around 8% or more, as measured in thin section.

Balsley (1982) believes that Blackhawk nearshore deposits are similar to those of the nonbarred, high-energy nearshore zone of the southern Oregon coast described by Clifton and others (1971). Both examples lack bars or bar-generated structures in the upper shoreface facies, indicating that the Blackhawk coast might have had extensive lateral distribution of sand along delta fronts resulting from high wave energy (Komar, 1973; and Coleman, 1976). Trough sets were probably formed by migrating three-dimensional dunes in an area of wave buildup and surf (Balsley, 1982) similar to modern upper shoreface zone depths of approximately up to 22 ft (Klein, 1974). Delta-front profiles of Blackhawk deposits in the Wasatch Plateau are reportedly steep (approximately 0.3^{o}; Balsley, 1982).

Foreshore Facies

Coarsening-upward sequences in the Blackhawk Formation are commonly capped by a white, parallel-laminated, well-sorted sandstone of the foreshore facies, which is slightly finer grained than the underlying upper shoreface sandstone. These well-sorted sandstones contain low-angle, parallel laminae, which dip seaward at 2 to 5^{o}, and are interpreted to be foreshore deposits reworked by swash motion. The top 2 ft (0.6 m) typically contain carbonaceous root structures and indistinct features which may be either rhizoliths or burrows. White coloration (whitecap) of the foreshore deposits (and typically uppermost upper shoreface deposits) is diagenetic and may be due to the absence/dissolution of Fe-dolomite common in the upper shoreface sandstones (J. Balsley, 1989, pers. comm.) as well as the presence of diagenetic illite/smectite and kaolinite (R. Cole, 1990, pers. comm.).

Backshore Facies

The backshore facies consists of a variety of lithologies which commonly overly the foreshore sandstones. These marginal marine to non-marine deposits include lagoonal coals and shales, fluvial sandstones, splay and washover fan siltstones, and tidal flat mudstones. Oyster body fossils are common in this backshore facies, with a modest amount of burrows. Although sandy coals were recognized in this area as well, no distinctive eolian structures were recognized. The absence of eolian features could be due to a lack of preservation.

Balsley (1982) suggests that the low relief of the Blackhawk shoreline is closely approximated by that of the modern Niger Delta coastline, which lack extensive eolian backshore deposits. This type of coastline appears to serve as a good modern analogue to the Blackhawk marginal marine system.

Shelf (Non-Shoreface-Attached) Deposits

Shelf deposits (largely sandy) are of particular interest in this study due to their relative "isolation" within the Mancos Shale, and hence their anomalous origins. These deposits are "non-shoreface attached", and cannot be laterally traced or directly linked to shoreline or deltaic deposits. Shelf deposits described here include: transitional turbidite sandstone, channel-fill sandstone and siltstone, oolitic ironstone, and coarse-grained sandstone lag.

Transitional Turbidite Facies

The Hatch Mesa sequence is composed of structureless, parallel-laminated, and rippled beds (similar to those recognized in transitional facies of shoreface-attached siltstones and sandstones), exposed in a lense-like body isolated in Mancos Shale (Plates 1 and 2). These transitional turbidite sandstones contain distinct Bouma sequences (ranging from Bouma A-E to partial sequences), and generally thicken upwards. A few particularly thick beds (up to 3 ft or 1 m) contain pinch and swell structures (Fig. 8). The Hatch Mesa sequence grades laterally into offshore facies of the Mancos Shale.

The 484 paleocurrent measurements of the Hatch Mesa sequence have a mean azimuth of approximately 71^{o} (N71E), or again parallel-to-oblique orientation to the interpreted paleoshoreline. Some beds within the non-shoreface-attached sequence contain two distinct crossing sets of directional indicators (see current rose at Section D, Plate 1). The predominant set is typically N71E, and the minor set is oriented at approximately 130^{o} (S40E). The minor set is represented by flute and groove marks that are commonly crosscut by the major set of groove marks.

The turbidite sandstone beds of the Hatch Mesa sequence are interpreted to be delta-front deposits of a fluvial-dominated delta system. Density flows may have been induced due to oversteepening of the delta front, perhaps associated with river flooding. The sequence is markedly similar to delta front sandstones (associated with distributary mouth bars) in other nearby Cretaceous examples, such as the Panther Sandstone (see Fig. 12 in Franczyk and others, 1989; and Fig. 1 of Van Wagoner and others, 1990). Some poorly-developed hummocks at the top of the

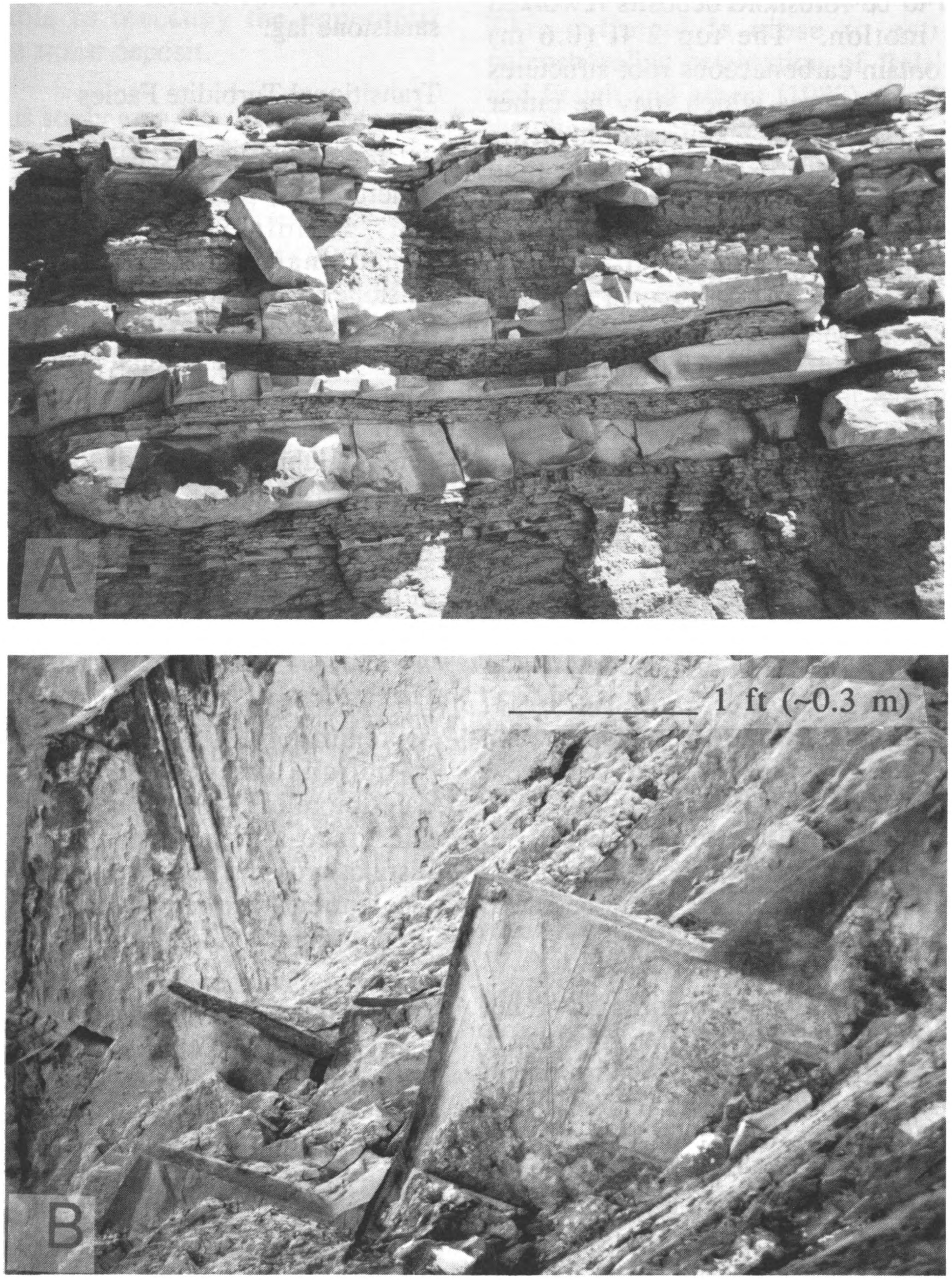

Fig. 8. Sedimentary structures in the transitional turbidite facies of the Hatch Mesa sequence. A. Pinch and swell features in sandstones (outcrop shown is 22 ft or 6.7 m high). Location: Section C, Plate 2. B. Two directions of groove casts along sandstone bases. Location: Section B, Plate 2.

Hatch Mesa sequence document deposition by storm wave processes and indicate that deposition was shallow. The range of directional indicators may represent both deltaic-directed currents, and longshore currents.

Thick beds may be explained by: 1) an unusually large pulse of sediment fed by river flooding, 2) several influxes of sediment within a short period of time (stacked beds), and/or 3) initially greater proximity to a locus of sedimentation, such as a distributary channel or mouth bar which may undergo channel avulsion.

Other hypotheses used to explain the transitional turbidite sandstone facies include a: turbidite fan (Balsley, 1982); or delta plume (Hudleson, 1984 citing Patterson, 1983). Balsley (1982) interprets this facies as a turbidite fan system, citing its lenticular cross section and "isolation" in Mancos Shale; deeply channeled upper surfaces; thickening and coarsening-upwards sequences; and the presence of turbidites (Bouma sequence beds). However, associated deposits (including the shales) seem to represent a shelf setting as opposed to a basinal, base of slope environment, and the turbidites can still be explained and genetically associated with similar delta front sandstones (Chan, 1986). In the delta-plume model, sand plumes are formed by sand deposition in eddies on the lee side of deltas. Deltaic sediments are entrained by longshore currents and deposited as a large "plume" upon leaving distributary mouths. Channels recognized within the Hatch Mesa sequence and the lack of evidence for "backplume eddies" give little support to the delta-plume idea.

Channel Fill Facies

Numerous large, siltstone- and sandstone-filled channels isolated in Mancos Shale occur in an interval approximately correlative to the Emery Sandstone (Fig. 9). Siltstone up to medium- and fine-grained sandstones commonly contain faint parting lineations (~108°), and are thinly bedded (few cms), with some ripple marks (Fig. 10) and small-scale trough cross stratification. Some crawling traces and horizontal (Planolites ?) burrows and broken bivalve shell hash are present along bedding planes. Various small tool marks (bounce, prod and drag marks) occur on platy sandstone bases. Most of the channels are about 32 to 66 ft (10 to 20 m) across, and 3 to 13 ft (1 to 4 m) deep, and others are smaller, shallow scoops. Paleocurrent measurements from four channels between Sections 1 and 2 (Plate 1) have an average axial orientation of 101°, with regional dip removed (strike: N70°E; dip: 6° N). A few sparse ripple crests and troughs generally indicate flow directions towards the east-southeast, 80-150°.

These small sandstone channels are interpreted as delta-front to prodelta channels which scoured into the fine-grained Mancos deposits below storm wave base, during periods of river flooding or when base level was relatively low. Various tool marks indicate tractive currents which probably supplied some of the silt and very fine-grained sand to the offshore setting of the siltstone-shale facies. These channels differ from shelf-edge or shelf-break channels of Swift and others (1987), or turbidite fan feeder channels of Balsley (1982) because of their limited extent, association with inner shelf faunas (within the shale-siltstone facies discussed previously), and the lack of connectable sand bodies that would have been sourced by such shelf-edge feeder channels.

Reworked Facies

Two reworked subfacies are recognized and distinguished as sand-rich intervals that are reworked and winnowed by marine processes. These subfacies include a coarse-grained sandstone and an oolitic ironstone that are interpreted as transgressive lags.

Fig. 9. Channel geometry in interval approximately correlative to the Emery Sandstone member of the Mancos Shale. Staff is 4 ft (1.2 m) long. Location: Section 3, Plate 1.

Coarse-Grained Sandstone.

A distinctive medium- to coarse-grained sandstone of white grains (quartz and feldspar) as well as dark grains (lithic grains, mostly chert) in approximately subequal amounts give the appearance of a "salt and pepper" sandstone. The subfacies is variable in thickness (< 3 to 10 ft; 1 to 3 m thick), is very localized, and has a sharp lower contact, which may be scoured. Fourteen paleocurrent measurements of high-angle cross-strata within the bar sandstones indicate an average down-dip azimuth of 159°. This orientation is close to the paleocurrent orientation and axial orientation of the channel fill facies previously described.

Internally, the sandstone is medium- to coarse-grained (average grain size 0.32 - 0.65 mm) and moderately sorted. A bimodal texture shows well rounded quartz grains, and angular to subangular chert, sandstone and siltstone fragments. The sandstone composition varies particularly at the top of the bed where it contains abundant carbonized wood, belemnites, *Baculites*, and phosphatic material, particularly fish teeth, as well as

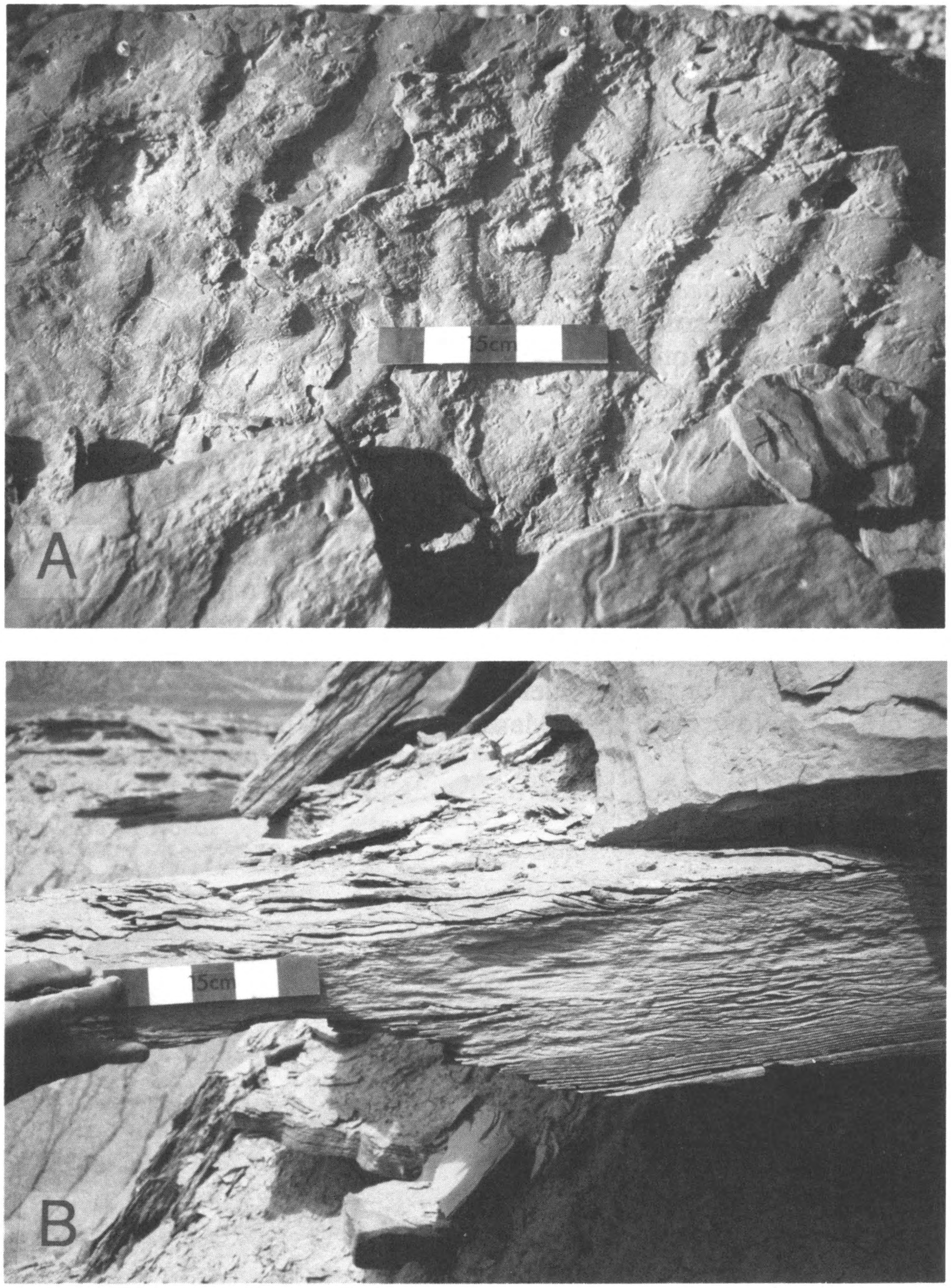

Fig. 10. Internal structure of channel fill: A. current ripples and crawling traces, and B. climbing ripples. Location: Section 2, Plate 1.

horizontal burrows (*Planolites*?). In some areas there is a gradational interbedding with a carbonate packstone to grainstone that contains broken shell (e.g., *Inoceramus*) fragments.

Inoceramus-packed biomicrites (Mount, 1985) commonly occur at a stratigraphic interval lower than the coarse-grained sandstone (Fig. 11). The *Inoceramus* tests are intact and stacked in a parallel fashion, suggesting an accumulation similar to modern "oyster banks". The coarse-grained sandstone also appears to be intimately associated with the oolitic ironstone. Stratigraphically, the coarse-grained sandstone facies occurs only slightly above the oolitic ironstone, or possibly in the same unit. Where the oolitic ironstone is absent, for example at the Hatch Mesa locality (Section D, Plate 2), there are still concentrations of shell material, fish teeth and bone material in a carbonate bed interval some 50 ft (18 m) below the Hatch Mesa sequence.

The coarse-grained sandstone is interpreted as a thin lag deposit in a moderately to well-oxygenated environment with current-swept conditions which winnowed, sorted, and concentrated the sand material originally derived from reworked shoreface, foreshore, and continental backshore deposits. This event interval is interpreted to occur where a transgressive rise reworked the lag. The range of textures and compositions in this coarse-grained lithic sandstone facies implies a mixture of reworked, rounded and resistant coarse-grained sand detritus (quartz, chert, and garnet grains), and the subangular lithic grains probably supplied to the shelf by river flooding during last phases of a regression, and before the ensuing transgression. The source of river flooding may also account for the limited extent of the coarse-grained sandstone facies. There is no evidence to indicate a ravinement surface, or any subaerial erosion. The interbedding with the carbonate packstone to grainstone at the Hatch Mesa

Fig. 11. *Inoceramus* fragments and casts in sandy micrite of shelf deposits. Location: Section I, Plate 2.

locality (Plate 2), concentration of fish teeth and other fossil hash, and the presence of burrows implies that the coarse-grained sandstone is of marine origin, and deposited contemporaneously with the carbonates or shale in inner shelf, shallow-water conditions.

Oolitic Ironstone.

The oolitic ironstone is a distinctive red-weathered lithology (Fig. 12) which occurs in localized, elongate bodies within a one mile (1.6 km) square area (Plate 2). It is a grain-supported, ooid-rich lithology containing iron-clay (berthierine), muscovite, hematite/goethite and carbonate minerals around clastic nuclei. Associated grains of phosphatic material (bone and fish teeth) are common, admixed with fossil debris and wood pieces. Internal structures within the mappable oolitic ironstone bodies include: small to medium scours (<1 ft deep by 2 ft across; 0.3 m by 0.7 m), cross-bedding, contorted bedding, mud rip-up clasts, and marine trace fossils. The thickness of the ironstone unit varies (0.6 to 4.0 ft; 0.2 to 1.5 m thick) partly due to scouring and/or from the fact that in some areas the unit has weathered to just a thin rubble. Some examples of contorted and wavy bedding are evident where there are differences in the mud content of the beds. At the westernmost locality of the oolitic ironstone exposure (Plate 2), the ironstone appears to dip several degrees in an azimuth direction of 115^{o}, and there are internal angular discordances which are interpreted as cross bedding and/or channel draping. The oolitic ironstone at this western locality may be structurally disrupted, but the nature of the Mancos Shale exposures make it difficult to determine if and how the unit may be faulted. A more detailed study on the oolitic ironstone is being conducted by the senior author of this report.

The presence of clastic nuclei and relatively high-energy features (e.g., cross stratification, scouring, rip-up clasts) within the oolitic ironstone and its association with the Hatch Mesa Bouma sequences, are used to interpret an inner shelf environment. The inner shelf setting may have been influenced by river-dominated flooding in the delta-front environment (providing sand fed through small channels) and by fluctuating or alternating sea-floor bottom conditions due to periodic storm or current action. The oolitic ironstone is inferred to have formed as shoals within the inner-shelf setting. The localized occurrence may be due to topographic irregularities on the ocean bottom, perhaps associated with some tectonism. A key factor in formation of the oolitic ironstones is eustatic control in the Western Interior seaway. The shift from relatively high-energy conditions (probably also relatively shallow) for the ironstone to the relatively quiet and deep-water conditions for the overlying shale are used to infer that the ironstone was deposited during a relative sea-level low and then reworked and winnowed during a transgressive rise.

Discussion of Macrofossils

Scattered macrofossils are present in the non–shoreface attached facies, and have some bearing on age interpretations for these isolated bodies. An August 1988 party of Bill Cobban, Tom Fouch, Chris Shaw, Bob Remy, Dag Nummedahl, and Karen Franczyk found several specimens of *Desmoschapthites basleri*, *Scaphities leei*, and inoceramids associated with marine scour surfaces in a section which Fouch (1983) correlated with the Emery Sandstone at Woodside (approximately Section 3, Plate 1) (T. Fouch, 1990, pers. comm.). These body fossils suggest the beds are latest Santonian in age. Additionally, the party found *Inoceramus balticus*, and *Desmoscaphites basleri* in mounds underlying the Hatch Mesa sequence, as well as some *Baculties*, *Lucinia*, and *Desmoscaphites basleri*, within beds less than 100 ft (30 m) from the cap of Hatch Mesa. These finds further suggest a Santonian age for the non-shoreface attached facies of the

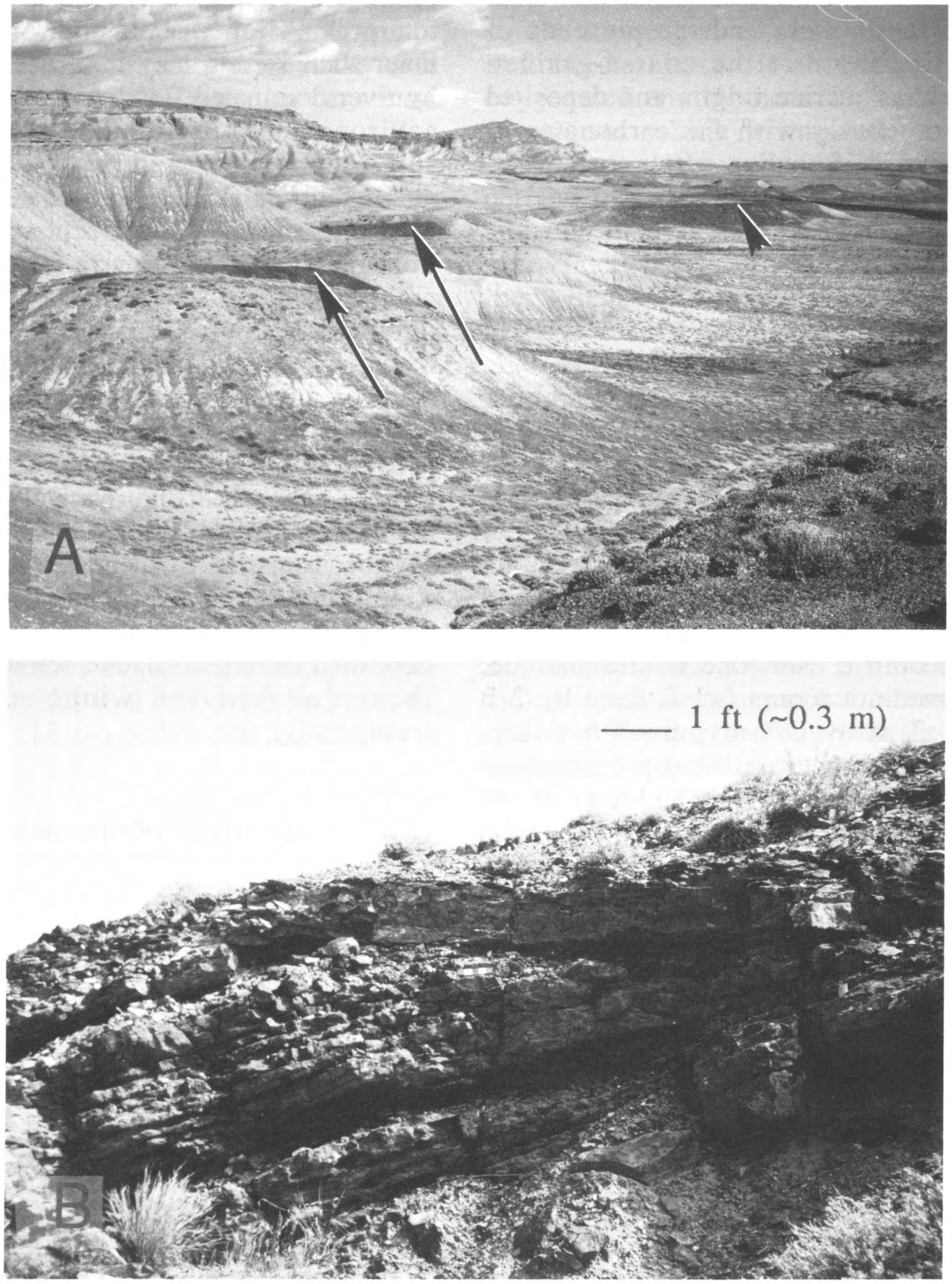

Fig. 12. Oolitic ironstone of shelf deposits showing: A. localized distribution (occurrence noted by arrows) in view toward the southeast; and B. internal cross-stratification. Location: Section I, Plate 2.

Hatch Mesa sequence. Additional palynological analyses to support these age interpretations are given in a later section on ages and palynofacies of the Hatch Mesa sequence.

FACIES MODEL

Emery Sandstone Member and Mancos Shale (Santonian?)

The various shelf deposits of the Mancos Shale (mostly beneath the Blackhawk tongues proper, and including the Emery beds) show influences of marine reworking of deltaic sediment. Although delta sand plume deposits (Patterson, 1983) should show a longshore orientation only in distal portions, the Hatch Mesa sequence shows both offshore and longshore current directions. Thus, the turbidite sandstones indicate density flows onto the shelf during instances of probable river flooding and river-dominated sedimentation (Figs. 13 and 14), with some longshore current influence. Small channels may have supplied some deltaic sand to the offshore/shelf area, some of which was reworked in lags during transgressive phases. The Western Interior seaway may have had a more irregular and varied shoreline morphology during the Santonian? deposition of these offshore sand bodies (Fig. 14).

Blackhawk Formation (Campanian)

The abundance of hummocky cross-stratification, wave ripples, and the presence of foreshore deposits in the study area and association with delta distributary channels (outside the study area) is largely indicative of a wave-dominated delta system for the Blackhawk Formation (Figs. 13, 14). This model is in marked contrast to the Emery Sandstone and Mancos Shale interval (Santonian). The study region would be largely the interdeltaic shoreface area. Common coarsening- and shallowing-upward packages which are "complete" (nearly a full range of facies) or "incomplete" (few or

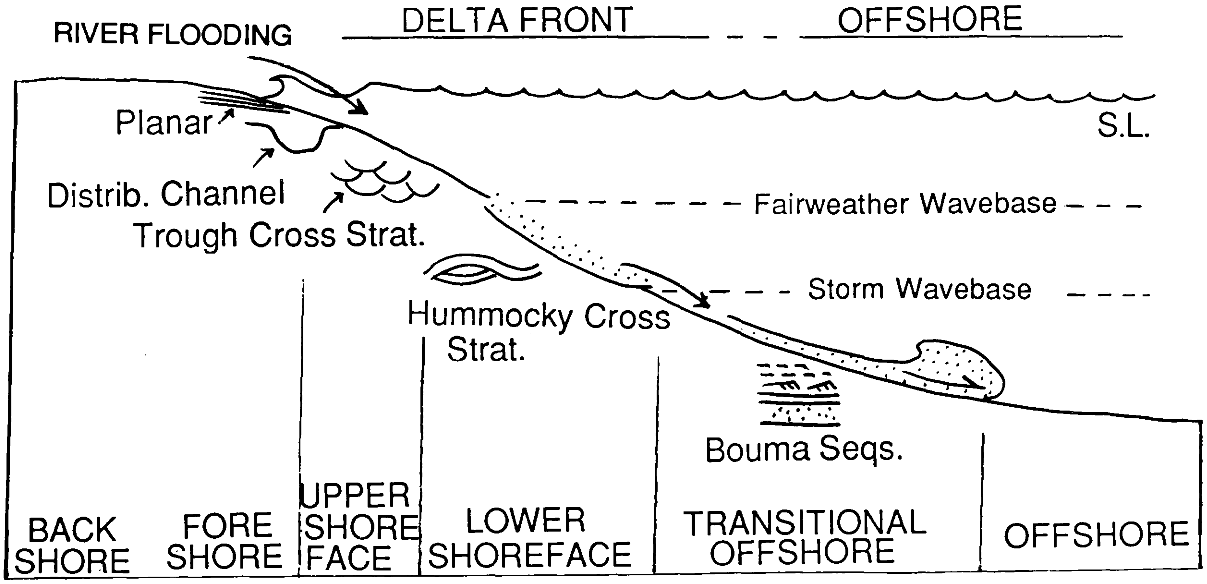

Fig. 13. Depositional environments and facies model for wave-dominated delta system and shoreface (Blackhawk deposition), with some periodic river flooding to move sand onto the shelf (Emery Sandstone and Mancos Shale deposition). Modified after Walker (1984).

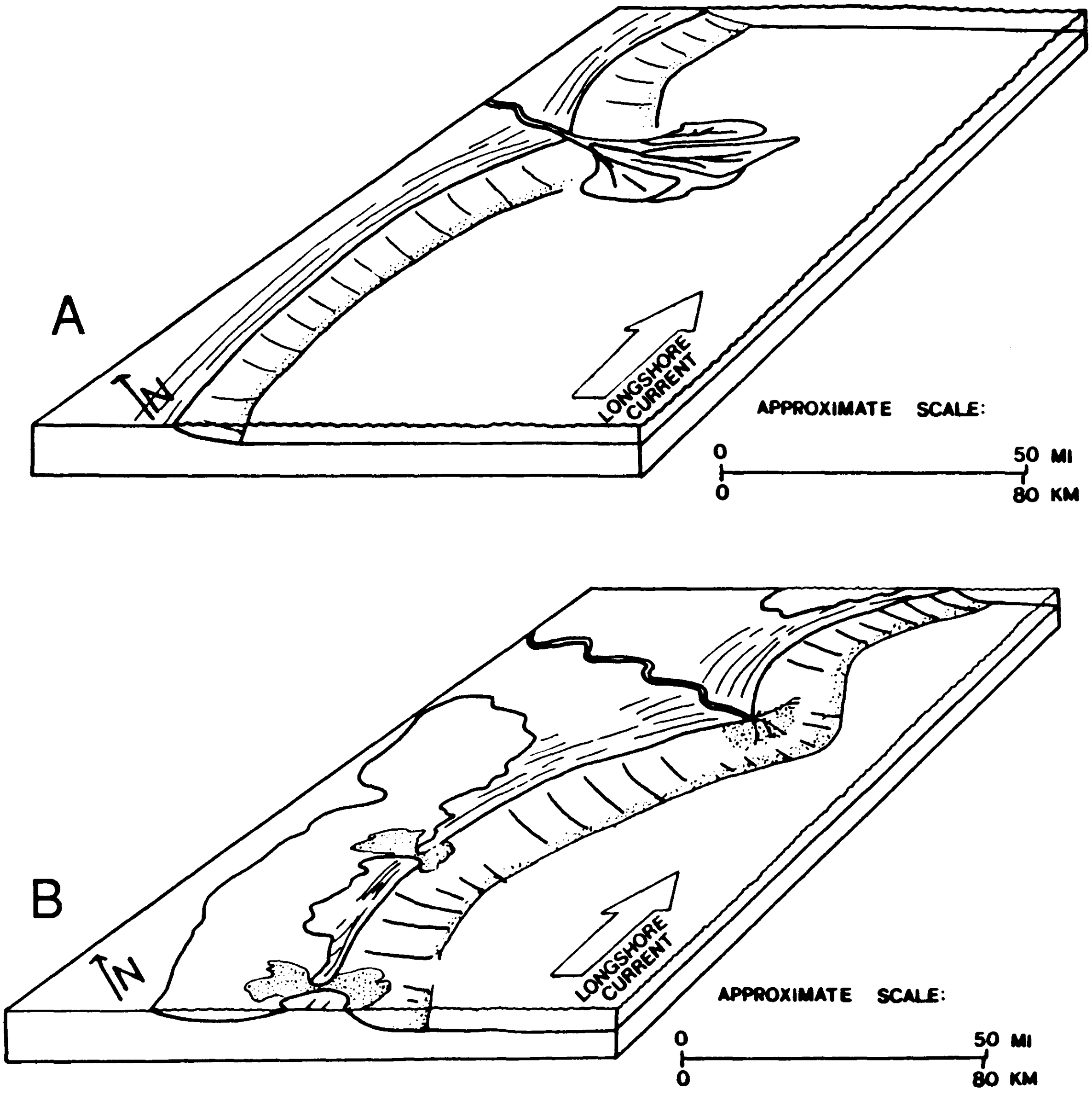

Fig. 14. Paleogeographic reconstructions of: A. Santonian? regression with deposition of various shelf deposits (channel fill, oolitic ironstone, and transitional turbidite facies) all sediment-supplied during relative periods of river flooding, for the Hatch Mesa sequence; and B. Campanian regression with deposition shoreface-attached deposits of the Kenilworth, Sunnyside, Grassy, and Desert Members of the Blackhawk Formation.

partial facies), are present in all the members (Fig. 15). Typically the base of the package is composed of offshore/prodelta mudstone, overlain by lower shoreface/delta front fine-grained sandstones, grading upward into middle shoreface/delta front sandstones, and capped by upper shoreface to beach sandstones. Most coarsening-upward sequences are about 30 to100 ft (10 to 30 m) thick, with thick sequences of > 125 ft (40 m). The coarsening-upward trends indicate progressive shoaling-upward due to progradation of the strandline basinward. Sandstone tongues abruptly overlain by shale suggest periodic transgression, and return to pelagic deposition. The cyclical nature of these packages is attributed to deltaic lobe switching, and shoreline progradation associated with eustasy (Fig. 16), and tectonic controls on sedimentation and subsidence. The thicker packages (> 125 ft; 40 m) may indicate greater subsidence within the foreland basin (Balsley, 1982), to allow the accomodation space for such thick packages. These packages are also interpreted as parasequences (in the terminology of Van Wagoner and others, 1990), and are further discussed in the later section on depositional sequences.

Balsley (1982) interprets all of the Kenilworth tongues as deltaic and interdeltaic except for the Grassy Member which he interprets as a barrier-island package. This barrier-island interpretation is based on the location of the Grassy shoreface sandstones seaward of lagoonal coal deposits west of the study area. The entire Blackhawk Formation represents an overall eastward progradation into the Western Interior Cretaceous seaway with superimposed small-scale transgressive and regressive fluctuations (Plate 1). These studies of the Blackhawk facies suggest that the Western Interior Cretaceous seaway was characterized by beaches (Fig. 14) with no localized flow to produce large protruding deltas or large interdeltaic embayments. Wave-dominated deltas with a cuspate morphology due to longshore currents smoothed out the Blackhawk coastline.

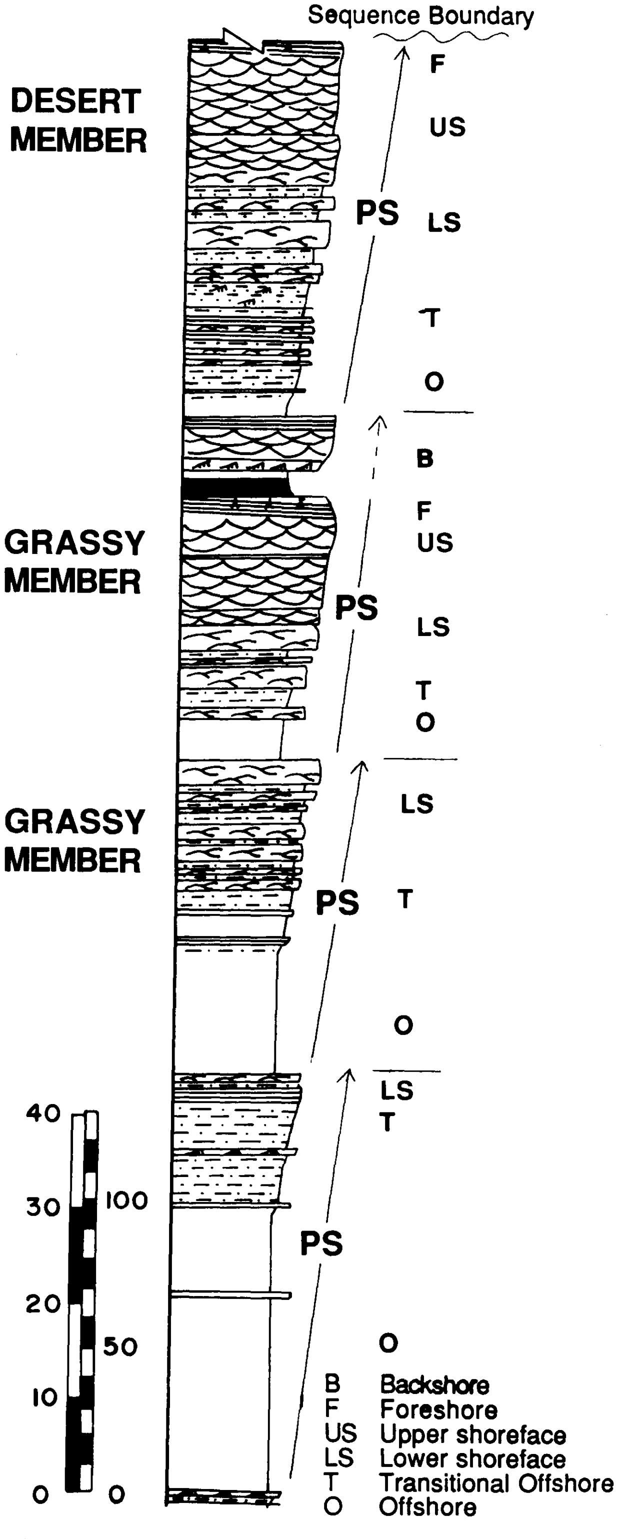

Fig. 15 Upward-coarsening sequences (shoreface-attached) in the Cretaceous Blackhawk Formation. Depositional packages are interpreted as parasequences (PS). Arrows indicate the direction of coarsening. Legend explanation is given in Plate 1. Location: partial Gray Canyon (Green River) Section 1, Plate 1.

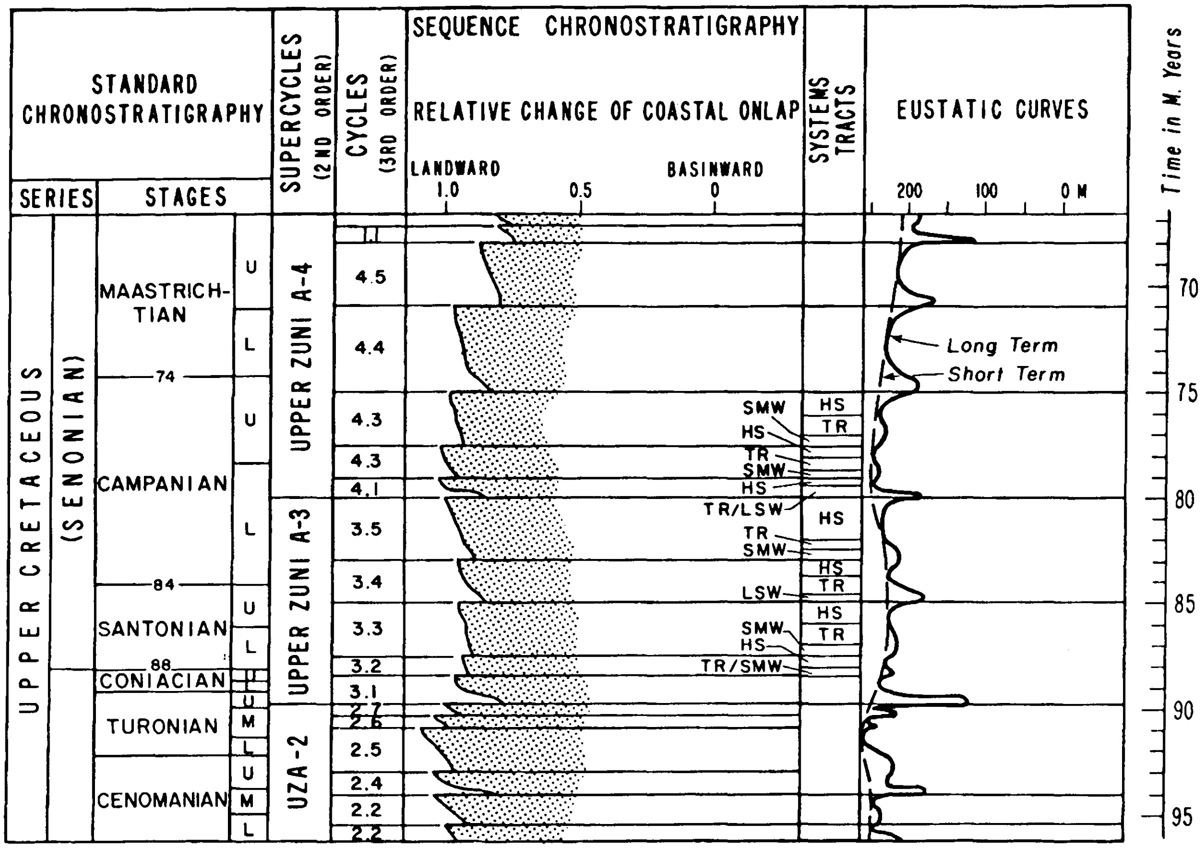

Fig. 16. Eustatic sea-level curve (Haq and others, 1988) for chronostratigraphic interval of this study (Santonian to Campanian). Systems tracts abbreviations: HS = high-stand, SMW = shelf-margin wedge, TR = transgressive, and LSW = low-stand wedge.

AGES AND PALYNOFACIES OF THE HATCH MESA SEQUENCE

Sampling

Stratigraphic correlations have been particularly difficult in sandstone-shale packages that occur isolated within the Mancos Shale. One of the major objectives of this study was to attempt to specifically date (e.g., Turonian, Coniancian, Santonian, Campanian) samples from the Mancos Shale, to correlate isolated sandstone bodies to the named shoreline units (e.g., Ferron Sandstone, Emery Sandstone, Panther Sandstone, or Kenilworth Member) in the Mesaverde Group (see Fig. 4). Ages of samples from beneath or above the isolated sandstone bodies would help determine whether or not these bodies occur at sequence (and/or stage) boundaries. The sampled intervals occur above the Lower Ferron Sandstone, and below the Desert Member of the Blackhawk Formation.

Initial attempts on radiometric age dates for the Mancos Shale proved to be futile due to the mixture of clastic sources (which would provide anomalous age results). Some rare macrofossils provided some age constraints (Cobban, 1987, pers. comm.), but generally these were not diagnostic. Shale analysis for palynomorphs and dinoflagellates was used to try to more precisely define and distinguish the Upper Cretaceous stages.

Relatively fresh shale samples were collected at intervals bracketing the Hatch Mesa turbidite sandstones and the oolitic ironstone. Sampling intervals are noted on Plate 2, with detailed descriptions of the samples in Appendix B. Although the Blackhawk Formation is dated as Campanian (about 80-83 my), there have been no definitive dates in this area for the Cretaceous Mancos section below the Blackhawk Formation on down to the Dakota Sandstone (covering the Santonian, Coniacian, Turonian, and Cenomanian).

Two independent palynological analyses were performed by Dr. Fred E. May of Palynex International, and Mr. Del W. Edelman of Edelman, Percival and Associates Biostratigraphers. Twenty-four shale samples were examined by May, and a select six of those were independently examined by Edelman. Their reports are given in Appendix B. Recovery of the palynomorphs was surprisingly excellent, with both abundant and diverse assemblages. Over 100 species of pollen, spores, and dinoflagellates were observed. Data on such occurrences and assemblages (Appendix B) for this part of the Mancos section are new and have not been previously documented or publicly reported.

The general characteristic of the assemblages from the shales indicates a marine-influenced sediment sequence that is Senonian (Late Cretaceous, Coniacian through Maastrictian) in age, and upon closer inspection is shown to be Santonian- Early Campanian. Although some palynological assemblages were distinctive and unique, more palynological analyses on shoreface-attached shoreline and deltaic deposits throughout the Cretaceous section would be required to definitively correlate the isolated sandstone units. Shale samples surrounding the oolitic ironstone and the coarse-grained sandstone lag appear to be Santonian to early-mid Campanian (Fig. 17).

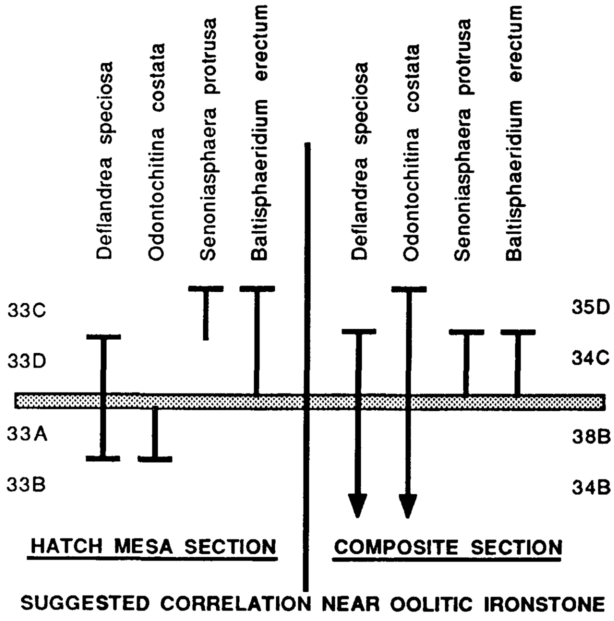

Fig. 17. Correlation chart showing four species with similar occurrence patterns at both Locality 89-33 and the composite section areas to the east. The tops of ranges suggest a correlation for the oolitic ironstone at both localities and suggest that these forms may be useful in broader correlations.

Palynofacies

The assemblages also more specifically show dinocysts which suggest shallow marine deposition in the inner to middle neritic (shelf) environment. These assemblages further corroborate the sedimentologic interpretation of the shelf facies. In particular, the turbidite sandstones are properly interpreted as shelf deposits related to deltaic influx, as opposed to a basinal turbidite fan. The background organic vascular plant debris indicates influx of fluviatile sediments across the delta system (Fig. 18). There appears to be some correlation between types of organic debris in palynomorph residues and the marine or nonmarine aspects of the assemblages. This is logical in sediments tied to deltaic systems because river influx brings in massive amounts of land-derived plant debris, especially from vascular herbaceous and woody plants from throughout the associated drainage basin(s). This introduces the concept of palynofacies, where not only the nature of the palynomorph assemblages is important, but also the nature of the background organic debris.

Most palynologists are aware of attempts of colleagues to utilize the nature of plant debris in palynomorph preparations to assist in determining palynofacies, but such approaches have never been well-developed nor available to the public. Fig. 18 portrays the qualitative abundances of three kinds of organic plant debris: 1) general abundance of organic debris on microscope slides relative to palynomorphs, 2) general amount of cellular sheets, and 3) presence of vascular tracheids and or vessels. Immediately below the oolitic ironstone the assemblage is strongly marine (Fig. 18) and there is very little of all three debris components listed above. Directly above the ironstone layer there is a noticeable jump in all three components, suggesting a terrestrial pulse likely from a river system charged with such organic debris. In the shale layers between the ironstone and the Hatch Mesa Sand Package the organic debris is only moderately present, suggesting a remaining, but lessened, terrestrial influence. Within the sand package, all three components increase noticeably, with sample 89-33G having relatively large amounts of cellular sheets and

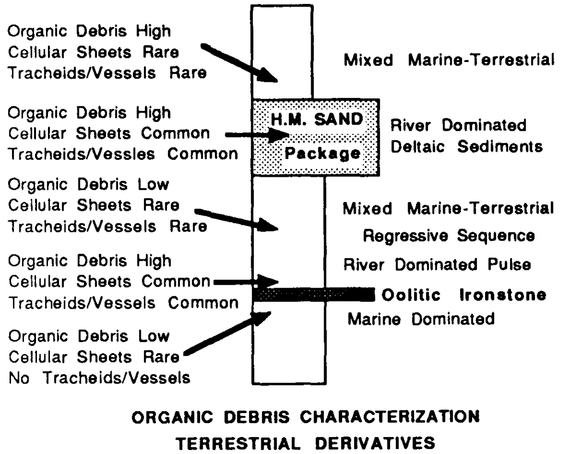

Fig. 18. Organic debris characterization for Locality 89-33. Three main types of organic debris are used to suggest fluviatile-marine influences on sedimentation: 1) general quantity of organic debris of terrestrial origin, 2) cellular sheets, and 3) vascular tracheids and vessels.

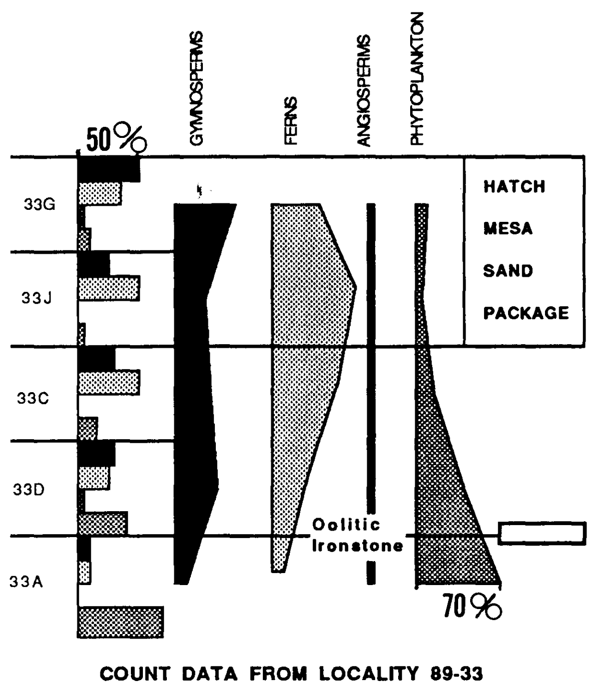

Fig. 19. Relative abundance count data for Locality 89-33 shows a decrease upsection of marine phytoplankton and an increase in fern spores and gymnosperm pollen supporting the hypothesis of a regressive sequence from the oolitic ironstone to the Hatch Mesa sand package.

tracheids/vessels. Although no quantitative means were used in the applications of these three debris components, it is noteworthy that the changes were visible. The more marine samples were also more clean and free from land-derived organic debris. This application assumes uniformity in processing, which was performed carefully by the author due to the research needs of this study. The qualitative abundancewas also weighed against the presence of palynomorphs on the microscope slides. Actual count data (Fig. 19) illustrates how marine phytoplankton dominate below the oolitic ironstone and then decrease upsection to the Hatch Mesa sand package. This correlates with the fern spores and gymnosperm pollen that increase upsection. This supports the assumption of a regressive sequence.

Although the pollen and spore assemblages were diverse, the key Senonian groups often useful in dating of sediments to Stage level were not notably present. The *Aquilapollenites* group was not observed at all and only a few simple Normapolles types were observed. However, pollen and spore components of assemblages do show a strong terrestrial influence, as one might expect from sedimentation associated with deltaic systems.

The palynomorph assemblages from the Hatch Mesa section are often diverse and well-preserved. Twenty-four samples were examined for palynomorphs. Approximately 100 species or form groups were observed (see occurrence charts for both Localities 89-33 and the eastern area composite section, in Appendix B). Detailed taxonomic work is required on the form groups and assemblage in general to differentiate species, new or existing. The general body of literature on Senonian assemblages worldwide concentrates mainly on the Campanian to Maastrichtian time interval. The general nature of the assemblages present at Hatch Mesa is strikingly similar to the Campanian assemblages reported throughout the North American inland Cretaceous seaway (see complete palynological analysis in Appendix B). However, the assemblages reported from Campanian sections elsewhere in the seaway sediments have many species that are known to range downward, as well. The Hatch Mesa forms contain many of those species. Thus, many of the Hatch Mesa forms observed are reported from other Western Interior Campanian-age locations. This study attempts to determine if sediments of Santonian-age are present. Santonian-age palynomorph assemblages would look considerably like Campanian-age assemblages (that typically range lower for most forms), with a few Santonian index palynomorphs. Reports including Santonian palynomorph assemblages are rare, and the only published report identified that appears to relate to the Hatch Mesa assemblages is on Upper Cretaceous assemblages from the Isle of Wight, England (Clarke and Verdier, 1967). Likewise, the Isle of Wight assemblages have a characteristic Senonian appearance, with forms extending into the Campanian. However, a few Isle of Wight forms are reported as being restricted to the Santonian portion of that section. Clarke and Verdier show 12 species as being stratigraphically confined to the Santonian. Despite Clarke and Verdier's assignments, most of these forms are known to range lower, and sometimes, higher. One form, *Senoniasphaera protrusa*, was named in that study as both a new genus and species, and its range might be significant, if actually confined to the Santonian, as shown in that report. Additionally, *Baltisphaeridium erectum* is shown as having a top range in the Santonian. Both forms appear to be present in the Hatch Mesa samples near and below the oolitic ironstone. The Mesozoic-Cenozoic Cycle Chart (Haq et. al, 1988) illustrates *S. protrusa* as having a more extended range of Middle Turonian to Early Campanian. If this is correct, then the upper range of *S. protrusa* is still useful, suggesting that the Hatch Mesa samples are not younger than Early Campanian. The presence of *Baltisphaeridium erectum* (name used by Clarke and Verdier, 1967) may suggest that the samples near the oolitic ironstone might not be younger than Santonian.

Age Discussion

Part of the problem in using the palynology to definitively date the shales (on a scale of ± 1 million years) is that there are few control or reference samples from the Santonian applicable to the Western Interior. For example, no Santonian control sections for palynology of the Western Interior have been reported on, and very few published Santonian control sections exist worldwide. Some awareness of Santonian and Campanian assemblages from the Gulf Coast are of help, but these can only limit the Hatch Mesa ages to Santonian-early Campanian, depending on the accuracy of previous dating of the Austin Chalk and Ozan Formations (Campanian near Austin-Taylor boundary) of Texas. Published assemblages from the Isle of Wight, England (Clarke and Verdier, 1967), suggest a possible Santonian age from samples near the "oolitic ironstone" near the base of the Hatch Mesa Section (see correlation chart, Fig. 17). Although a few species from samples collected for this study appear "new" and are part of some fairly unique palynomorph assemblages, additional taxonomic studies and sampling throughout the upper Cretaceous section of Utah would be required to further distinguish the correlations to shoreline units. This study emphasizes that workable assemblages are present in this part of the section and that there is a need for further investigations on Santonian-Early Campanian palynomorphs from the Western Interior seaway.

The correlation of Locality 89-33 with the more eastern localities collected and considered as a composite section (Fig. 17) is based generally on the overall similarity of the palynomorph assemblage, but more specifically above and below the oolitic ironstone the correlation is based on similar patterns of occurrence of *Deflandrea speciosa*, *Senoniasphaera protrusa*, *Baltisphaeridium erectum*, and *Odontochitina costata*. It is possible that this pattern is strictly related to environmental affinity, although upper limits of ranges may apply to *S. protrusa* and *B. erectum*. A population study should be performed in *D. speciosa* to determine its full affinity to the holotype, and other types, of that species. This form is so diagnostic of this interval, with persistant and large numbers (in several samples) that it appears to be useful.

In summary, the palynomorphs (and organic terrestrial debris) suggest a regressive sequence from the oolitic ironstone through the Hatch Mesa sand package. An age of Santonian to possibly Early Campanian appears documentable near the oolitic ironstone, although the age of the overlying shale and sandier layers appears closely related. It appears possible to correlate assemblages near the oolitic ironstone between both studied localities. The assemblages appear consistent with a nearshore deltaic-marine system, being marine dominated below the oolitic ironstone and river (delta) dominated in the Hatch Mesa sand package. A marine influence is visible in all samples examined, from a strong influence to a minor influence.

CRETACEOUS DEPOSITIONAL SEQUENCES

Sequence stratigraphy concepts (e.g., Van Wagoner and others, 1988 and Van Wagoner and others, 1990) are applicable to the stratigraphic sections of this study, although detailed analyses are not attempted here. Depositional history and resulting stratigraphic relationships (stacking) of the study section can be described in terms of relative sea-level change (Fig. 16). and are compared to the eustatic sea level curves of Haq and others (1987, 1988). Each Blackhawk member represents a regression (or series of regressions) where multiple coarsening-upward parasequences are recognized. In these Blackhawk members, primary regional marine deposition was controlled by clastic shoreline sedimentation (Fig. 14). Backshore lithologies capping the coarsening-upward sequences suggesting lagoon, swamp, and fluvial environments.

Cyclic, transgressive-regressive depositional sequences within the Blackhawk Members are recognized as parasequences. Each Cretaceous parasequence (Fig. 15) coarsens upward in grain size (from shale to sandstone), and bed thicknesses also increase upwards. The stacking of parasequences from the Grassy Member up through the Desert Member indicates progradation in the seaward direction (highstand systems tract). These forward or seaward stepping parasequences are interpreted to represent conditions where the ratio of rate of deposition to accomodation was greater than unity (Van Wagoner and others, 1988; Van Wagoner and others, 1990).

Depositional sequences in the non-shoreface attached facies are difficult to interpret because of their isolation in the Mancos Shale. The oolitic ironstone may represent a lowstand turnaround as well as a parasequence boundary. The general shoaling up into the Hatch Mesa turbidite sandstones may be part of another systems tract, before the overlying highstand system of the Blackhawk Members proper.

On a regional scale, the stacked parasequences (parasequence set) of the Blackhawk Members are superimposed on a larger, overall regressive stage (Upper Zuni A-3 sypercycle, Fig. 16). The progradational Blackhawk parasequences coincide with the highstand systems tract (about 80-82 million years, of the Haq 3.5 3rd order cycle; Fig. 16). The unconformity between the Blackhawk Formation and the overlying Castlegate Sandstone is marked by the sea level drop at 80 million years (Fig. 16).

Upper Cretaceous units in the Book Cliffs illustrate a variety of facies of a clastic-dominated shoreline with deltaic influence. The cyclic nature of progradation sequences and transgressive-regressive tongues indicates the interplay of sedimentation, eustasy and tectonics in the Western Interior seaway, particularly where it can be documented in the Price, Utah area (Van Wagoner and others, 1990). Future studies of sequence stratigraphy in the Upper Cretaceous section require good age dates, particularly for shelf deposits which may show no obvious shoreline connection.

CONCLUSIONS

The Mancos Shale and Blackhawk Formation within the study area record the shoreline evolution and deltaic influence along the western edge of the Western Interior Cretaceous seaway. Internal structures, lithologies, and morphologies of the clastic deposits aid facies interpretations as well as paleogeographic reconstructions. Recognized facies include shoreface-attached deposits of backshore, foreshore, upper shoreface, middle shoreface, lower shoreface, transitional and offshore facies; and a variety of shelf (nonshoreface-attached) deposits including channel fill, transitional turbidite, and reworked facies. The shoreface-attached facies in the Blackhawk Members indicate largely wave-dominated interdeltaic deposition. In contrast, Mancos Shale sections approximately equivalent to the Emery Sandstone interval (Santonian) indicate delta-front sedimentation with periodic river flooding (during probably sea-level lows) providing sand detritus to the shelf.

The shelf deposits are difficult to date, but sedimentologic data and preliminary palynological analyses suggest that the reworked facies mark a parasequence boundary within the Santonian and Early Campanian time interval. Palynological studies also indicate fairly unique assemblages from this time interval which need further documentation throughout the

Cretaceous Western Interior, in order to refine the biostratigraphic scale. Paleobathymetric information from the dinoflagellates, pollen and spores, and organic plant debris confirm the facies interpretations of shelf deposits closely tied to a deltaic system.

Distinctive upward-coarsening sequences (parasequences as well as the members) show distinctive stacking patterns. The stacked facies succession of wave-dominated delta systems indicate general eastward progradation of siliciclastic tongues into the Western Interior Cretaceous seaway during Blackhawk deposition (Campanian). Minor cyclic, transgressive and regressive fluctuations are superimposed on the overall third-order cycle of a sea-level highstand (Vail, 1977; Haq and others, 1988).

This study illustrates the variety of facies present in the Upper Cretaceous of east-central Utah, and documents depositional patterns and stratigraphic relationships. The sedimentologic character of these deposits may have useful application to similar Cretaceous examples and can be used to model scales, geometries, and boundaries in deltaic and shelf systems.

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APPENDIX A

Paleocurrent Measurements and Analyses

Abbreviations:

Formations
  B - Blackhawk
  M - Mancos
Members
  D - Desert
  G - Grassy
  K - Kenilworth
  E - Emery
  F - Ferron
Facies
  SH - Shoreface-attached deposits (including all shoreface facies)
  N - Nonshoreface-attached / Shelf deposits
  C - Channel fill
  CG - Coarse-grained sandstone lag (reworked facies)
  BS - Backshore
  FS - Foreshore
  US - Upper shoreface
  LS - Lower shoreface
  TR - Transitional Offshore
  OF - Offshore

Notes
  SL - Single location
  AD - All data for member(s) and facies(s)

  $\underline{xx}$ Numeration = number of paleocurrent readings
  xx Denominator = mean vector of readings

Current Rose #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Formation	B	B	B	B	F	B	B	B	B	B	B	B	B	B	B	B
Member(s)	G	G	G	G	I	G	G	G	G	D, G	S	S	S	K	K	K
Facies	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH
Facies Zone(s)	BS	US	US	US	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	TR
Notes	SL	SL	SL	AD	SL	SL	SL	SL	SL	AD	SL	SL	AD	SL	SL	AD
Sample Size	12	25	16	41	12	12	12	6	6	36	11	2	13	27	29	56
Vector Mean	50	140	140	140	77	70	72	65	72	70	71	66	70	49	86	66
Standard Deviation	2	5	5	5	2	8	2	1	2	6	1	54	21	14	41	35

Current Rose #	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Formation	B	B	B	B	B	B	B	B	B	B	M	M	M	M	M	M	M
Member(s)	D,G, S,K	K	K	K	K	K	K	K	K	K	E	E	E	E	E	E	F
Facies	SH	N	N	N	N	N	N	N	N	N	C	C	C	C	C	CG	CG
Facies Zone(s)	BS,US, TR	TR	TR	TR	TR	TR	TR	TR	TR	TR	OF	OF	OF	OF	OF	OF	OF
Notes	AD	SL	SL	SL	SL	SL	SL	SL	SL	AD	SL	SL	SL	SL	AD	SL	SL
Sample Size	115	109	178	12	148	12	12	6	7	484	14	5	6	11	36	14	11
Vector Mean	68	84	69	69	67	69	68	77	64	71	102	129	112	149	123	159	11
Standard Deviation	26	46	13	4	16	5	3	4	12	25	30	12	4	10	28	4	2

Table A-1 Locations, facies associations, and analyses for paleocurrent Roses numbered 1 through 33.

A

Location	1
Current rose #	5
Current Ripples	12 77
Total	12 77

B

Location	1	2	Total
Current rose #	2	3	4
Trough cross-strata	25 140	16 140	41 140
Total	25 140	16 140	41 140

C

Location	I	6	Total
Current rose #	32	33	*
High-angle cross-strata	14 159	11 11	25 *
Totals	14 159	11 11	25 *

* Not applicable: large chronostratigraphic difference.

D

Location	2	2	2	3	Total
Current rose #	27	28	29	30	31
Current ripples	14 102	4 131	6 112	11 149	35 122
Groove marks	—	1 122	—	—	1 122
Totals	14 102	5 129	6 112	11 149	36 123

Table A-2 Types and numbers of paleocurrent measurements, and resultant vector means within: A. Backshore facies; B. Upper shoreface facies; C. Oolitic ironstone and coarse-grained sandstone; and D. Channel fill facies.

Location	1	3	4	6	2	4	2	4	A	B	C	D	E	G	H	I	Total
Current rose #	6	7	8	9	11	12	14	15	18	19	20	21	22	23	24	25	*
Current ripples	$\frac{12}{70}$	$\frac{12}{72}$	$\frac{5}{64}$	$\frac{4}{72}$	$\frac{11}{71}$	$\frac{1}{10}$	—	$\frac{12}{30}$	$\frac{4}{114}$	$\frac{12}{67}$	$\frac{4}{68}$	$\frac{3}{60}$	—	$\frac{12}{68}$	$\frac{6}{77}$	$\frac{4}{69}$	$\frac{102}{*}$
Flute marks	—	—	$\frac{1}{65}$	$\frac{2}{72}$	—	$\frac{1}{121}$	$\frac{8}{66}$	$\frac{2}{73}$	$\frac{22}{51}$	$\frac{103}{70}$	$\frac{4}{66}$	$\frac{70}{57}$	$\frac{2}{69}$	—	—	—	$\frac{215}{*}$
Groove marks	—	—	—	—	—	—	$\frac{13}{42}$	$\frac{15}{50}$	$\frac{83}{96}$	$\frac{63}{68}$	$\frac{4}{72}$	$\frac{72}{77}$	$\frac{10}{69}$	—	—	—	$\frac{260}{*}$
Prod marks	—	—	—	—	—	—	$\frac{6}{50}$	—	—	—	—	$\frac{2}{50}$	—	—	—	—	$\frac{8}{*}$
Rib and furrow	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	$\frac{3}{57}$	$\frac{3}{*}$
Bounce marks	—	—	—	—	—	—	—	—	—	—	—	$\frac{1}{80}$	—	—	—	—	$\frac{1}{*}$
Totals	$\frac{12}{70}$	$\frac{12}{72}$	$\frac{6}{65}$	$\frac{6}{72}$	$\frac{11}{71}$	$\frac{2}{66}$	$\frac{27}{49}$	$\frac{29}{86}$	$\frac{109}{84}$	$\frac{178}{69}$	$\frac{12}{69}$	$\frac{148}{67}$	$\frac{12}{69}$	$\frac{12}{68}$	$\frac{6}{77}$	$\frac{7}{64}$	$\frac{589}{*}$

* Not applicable: large chronostratigraphic difference

Table A-3 Types and numbers of paleocurrent measurements, and resultant vector means within the shelf deposits (refer to Plate 2 for locations)

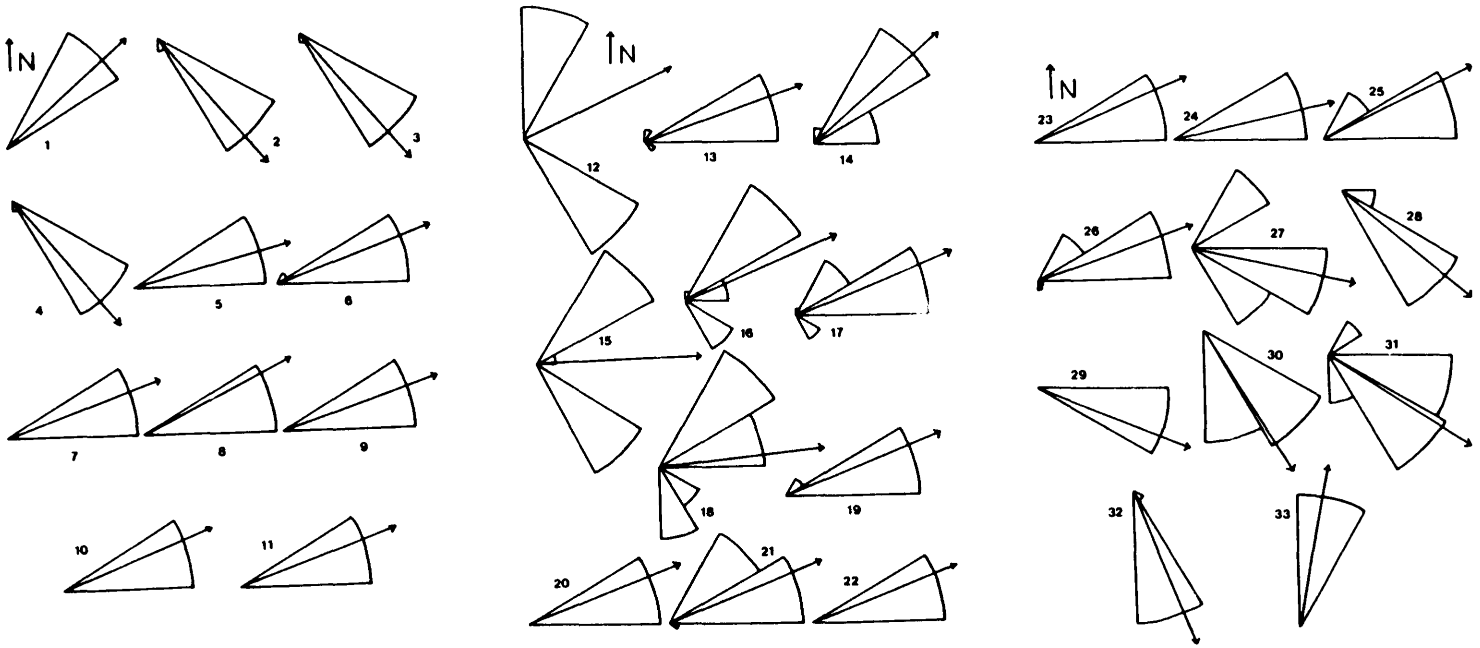

Fig. A-1 Summary paleocurrent rose diagrams for select stratigraphic intervals (Plate 1). Detailed data for rose diagrams given in Table A-1.

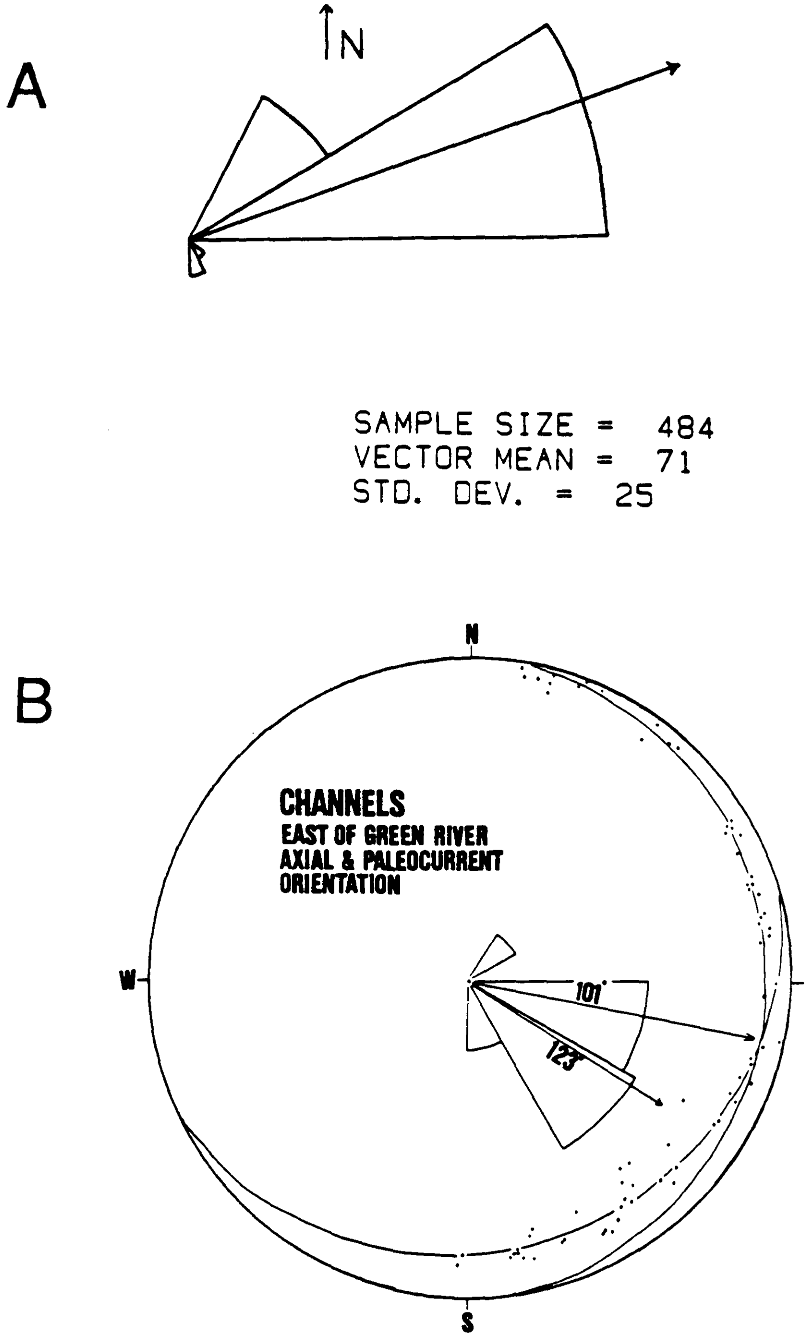

Fig. A-2 Paleocurrent measurements of: A. all Hatch Mesa shelf (nonshoreface-attached) deposits combined; and B. channel flank measurements showing interpreted axial orientation (bisection of great circles at 101°), and superimposed rose diagram of 36 current measurements (123°) from four channels in the approximate Emery interval (regional dip of strike N70E, dip 6°N removed).

APPENDIX B

Palynological Sampling and Analysis

Cretaceous Mancos Shale Samples collected Sept. 1989. Sample localities also noted on Plate 2.

Locality UT89-32: Old Hwy 6 just E of Green River, UT. Sec. 14, T 21S, R16E

Samples:	UT89-32b	Sh 1' below crse ss with fishteeth
	UT89-32b	Sh ~ 2' above crse ss with fishteeth

Locality UT89-33: Hatch Mesa. Sec. 32, T21S, R18E (See Fig. 2)

Samples:	UT89-33a	Sh from ~3' below crse salt-pepper ss
	UT89-33b	Sh from ~12' below crse salt-pepper ss
	UT89-33c	Sh from ~10' above crse salt-pepper ss
	UT89-33d	Sh from just above ? crse salt-pepper ss
	UT89-33e	Sh ~2' below 1st turbidite bed
	UT89-33g	Sh from turbidite beds, ~1/3 from top of turbidite pkg, ~2/3 way up from 33e
	UT89-33h	Sh from ~6-12' above turbidite pkg
	UT89-33i	Sh from turbidite bed
	UT89-33j	Sh from dark turbidite sh, same interval as 33i

Locality UT89-34: Floy Canyon. Sec. 3, T22S, R18E (Oolite body #55)

Samples:	UT89-34a	Sh from ~12' below oolitic ironstone
	UT89-34b	Weathered Sandy sltst ~1' below oolitic ironstone oolite
	UT89-34c	Sh from ~4-5' above salt-pepper ss
	UT89-34d	Sh from ~6' below *Inoceramus* mound cap (mound lies below oolitic ironstone)

Locality UT89-35: W. Floy Canyon "Hatch Mesa" beds, 0.7 mi N of RR tracks
Sec. 4 T22S, R18E

Samples:	UT89-35a	Sh from ~35' below base of turbidite beds
	UT89-35b	Sh from ~2-3' beneath turbidite beds
	UT89-35c	Sh from ~13-14' beneath turbidite beds
	UT89-35d	Sh from ~16-20' beneath turbidite beds

Locality UT89-36: Floy Canyon. Sec. 3, T22S, R18E (Oolite body #44)

Samples:	UT89-36a	Sh from ~13-14' beneath oolitic ironstone

Locality UT89-37: Floy Canyon. Sec. 3, T22S, R18E (Oolite body #34 by RR)

Samples:	UT89-37a	Sh from ~3' beneath oolitic ironstone and thin crse ss layer
	UT89-37b	Sh from ~2' beneath oolitic ironstone

Locality UT89-38: Floy Canyon. Sec. 3, T22S, R18E (Oolite body #47)

Samples:	UT89-38a	Sh from ~6' below oolitic ironstone
	UT89-38b	Sh from ~4' above oolitic ironstone

Notations and abbreviations:

ss = sandstone, sltst= siltstone, sh= shale, crse= coarse-grained, pkg= package, salt-pepper ss= coarse-grained sandstone lag

PALYNOLOGY OF EMERY SANDSTONE EQUIVALENT STRATA IN THE EASTERN BOOK CLIFFS

by

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December 1990

Twenty-four samples were examined from suspected Emery Sandstone equivalent strata collected from the eastern Book Cliffs to the east of Green River, Utah. To the west, in Castle Valley, the Emery Sandstone (sometimes referred to as the Emery Sandstone Member of the Mancos Shale) is relatively terrestrial in origin, but east of there the unit grades into marine shales. It is from this eastern area that these samples were collected. They were, therefore, anticipated to be marine in origin and to contain marine palynomorphs. Palynological studies of the Emery Sandstone in the Henry Mountains area indicate that assemblages there have "only" terrestrial components - pollen and spores. The assemblages reported on in this present study, almost without exception, have a prominant marine component - dinoflagellates and acritarchs. Dinoflagellates are a form of marine phytoplankton, and acritarchs are thought to be primarily marine phytoplankton as well. Dinoflagellates generally prove to be more age diagnostic than pollen and spores, although one can encounter pollen groups that are also age specific.

The following samples were processed and examined for palynology. Sample numbers are those of Dr. Marjorie Chan of the Geology Department, University of Utah. They correspond to her collecting localties and stratigraphic horizons in the Emery Sandstone equivalent strata in the eastern Book Cliffs, east of Green River, Utah. All samples yielded palynomorphs. Over 100 species of pollen, spores, and dinoflagellates were observed.

89-32b
89-32c
89-33a
89-33b
89-33c
89-33d
89-33e
89-33g
89-33h
89-33i
89-33j
89-34a
89-34b
89-34c
89-34d
89-35a
89-35b
89-35d
89-37a
89-37b(1)
89-37b(2)
89-38a
89-38b

SAMPLE PROCESSING: Standard palynological maceration techniques were used, including sieving with 20um sieve cloth and staining in Bismarck Brown. Strewn mounts were prepared using glycerin jelly mounting medium.

GENERAL CHARACTERISTICS OF ASSEMBLAGES

The assemblages are, almost without exception, marine in nature. The general aspect is a Senonian-age dinoflagellate assemblage which upon closer examination appears to be Santonian-Campanian in age. A few forms, to be discussed, suggest a possible Santonian age for the Emery sandstone equivalent in this area. Typical forms present are *Senoniasphaera* (*rotundata* and *protrusa*) and *Chatangiella* (species similar to *ditissima, tripartita, armata*, and *microarma*, and *Isabelia* (species similar to *glabra* and *cooksonae*) and *Spinidinium* (species similar to *densispinatum, lanterna, styloniferum, clavum*, and *echinoideum* and *Vozzhennikovia* (species similar to *apertura*) and *Alterbia* (species similar to *macrocysta*, and *Deflandrea* (species similar to *pannucea, asymmetrica, boloniensis, granulostriata*, and *speciosa, Subilisphaera* (*trendalli, senegalensis*, and *crassigranulosa*), and *Cribroperidinium edwardsii, Apteodinium* sp., *Gonyaulacysta* sp., *Impagidinium* sp., *Cyclonephelium* (species similar to *clathromarginatum, compactum*), *Canningia* sp., *Areologera senonensis, Palaeohystrichophora infusorioides, Exochosphaeridium* (species similar to *striolatum, bifidum*), *Trichodinium hirsutum, Cleistosphaeridium* (several species), and *Oligosphaeridium complex, Hystrichosphaeridium tubiferum, Baltisphaeridium erectum, Cordosphaeridium* sp., *Achomosphaera ramulifera, Spiniferites ramosus ramosus, Odontchitina (operculata and costata), Xenascus ceratioides, Dinogymnium pustulicostatum, Palambages morulosa,* and *Pediastrum* sp.

SANTONIAN ASPECT OF PORTIONS OF THE OVERALL ASSEMBLAGE

In palynology, there are some parts of the stratigraphic column that are not well represented in the literature, and the Santonian is one of them. Although many publications cover the Senonian, few publications deal specifically With the individual stages of the Senonian, with the exception of the Upper Campanian and Maastrichtian. However, there are a few publications which include the Santonian, plus Palynex has palynological experience in the Texas and Arkansas Gulf Coastal Plain Santonian and Early Campanian. There are also certain difficulties in utilizing the existing literature. One difficulty is that few palynologists have understood that dinoflagellates reproduce sexually and that specimens in populations show some degree of variability due to genetic recombination. Variability in morphology can also be caused by ecophenotypic response, and algae display some morphologic flexibility from environmental factors. What this means is that most workers speciate according to artificial form taxonomy, likely creating more species than really exist. A dinoflagellate taxonomist or biostratigrapher should be able to deal with this in evaluating published assemblages and the assocated nomenclature. For this reason, this report sometimes refers to a cluster of species that are of similar morphology and age, assuming that they could repesent ecophenotypes of the same species. Another difficulty arises from simple misidentifications in the literature. To be safe, accurate identifications should be made relative to holotypes and their descriptions (unfortunately older descriptions can be archaic in content). The numbers of pollen and spore species for a geologic period is staggering, representing a typical massive land flora. There are considerably fewer species of dinoflagellates (that produced the fossilizable cysts) existing at any one time, but these often prove to be more age-diagnostic because they appear to evolve faster. The published literature must be dealt with somewhat carefully, and I think this is especially true with Senonian dinoflagellate assemblages. Among the many dinoflagellate species present in the Emery material are a few that suggest a Santonian age, as opposed to a broader Santonian-Campanian age. These are *Senoniasphaera protrusa* and *"Baltisphaeridium" erectum.* The biostratigraphic age information on these two forms is found in Clarke and Verdier 1967, which is a study of microplankton assemblages from the Isle of Wight, England. Several references are also made to *S. protrusa* in the various publications of Fouchier from sections in France. *B. erectum* ranges from Cenomanian to Santonian, while *S. protrusa* is restricted to the Santonian in the Isle of Wight section. In the Texas Gulf Coast, the author has observed *S. protrusa* in and above the Austin Chalk, as high as the Ozan Formation. This may extend *S. protrusa* into the early Campanian, but this depends on the accuracy of Lower Taylor dates. Perhaps the Lower Taylor is still Santonian. If so, then the presence (concurrent ages) of S. protrusa and *"B." erectum* may suggest Santonian. Addtionally, the Emery material contains other forms which Clarke and Verdier (1967) report as being Santonian. These are *Gonyaluacysta striata, Canningia senonica, Deflandrea victoriensis, Deflandrea acuminata, Deflandrea cf. cooksoni* , and *Deflandrea echinoidea.* These scientific names of species are those used by Clarke and Verdier (1967) , and although name changes have occurred, this report will use Clarke and Verdier's assigned names.

In general appearance, the "Emery" assemblage also bears a rather strong overall resemblance to the Santonian Isle of Wight assemblage of Clarke and Verdier. For example, C&V's *Deflandrea acuminata*, which is restricted to the Santonian, is identical to some of the Emery *Chatangiella* (example, specimen 18-2L, 25-2M) forms observed, having two well-developed antapical horns, little indication of a paracingulum, and being rather inflated in appearance. The C&V forms identified as *Deflandrea cf. cooksoni* bear a strong resemblance to the smaller *Chatangiella*s (example, specimen 2-5L, 18-5A, 20-1L, 25-2P, and 21- 13A) observed in the Emery material . C&V's *Gonyaulacysta striata* is also strikingly similar to the *Impagidinium* sp. observed in sample 89-38b (specimen 27-8I). C&V reports three types of *Dinogymnium* (*hetercostatum, microgranulosum*, and *denticulatum*), and the Emery material also has several specimens of *Dinogymnium,* which all may, in reality, be of one species (C&V's also appear to be the same single species, rather than three species). C&V reports that *Deflandrea echinoidea* is restricted to the Santonian. This species is now assigned to *Spinidinium* or *Vozzhennikovia* (depending on the literature used), and several Emery forms appear identical to C&V's forms (see specimens 24-4"o", 13-11a, 24-1k, 24-3m, 21-2a). However, *Spinidinium* forms similar to these are known to range higher and lower. Other comparisons can be drawn to the C&V assemblages and to those of Fouchier of France.

COMPARISON OF EMERY ASSEMBLAGE WITH ASSEMBLAGES FROM OTHER AREAS:

Some of the Emery marine assemblage also bears a strong similarity to parts of an assemblage reported by Stanley (1966) from the Hell Creek Formation of South Dakota. Such a similarity is not unusual in that palynomorphs can range through that much section. The similarity might be more indicative of a comparable physical environment and may have less to do with synchroneity. In some ways this similarity is stronger than with the Santonian Chalk at the Isle of Wight, but the differences appear to lie with index fossils versus potential environmental indicators. Hell Creek similarities lie mainly among the peridinioid components: *Deflandrea pannucea, Deflandrea speciosa*, and the *Spinidinium* forms (*densispinatum*). The Hell Creek also contains *Dinogymnium nelsonense* (likely = *pustilicostatum*), and *Micrhystridium piliferum*, and *Pterospermopsis australiensis*, and *Pediastrum borianum*, and *Areoligera senonensis*. Several spore and pollen components are also similar, such as *Foveosporis triangulus*, *Foveosporites cyclicus*, *Hamulatisporites* amplus, *H. hamulatis, Osmundacites comaumensis, Appendicisporites tricornitatus*, *Schizosporis complexus, Cycadopites scabratus*, and *Proteacidites retusus*.

Among the various comparisons made between assemblages, one was made with the Coniacian of France (Foucher, 1971). There was no strong similarity, although a few species were found in common: *Palaeohystrichophora infusorioides, Achomosphaera ramulifera, Spiniferites ramosus ramosus*, *Exochosphaeridium striolatum, Oligosphaeridium complex,* Xenascus *ceratioides, Odontochitina costata, and Deflandrea victoriensis* (basic *Chatangiella* form). This similarity is not much more than would be expected between Senonian assemblages.

A comparison was made with the assemblages of Drugg (1967) from the Upper Moreno Formation (Late Cretaceous-Paleocene) of Escarpado Canyon, California. Similar forms include: *Deflandrea speciosa, Spindinium densispinatum, Areoligera* sp., *Leptolepidites major, Proteacdites retusus*, and *Quadripollis krempii, Quadripollis krempii* is a significant discovery in the literature, because a near-identical type occurs throughout the Emery equivalent. *Q. krempi* was described as a new genus and species by Drugg (1967), and is rarely reported elsewhere in the literature. Drugg indicates that its occurrence in the Moreno Formation is Maastrichtian, but it has been reported from the Western Interior Almond Formation (Upper Campanian) and the Maastrichtian Edmonton

Formation of Alberta. It's occurrence in the Emery equivalent strata means that its range extends down into probable Santonian-age strata. This does preclude considering it as a Santonian index fossil in the Western Interior and unless it proves to be a new species. This will require a more detailed examination of the original description and illustrations and of the Emery-equivalent specimens. A Comparison was made with the pollen and spore assemblages reported by Anderson (1960) from the San Juan Basin of New Mexico (probable Maastrichtian-Paleocene). Drugg (1967) had referred to individual pollen grain specimens that perhaps had broken out of the pollen tetrad *Quadripollis* as being named *Inaperturopollenites limbatus* Balme 1947, and had been reported in Anderson's study on the San Juan Basin. An examination of Anderson's specimens showed some similarity, but one would have to imagine what individual specimens split from a tetrad might look like; Drugg, himself, had never seen these. Drugg's *Quadripollis* had obligate tetrads, and his specimens were not observed as individual grains. Anderson's assemblages are apparently Maastrichtian. There is only slight general similarity between the Emery-equivalent assemblages and Anderson's assemblages from the Naciemento, Ojo Alamo, Kirtland Shale, and Lewis Shale Formations. Anderson concluded that his sequence was likely correlatable with the Lance-Fort Union Formations to the north. The few dinoflagellates that he found are not at all like the Emery-equivalent dinoflagellates, and the pollen and spores assemblages only bear a superficial resemblance.

A comparison was made with the marine and terrestrial palynomorphs of the Almond Formation (Upper Campanian) of the Rock Springs Uplift area of Wyoming. One important form observed (again) in both sections is *Quadripollis krempii* , which appears persistently in the Emery-equivialent samples. This obligate tetrad described by Drugg (1967) and discussed above from Maastarichtian strata, and here in Stone's Upper Campanian strata in the Western Interior precludes its consideration as an Emery index palynomorph, but it is certainly a major part of the Emery assemblage. Its unique morphology would normally prove quite helpful in biostratigraphy. Other forms in common include *Pediastrum* (lacustrine green alga), Palambages (colonial marine green alga), various types of *Dinogymnium*, *Chatangiella/Isabelia* forms similar to those of the Emery, *Deflandrea pannucea, Spinidiniinm densispinatum/echinoideum, Hystrichisphaeridium tubiferum, Diphyes colligerum, Spiniferites ramosus*-types, *Deltoidospora* sp., *Gleicheniidites senonicus, Foveosporis triangulus, Hamulatisporites hamulatus, Cicatricosisporites dorogensis, Laricoidites magnus, Cycadopites scabratus, Quadripollis krempii , Corallina classoides, Liliacidites complexus, Tsugaepollenites igniculus,* and *Proteacidites retusus* and *thalmanni* . The similarity of this assemblage with the Emery-equivalent assemblage is striking; however, the Almond Formation contains several known-younger marine palynomorphs which indeed suggests a younger (Upper Campanian) age. Certainly, the Almond is similar in age, but it does not preclude a Santonian age assignment for the Emery equivalent strata which contain a few forms apparently more indicative of Santonian-Early Campanian. Additionally, the Emery-equivalent assemblages lack the known-younger forms seen in the Almond Formation. Comparisons were also made to Cretaceous and Tertiary assemblages from Banks Island and adjacent areas of the North West Territories and the District of Mackenzie of Canada, several localities in Australia, Cretaceous deposits of the USSR, the Upper Campanian Judith River Formation of Montana, The Edmonton Formation (Maastrichtian of Alberta (which bears a strong likeness in the pollen and spore components), the Navarro Group of Texas, the Campanian-Maastrichtian of the Senegal Basin of West Africa, Late Santonian to Campanian sections along the Horton River in the District of Mackenzie (NWT, Canada), and other locations (see Bibliography). An understanding of these other similarities will continue to be developed this year, until more material can be collected and examined. It is important to note that the Emery-equivalent assemblages do fit nicely within the established Inland Cretaceous Seaway Santonian/Campanian -Maastrichtian assemblages of Wyoming. Montana, and Alberta. There are some difference that should also prove helpful in detailed biostratigraphy.

MARINE AND TERRESTRIAL RELATIONSHIPS

Most samples examined contain a balance between marine and terrestrial species, but generally speaking the numbers of marine specimens (not species) dominate the terrestrial specimens. A few samples examined appear terrestrial (mainly lacking marine phytoplankton specimens); these are marked below with an asterisk. This may suggest changes in depositional regimes where the terrestrial sediments and associated palynomorphs dilute the marine counterparts. Such samples are:

*89-32b: A few conifer pollen grains and other bits and pieces.

89-32c: Marine species dominate terrestrial

89-33a: Marine species dominate terrestrial

89-33b: Contains sparse marine phytoplankton, but also a somewhat equal represenation of pollen and spores.

89-33c: Terrestrial palynomorph species dominate marine.

89-33d: Terresrial palynomorph species dominate marine.

89-33e: Terrestrial palynomorph species somewhat equal to marine.

*89-33g: Terrestrial palynomorph species dominate marine.

*89-33h: Terrestrial palynomorph species dominate marine.

*89-33i : Sparse terrestrial palynomorph species dominate marine.

*89-33j : Diverse terrestrial palynomorph species dominate marine.

*89-34a: Terrestrial palynomorph species dominate marine.

89-34b: Sparse terrestrial spcies dominate marine.

89-34c: Diverse terrestrial species somewhat equal to marine.

89-34d: Terrestrial species somewhat equal to marine.

89-35a: Terrestrial species somewhat equal to marine.

89-35b: Sparse terrestrial species dominate marine.

89-35c: Terrestrial species somewhat dominate marine.

89-35d: Marine species dominate terrestrial

89-36a: Sparse marine species dominate terrestrial

89-37a: Sparse terrestrial species dominate marine.

89-37b: Marine species dominate terrestrial

89-38a: Marine species dominate terrestrial.

89-38b: Marine species dominate terrestrial

APPARENT CORRELATABLE CHARACTERISTICS

There is a certain taxonomic characterization, or grouping of unique forms, that may serve as a means of correlating these Eastern Book Cliffs Emery-equivalent strata with with other sections to the east, and perhaps somewhat to the west. Additionally, a study by Sarmiento (1965 Microfossil Zonation of the Mancos Group) suggests that ratios of general palynofloral and phytoplankton groups can be used to correlate within the Mancos. Sarmiento identifies a "Zone B" which is highly marine in its lower third, and which appears to represent approximately the position of the Emery-equivalent strata. It appears likely that a more detailed study of species present, and the more generalized information from Sarmiento, can be used in correlation. Count informaton will need to be developed to test Sarmientos zones. Certainly, the overall assemblage and the more unique forms as documented in this present study (some 300 photomicrographs) will prove useful in correlation.

The frequent presence of *Senoniasphaera rotundata*, and the less frequent presence of *Senoniasphaera protrusa*, should prove helpful in correlation; these forms have not been reported in the published literature from the Western Interior before. In fact, they haven't been reported from the Gulf Coast, although I have seen them there in the Austin and Lower Taylor. The overall complex of more than 100 species should also prove useful in correlation. The high numbers of *Quadripollis krempii* should also prove helpful.

SAMPLE BY SAMPLE ANALYSIS OF SPECIES

Note: In most cases the scientific names used are those of particular publications used in this study and may not reflect the latest taxonomy.

Note: Possible Santonian age assignments are based primarily on occurrences found in Clark and Verdier (1967), and are subject to the accuracy of their findings. There was no other Santonian literature from the Inland Cretaceous Seaway, only Campanian and Maastrichtian.

Note: The microscope notes indicate the presence of more than 100 species of pollen, spores, dinoflagellates, and acritarchs. Some of these have yet to be located in the literature, but most are listed below, according to sample/occurrence.

Sample 89-32B

The assemblage is very sparse with few forms observed. Pollen grains of Pine and a few nonidentifiable fragments of other pollen were observed.

Age: Nondiagnostic

Environment of Deposition: Nondiagnostic

Sample 89-32C

The assemblage is highly diverse.

Marine forms observed include: *Spinidiniun, Vozzhennikovia echinoideum*, Various small peridinioids, including primarily *Subtilisphaera* spp., *Apteodinium* sp , *Spiniferites ramosus ramosus, Oligosphaeridium complex, Chatangiella tripartita, C. ditissima, Isabelia glabra, Cyclonephelium cf C. crassimarginatum, Palaeohystrichophora infusorioides, Achomosphaera ramulifera, Trichodinium hirsutum, Canningia senonica, Canningia spp., Baltisphaeridium cf. B. striolatum, Cleistosphaeridium spp., Hexagonifera sp., ?Tasmanites,* and *?Pterospermopsis* (large variety).

Terrestrial Forms observed include: *Hamulatisporites amplus Appendicisporites cristatus., Gleicheniidites senonicus, Cicatricosisporites furcatus, Triporolites stellatus, Leptolepidites major, Cicatriosisporites ornatus,* and *?Mancicorpus tripodiformus.*

Other forms: fungal spore chains.

Age: General Senonian appearance; possibly Santonian to Campanian.

Environment of Deposition: Marine

Sample 89-33A

Assemblage is moderately diverse.

Marine forms include *Gonyaulacysta spp., Spinidinium echinoideum/ Vozzhennikovia apertura, Apteodinium sp., Oligosphaeridium complex, Cyclonephelium compactum, Deflandrea asymmetrica, Deflandrea pannucea, Deflandrea speciosa, Trithyrodinium n. sp., Cleistosphaeridium multifurcatum, Odontochitina costata, Senoniasphaera rotundata, Trichodinium hirsutum, Baltisphaeridium armatum,* and *Isabelia glabra.*

Terrestrial forms include *Aequitriradites ornatus, Cycadopites scabratus, and ?Normapolles* Forma A.

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-33B

The assemblage is sparse.

Marine forms include *Cleistosphaeridium spp., Senoniasphaera rotundata, Spinidinium/ Vozzhennikovia echinoideum,* and *Gonyaulacysta/ Cribroperidium sp.*

Terrestrial forms include *Proteacidites thalmannii* and *Ceratosporites cf. C. coulienis.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-33C

Assemblage is highly diverse.

Marine forms include *Chatangiella tripartita, Isabelia glabra, Palaeohystrichphora infusorioides, Dinogymnium pustulicostatam, Senoniasphaera rotundata/protrusa, Senoniasphaera protrusa* and *Areoligera senonensis.*

Terrestrial forms include *Lycopodiacidites bullerensis, Neoraestrickia truncata, Monosulcites* sp. (?n. sp.) , *Aequitriradites ornatus, Sphagnum, Tsugaepollenites insignis,* and *Appendicisporites* spp.

Age: Santonian to Early Campanian

Environment of Deposition: Marine

Sample 89-33D

Assemblage is moderately diverse.

Marine forms include *Odontochitina operculata, Isabelia glabra, Areoligera senonesis, Senoniasphaera rotundata, Baltisphaeridiinm erectum,* and *Deflandrea speciosa.*

Terrestrial forms include *Pilularia novae-zealandica, Cyathidites minor, Appendisporites tricornitatus,* including A. *cristatus, Quadripollis krempii* , *Normapolles* forma A, *Hamulatisporites amplus,* and a tricolporate pollenium.

Age: Santonian to Early Campanian

Environment of Deposition: Marine

Sample 89-33E

Assemblage is highly diverse.

Marine forms include *Senoniasphaera rotundata, Spinifirites ramosus ramosus, Apteodinium* sp. , *Cleistosphaeridium* spp. , *Areoligera senonensis, Oligosphaeridium complex, Isabelia glabra, Canningia senonica, Odontochitina costata, Subtilisphaera* spp. , and *Baltisphaeridium erectum.*

Terrestrial forms include *Leptolepidites verrucatus, Triletes hayii, Cyathidites minor, Cicatricosisporites furcatus,* and *Tsugaepollenites insignis.*

Age: Santonian

Environment of Deposition: Marine

Sample 89-33G

Assemblage is moderately diverse.

Marine forms include *Apteodinium sp., Cleistosphaeridium spp.* , and *Senoniasphaera rotundata.*

Terrestrial forms include *Quadripollis krempii* , *Tsugaepollenites insignis, Foraminisporis cf. F. wonthaggiensis, Schizosporis/Liliacidites complexus, Monosulcites* n. sp.? (Pl 1, Fig. 3), *Ephedripites* sp., and *Pinus.*

Age: Santonian to Campanian.

Environment of Deposition: Marine

Sample 89-33H

Assemblage is moderately diverse.

Marine forms include *Areoligera senonensis, Isabelia glabra*, *Cleistosphaerium* spp., and a small Hystrichosphaeridium sp.

Terrestrial forms inclinude *Monosulcites* n. sp.?, *Gleicheniidite senonicus, Laricoidites magnus, Aequitriradites ornatus*, Spore Type B and *Proteacidites thalmanni.*

Age: Senonian

Environment of Deposition: Marine

Sample 89-33I

Assemblage is sparse.

Marine forms include *Tasmanites* spp.
Terrestrial forms include *Tsugaepollenites insignis, Deltoidospora hallii.*

Age: Cretaceous

Environment of Deposition: Difficult to determine; stronger terrestrial influence.

Sample 89-33J

Assemblage is highly diverse. No marine forms were observed.

Terrestrial forms include *Deltoidospoa hallii* , *Monosulcites* n. sp?, *Cyathidites minor, Tsugaepollenites insignis, Gnetaceae, Aequitriradites ornatus, Cycadopites scabratus, Cicatricosisporites furcatus, Hamulatisporites amplus, Trochicola scollardiana, Hamulatisporites comauensis, Proteacidites thalmanni, Osmundacidites wellmanii* and *Retitriletes singhi.*

Other forms: Fungal spore chains.

Age: Upper Cretaceous

Environment of Deposition: Strong terrestrial influence; little apparent marine influence.

Sample 89-34A

Assemblage is moderately diverse.

Marine forms include *Isabelia glabra, Chatangiella/Deflandrea acuminata, Spinidinium/ Vozzhennikovia echinoideum*, small *Diconodinium* sp., and *Subtilisphaera* spp.

Terrestrial forms include *Appendicisporites* spp., *Cycadopites scabratus, Tsugaepollenites insignis, Quadripollis krempii, Deltoidospora hallii , Triporoletes tympanoideus,* and *Monosulcites* n. sp.?

Age: Santonian to Campanian, perhaps to Maastrichtian.

Environment of Deposition: Marginal marine

Sample: 89-34B

Assemblage is sparse.

Marine forms include *Deflandrea acuminata, Senoniasphaera rotundata, Odontochitina operculata,* and *Cleistosphaeridium* spp.

Terrestrial forms include *Monosulcites* n. sp.? *Tsugaepollenits insignis, Appendicisporites* spp., and *Deltoidospora hallii.*

Age: Santonian to Campanian.

Environment of Deposition: Marine

Sample 89-34C

Assemblage is highly diverse.

Marine forms include *Oligosphaeridiinm complex, Isabelia glabra, Deflandrea acuminata, Canningia* sp., *Odontochitina costata, Palaeohystrichphora infusorioides; Operculodinium* sp., *Spiniferites ramosus ramosus , Deflandrea speciosa, Subtilisphaera* sp., *Stephodinium* sp. , *Senoniaspaera rotundata, Senoniasphaera protrusa, Spinidinium/Vozhennikovia echinoideum, Baltisphaeridium erectum,* and *Gonyaulacysta* sp.

Terrestrial forms include *Tsugaepollenites insignis, Quadripollis krempii* , Pinus is common (and in most other samples as well), *Cycadopites* scabratus, *Cicatricosisporites furcatus, Cicatricosisporites ornatus, Triporoletes tympanoideus, Deltoidospora hallii* , and *Monosulcites* n. sp.?

Age: Santonian

Environment of Deposition: Marine

Sample 89-34D

Assemblage is moderately diverse.

Marine forms observed include *Senoniaspahera rotundata, Apteodinium sp., Spinidinium echinoideum, Deflandrea acuminata, Deflandrea speciosa*, and *Subtilisphaera trendalli.*

Terrestrial forms observed include *Deltoidospora hallii , Cyathidites minor, Appendisporites cristatus, Quadripollis krempii, Cicatricosisporites furcatus*, and *Tsugaepollenites insignis.*

Age: Santonian to Campanian.

Environment of Deposition: Marine

Sample 89-35A

Assemblage is moderately diverse.

Marine forms observed include *Dinogymnium pustulicostatum, Isabelia glabra/Deflandea acuminata, Senoniasphaera rotundata, Areoligera senonensis, Cleistosphaeridium* spp., *Palambages morulosa, Odontochitina operculata, Gonyaulacysta* sp., and *Spinidinium echinoideum.*

Terrestrial forms include *Deltoidospora hallii , Corallina classoides, Monosucites* n. sp.?, *Tsugaepollenites insignis, Quadripollis krempii , Proteacidites thalmanni.* and *Schizosporis parvus.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-35B

Assemblage his low diversity.

Marine forms observed include *Deflandrea acuminata.*

Terrestrial forms observed include *Deltoidospora hallii , Quadripollis krempii, Cyathidites minor, Cycadopites scabratus, Monosulcites* n. sp.?, *Tsugaepollenites krempii , Corallina classoides,* and *Cicatricosisporites furcatus.*

Age: Senonian.

Environment of Deposition: Marine

Sample 89-35C

Assemblage is moderately diverse.

Marine forms observed include *Areoligera senonica, Isabelia glabra, Senoniasphaera rotundata, Spiniferites ramosa ramosa, Apteodinium sp. Pterospermopsis* sp., and *Subtilisphaera* sp.

Terrestrial forms observed include *Cyathidites minor, Tsugaepollenites insignis, Deltoidospora hallii, Appendicisporites tricornitatus, Hamulatisporits hamulatus, Quadripollis krempii* , *Deltoidospora hallii* , *Cicatricosisporites ornatus*, and Cicatricosisporites dorogensis.

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-35D

Assemblage is highly diverse.

Marine forms observed include *Senoniasphaera rotundata, Palaeohystrichophora infusorioides, Spinidinium echinoideum/styloniferum, Deflandrea acuminata, Xenascus ceratioides, Canningia* sp., *Odontochitina costata, Hystrichospheridium tubiferum, Apteodinium* sp. , *Deflandrea speciosa, Cyclonephelium compactum, Diphyes colligerum*, and *Areoligera senonensis.*

Terrestrial forms include *Hamulatisporites hamulatus.* and *Cicatricosisporites furcatus.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-36A

Assemblage is relatively sparse.

Marine forms observed include *Deflandrea speciosa, Senoniasphaera rotundata, Oligosphaeridium complex, Spinidinium echinoideum,* and *Spiniferites ramosus ramosus.*

Terrestrial forms observed include *Pinus, Corallina classoides*, and *Proteacidites thalmanni.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-37A

Assemblage is sparse.

Marine forms observed include *Senoniasphae rotundata, Deflandrea acuminata*, and *Pterospermopsis* sp..

Terrestrial forms observed include *Deltoidospora hallii* and *Pinus.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-37B

Assemblage is moderately diverse.

Marine forms observed include *Senoniasphaera rotundata, Spinidinium echinoideum, Deflandrea acuminata, Isabelia glabra, Chatangiella microarma, Senoniasphaera protrusa/Canningia senonica, Heterosphaeridium conjunctum, Apteodinium* sp. , *Achomsphaera ramulifera, Odontochitina costata, Deflandrea speciosa, Alterbia macrocysta, Trichodinium hirsutum,* and *Gonyaulacysta* sp.

Terrestrial forms observed include *Pinus* and *Proteacidites thalmanni.*

Other Forms: *Pediastrum* (lacustrine influence); *Palambages morulosa.*

Age: Santonian

Environment of Deposition: Marine

Sample 89-38A

Assemblage is Relatively sparse.

Marine forms observed include *Spinidinium echinoideum, Deflandrea speciosa, Deflandrea acuminata, Senoniasphaera rotundata,* and *Cleistosphaeridium* sp. (lanceolate spines).

Terrestrial forms observed include *Pinus, Sphagnum, Appendicisporites tricornitatus*, and *Deltoidospora hallii.*

Age: Santonian to Campanian

Environment of Deposition: Marine

Sample 89-38B

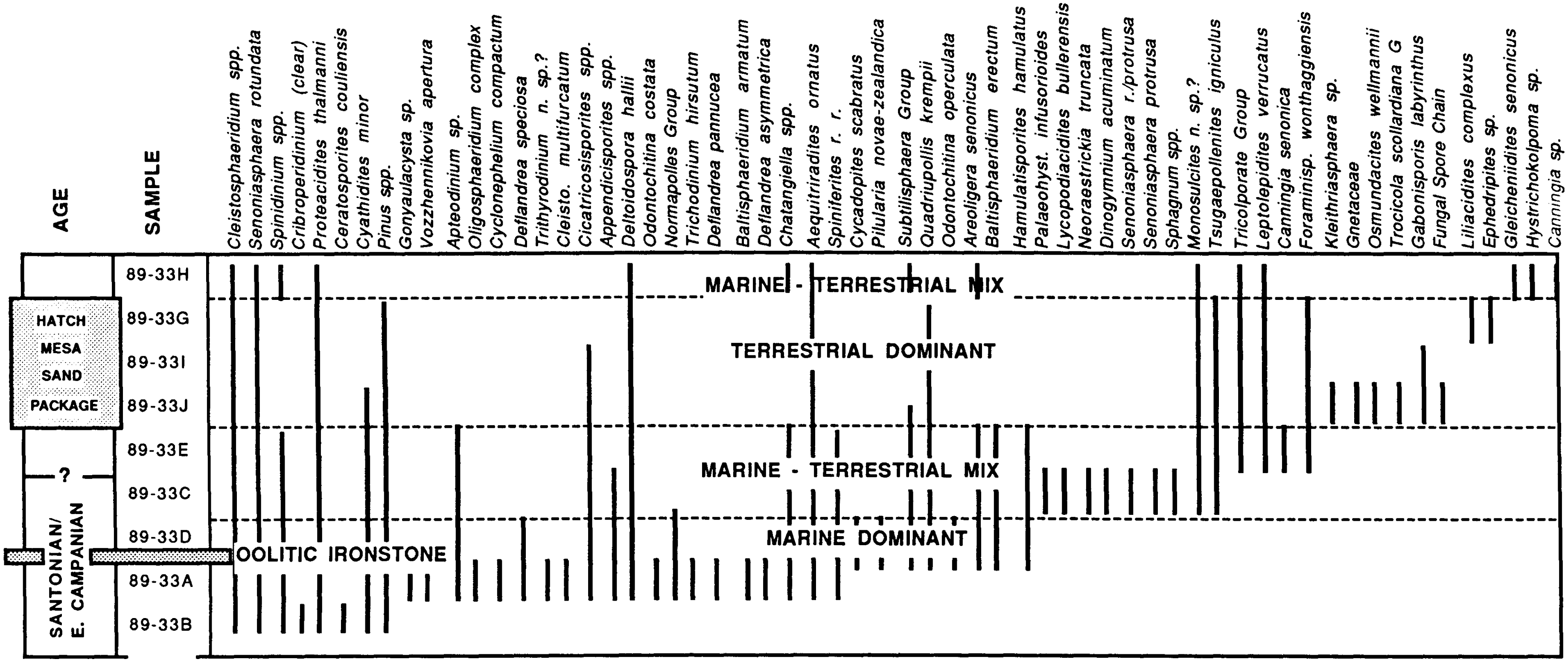
Assemblage is highly diverse.

Marine forms observed include *Deflandrea acuminata, Isabelia glabra, Apteodinium sp., Senoniasphaera rotundata, Odontochitina costata, Deflandre asymmetrica, Spinidinium echinoideum, Alterbia macrocysta, Deflandrea speciosa, Cyclonephelium distinctum, Areoligera senonensis, Impagidinium sp., Cleistosphaeridium sp., Palaeohystrichophora infusorioides, Spiniferites ramosus ramosus, Cribroperidinum edwardsi*, and *Oligosphaeridium complex.*

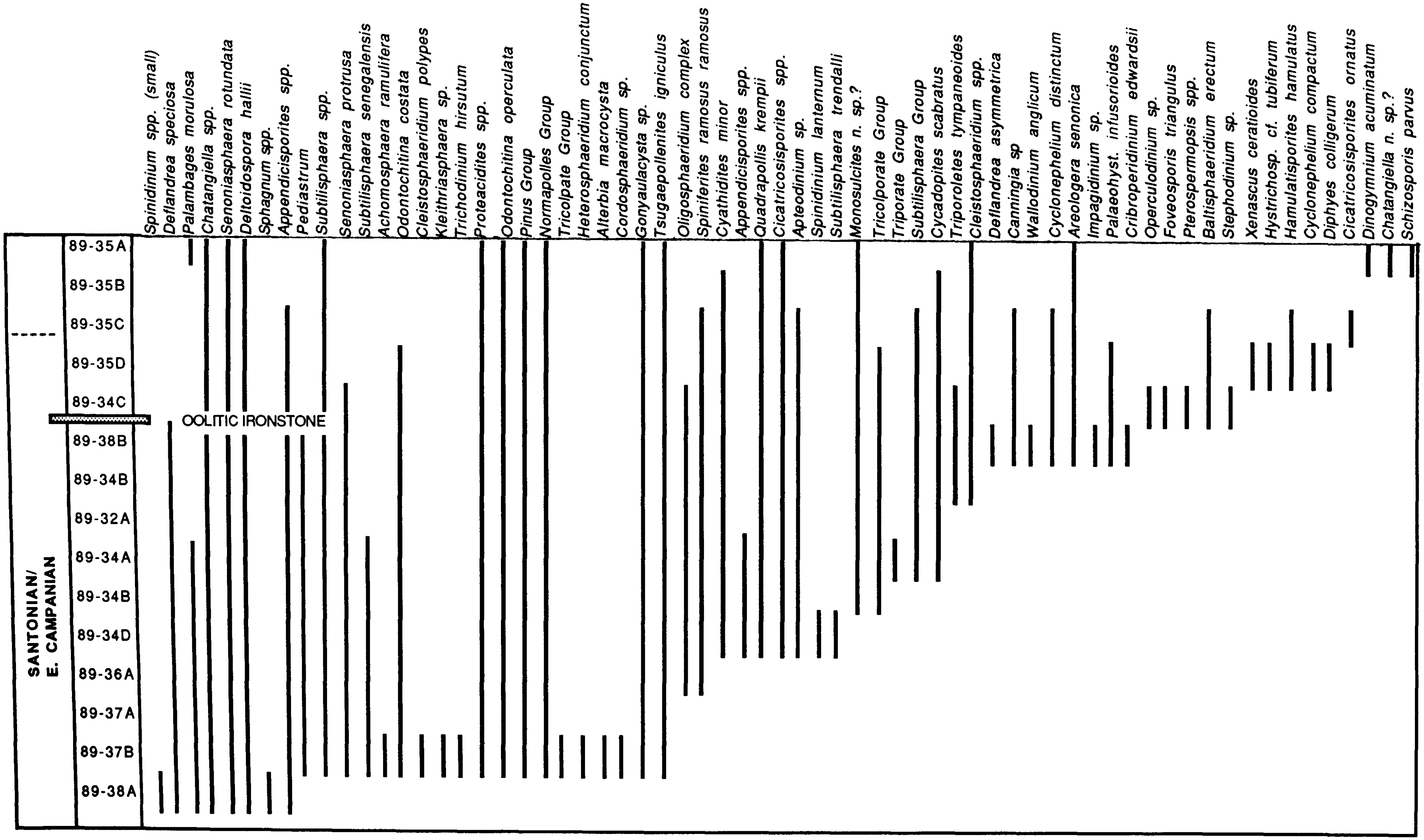
Terrestrial forms observed include *Proteacidites thalmanni* and *Pinus.*

Age: Santonian to Campanian

Environment of Deposition: Marine



OCCURRENCE CHART. HATCH MESA, LOCALITY 89-33. COMPLETE SECTION FROM OOLITIC IRONSTONE THROUGH THE HATCH MESA SAND PACKAGE.



OCCURRENCE CHART. HATCH MESA AREA. COMPOSITE SECTION COLLECTED EAST OF LOCALITY 89-33.

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PLATE 1

Fig. 1 Large pored triporate. 23um. Specimen 6-3D, Sample 89-33D

Fig. 2 *Proteacidites thalmanni* . 40um. Specimen 27-12J, Sample 89-38B

Fig. 3 Large monosulcate pollen grain. 82um Specimen 9-41, Sample 89-23H

Fig. 4 *Cycadopites scabratus*. 57um. Specimen 3-13A, Sample 89-33A

Fig. 5 *Laricoidites magnus*. 85um. Specimen 9-2A. Sample 89-33H

Fig. 6 *Tsugaepollenites igniculius*. 54um. Specimen 5-11A, Sample 89-33C

Fig. 7 Gnetaceae. 53um. Specimen 11-7A, Sample 89-33J

Fig. 8 *Schizosporis complexus*. 72um. Specimen 8-2A, Sample 89-33G

Fig. 9 *Schizosporis complexus*. 60um. Specimen 8-28, Sample 89-33G

Fig. 10 *Retitriletes singhii* . 48um. Specimen 10-51, Sample 89-331

Fig. 11 Spore B. 43um. Specimen 9-1A, Sample 89-33H

Fig. 12 *Ceratosporites* sp. cf. C. couliensis. 54um. Specimen 4-10A, Sample 89-3B

Plate 1


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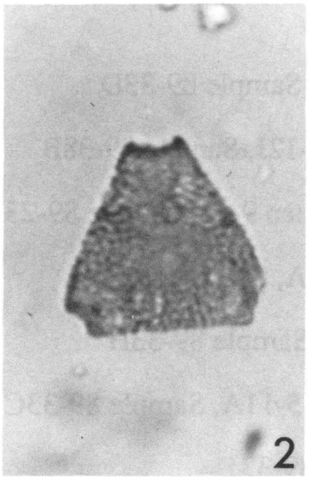
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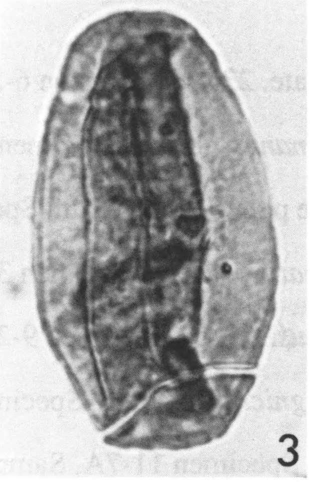
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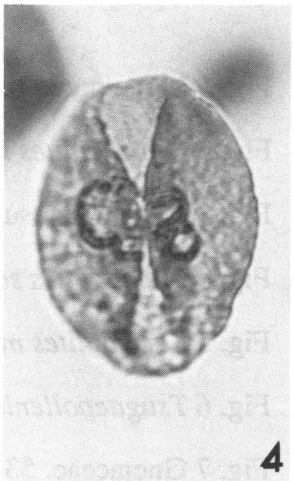
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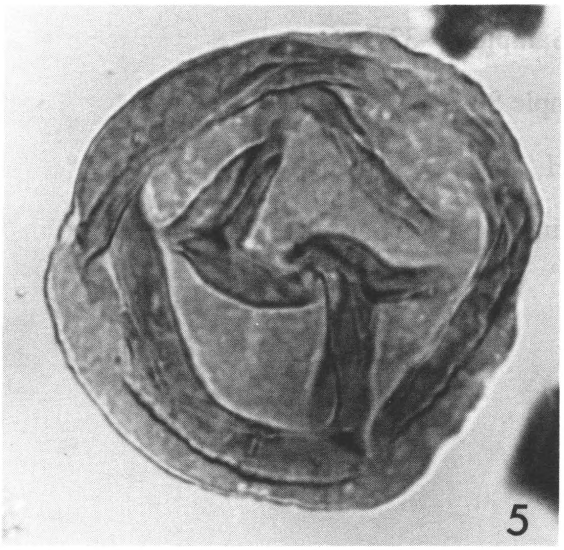
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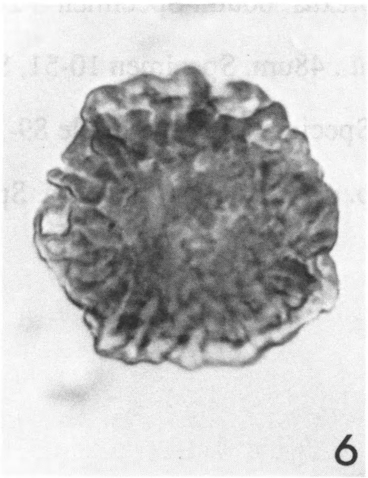
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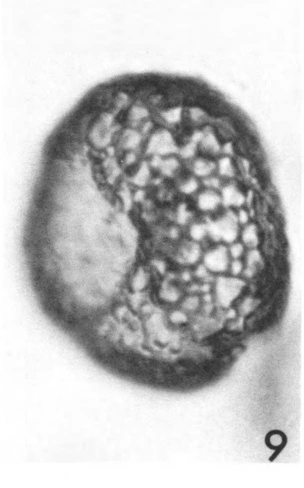
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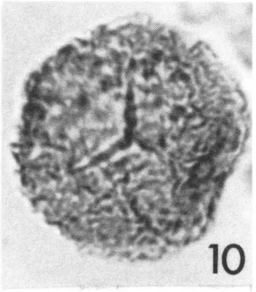
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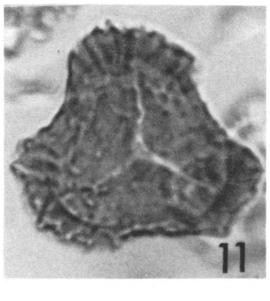
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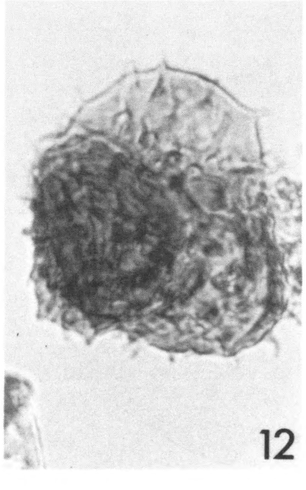
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PLATE 2

Fig. 1 *Quadripollis krempii.* 50um. Specimen 8-4E, Sample 89-33G

Fig. 2 *Q. krempii.* 49um. Specimen 8-4D, Sample 89-33G

Fig. 3 *Q. krempii.* 59um (top to bottom) Specimen 8-4B, Sample 89-33G

Fig. 4 *Q. krempii.* 49um. Specimen 20-5B, Sample 89-35C

Fig. 5 *Q. krempii.* 60um. Specimen 17-5A, Sample 89-34D

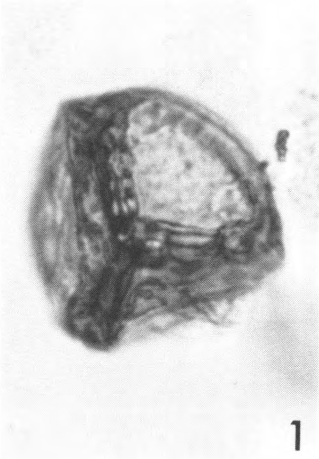
Fig. 6 *Q. krempii.* 64um. Specimen 8-4C, Sample 89-33G

Fig. 7 *Hamulatisporites amplus.* 72um. Specimen 2-3H, Sample 89-32C

Fig. 8 *Hamulatisporites hamulatus.* 54inm. Specimen 6-9A, Sample 89-33D

Fig. 9 *Gleicheniidites senonicus.* 53um. Specimen 2-3F, Sample 89-32C

Plate 2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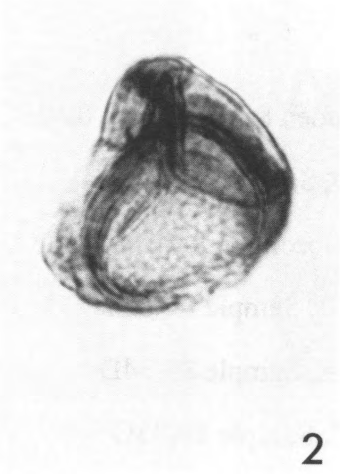
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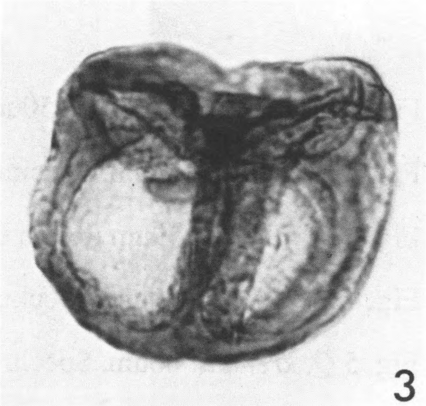
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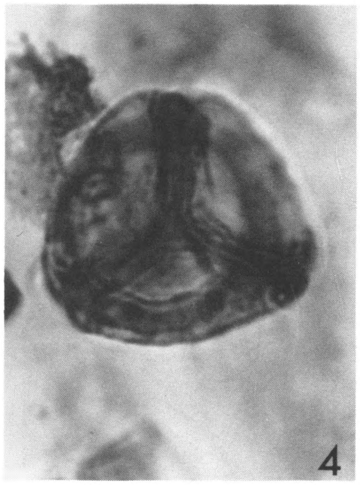
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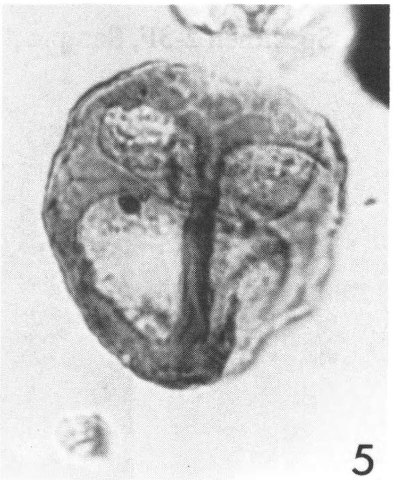
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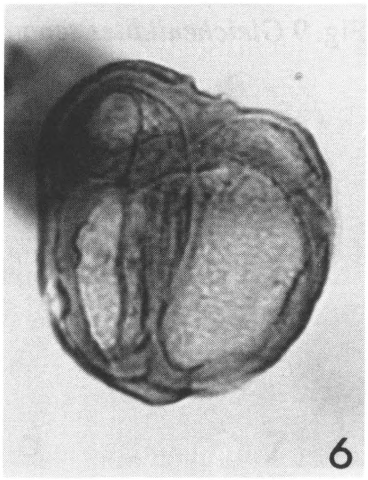
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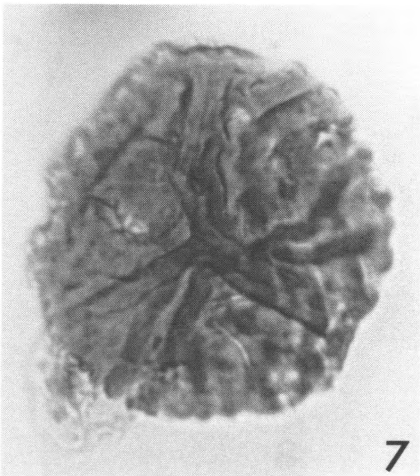
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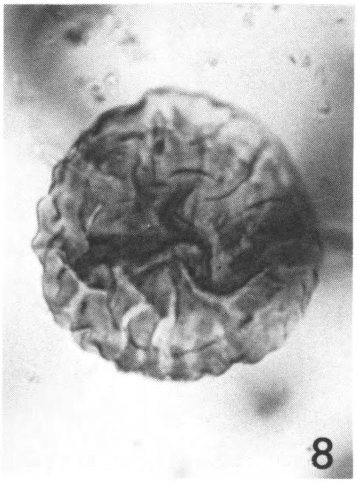
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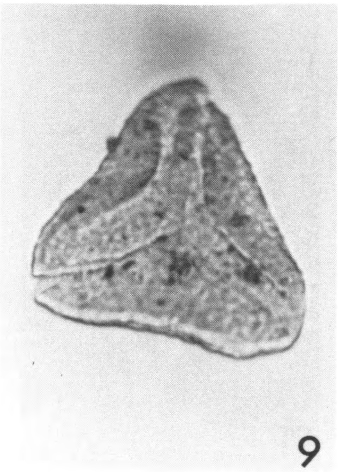
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PLATE 3

Fig. 1 *Pilularia novae-zealandica.* 85um. Specimen 6-1A, Sample 89-33D

Fig. 2 *Matoniporites* sp. 53um. Specimen 2-3-"0", Sample 89-32C

Fig. 3 *Cicatricosisporites furcatus.* 50um. Specimen 3-5L, Sample 89-33A

Fig. 4 *Aequitradities* sp. 49um. Specimen 5-2C, Sample 89-33C

Fig. 5 *Osmundacidites* wellmanii. 50um. Specimen 11-71, Sample 89-33J

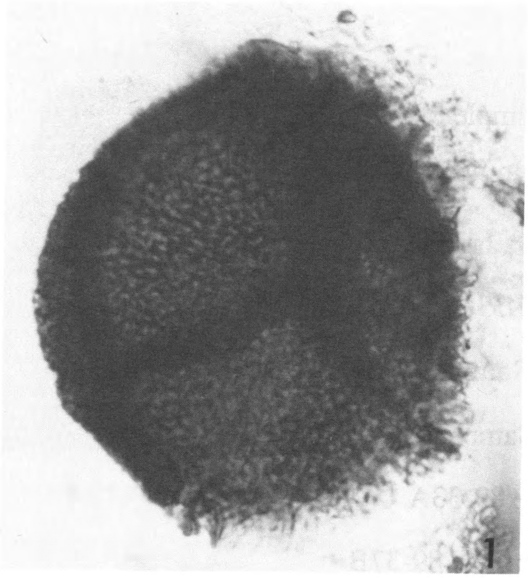
Fig. 6 *Cicatricosisporites ornatus.* 60um. Specimen 2-4D, Sample 89-32C

Fig. 7 *Deflandrea pannucea.* 87um. Specimen 3-9A, Sample 89-33A

Fig. 8 *Deflandrea echinoidea.* 80um. Specimen 25-5"O", Sample 89-37B

Fig. 9 *Trithyrodinium* sp. 94um. Specimen 3-4K, Sample 89-33A

Plate 3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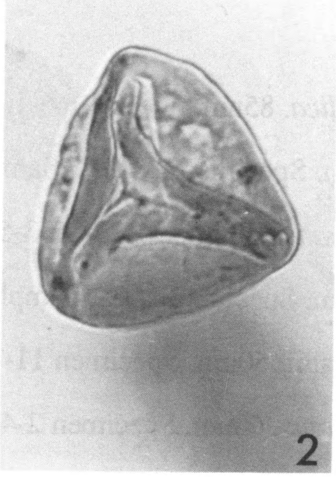
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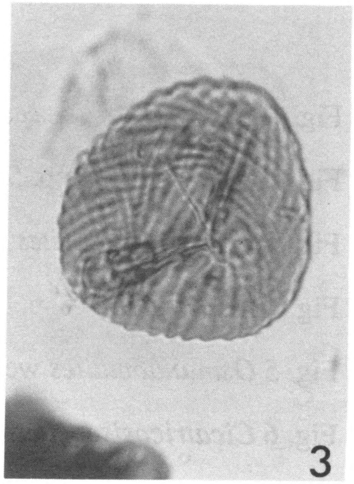
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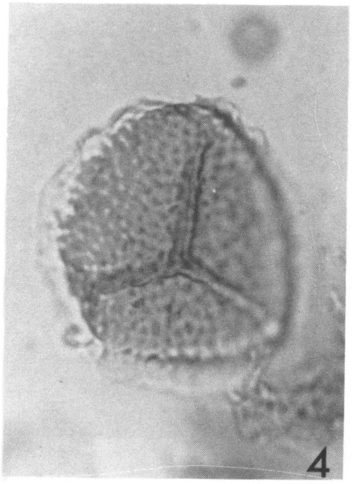
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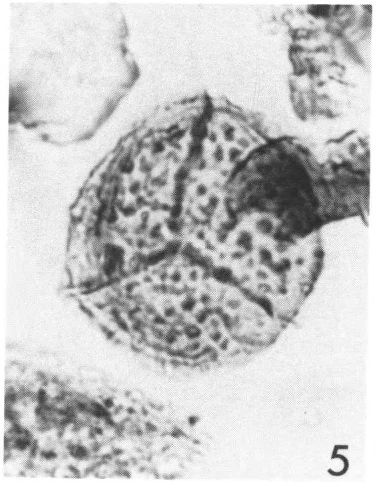
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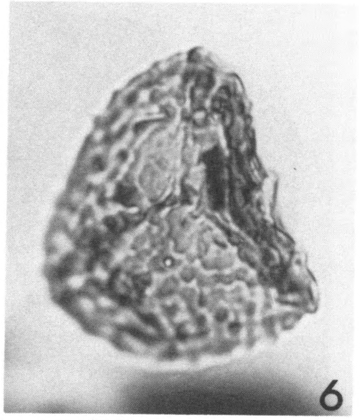
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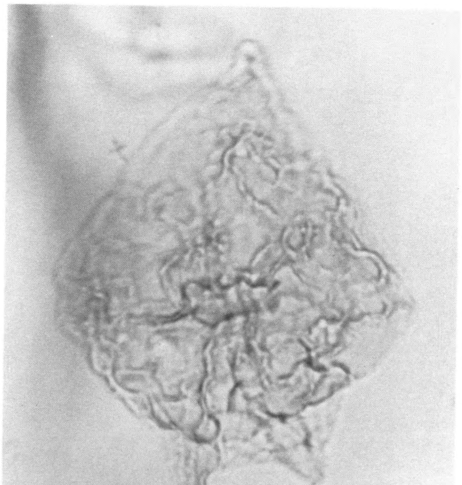
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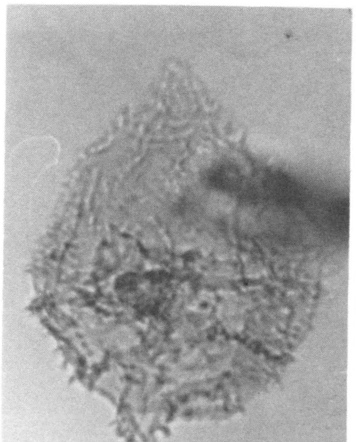
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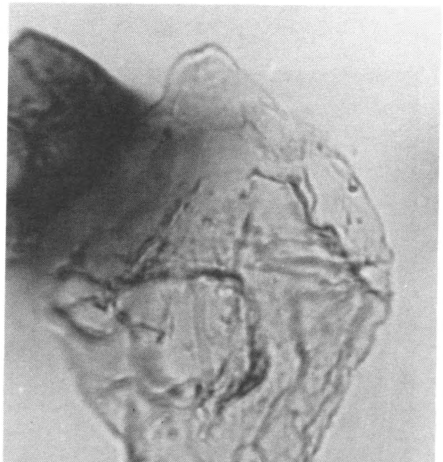
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PLATE 4

Fig. 1 *Appendicisporites*. See Spore Type A, Hedlund (1966). 50um. Specimen 3-5N, Sample 89-33A

Fig. 2 *Appendicisporites cristatus*. 56inm. Specimen 2-3K, Sample 89-32C

Fig. 3 *Trochicola scollardiana*. 46inm. Specimen 11-12A, Sample S9-33J

Fig. 4 *Stephodinium* sp. 50um. Specimen 16-6A, Sample 89-34C

Fig. 5 Same as above

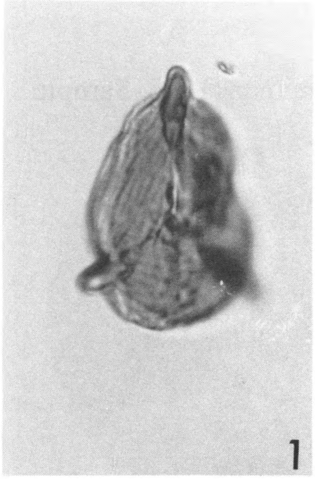
Fig. 6 *Palaeohystrichopohora infusorioides*. 64um. Specimen 2-7P, Sample 89-32C

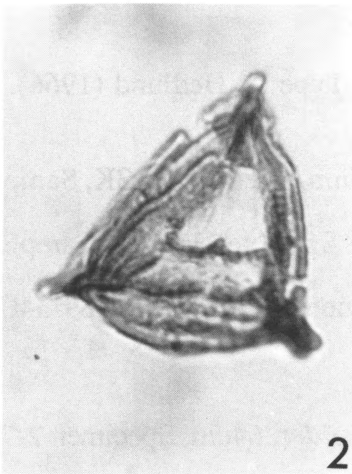
Fig. 7 *Subtilisphaera* sp. 80um. Specimen 25-11A, Sample 89-37B

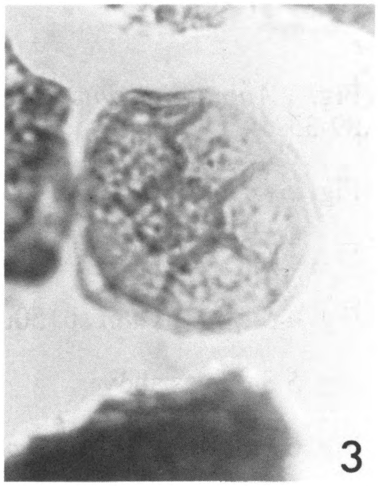
Fig. 8 *Dinogymium pustulicostatum*. 72um. Specimen 13-2A, Sample 89-35A

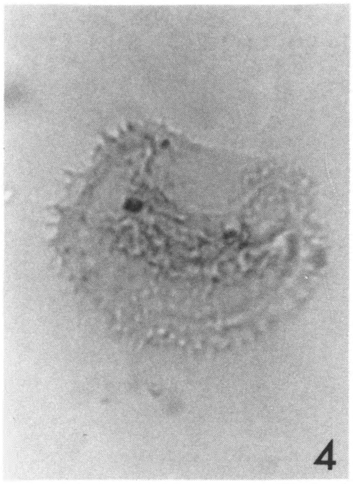
Fig. 9 *Palaeohystrichophora infusorioides*. 74um. Specimen 15-7A, Sample 89-34C

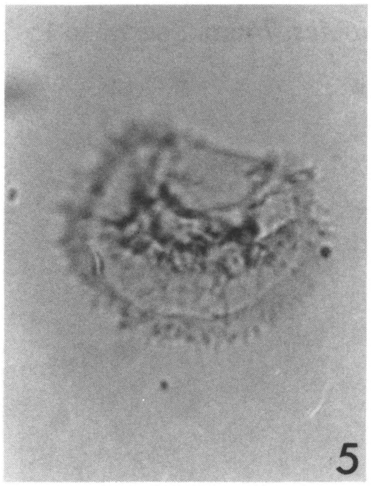
Plate 4

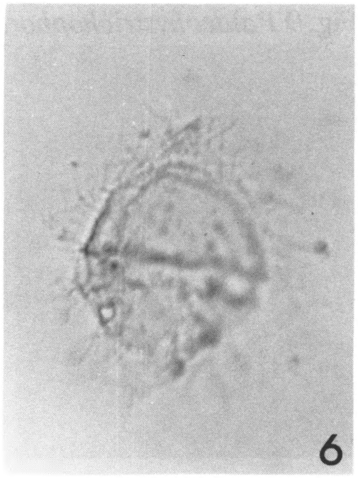


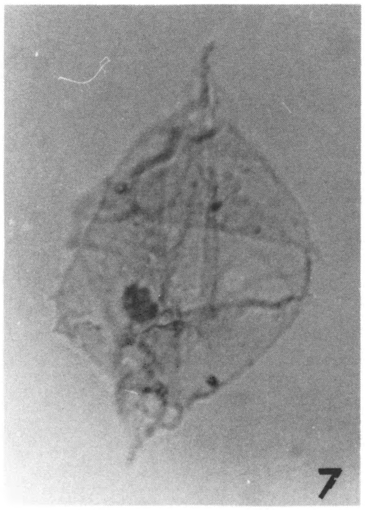


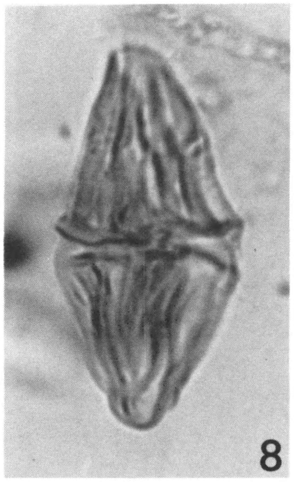












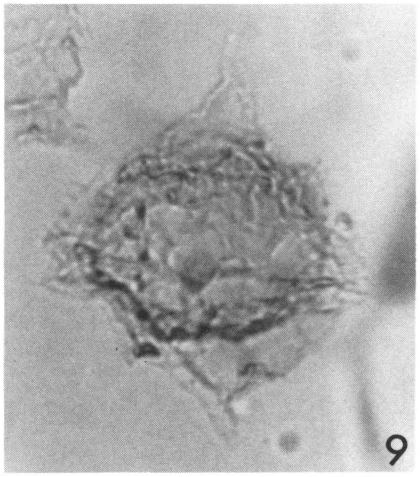


PLATE 5

Fig. 1 *Baltisphaeridium armatum*. 36inm (main body). Specimen 3-lOB, Sample 89-33A

Fig. 2 *Trichodinium hirsutum*. 56inm (main body). Specimen 2-91, Sample 89-32C

Fig. 3 *Cyclonephelium membraniphorum*. 57um (main body?. Specimen 2-6I, Sample 8 -32C

Fig. 4 *Achomosphaera ramulifera*. 41 um (main body). Specimen 25-6I, Sample 89-37B

Fig. 5 *Micrhystridium pelliferum*. 29um (main body). Specimen 2-11E, Sample 89-32C

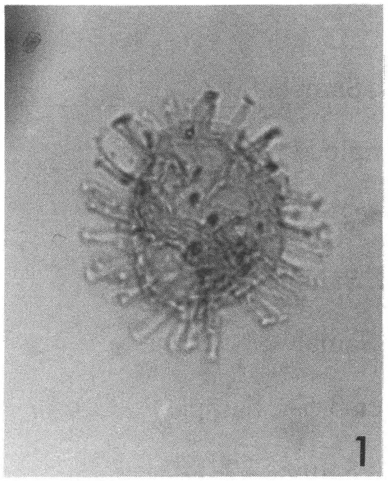
Fig. 6 *Exochosphaeridium multifurcatum*. 72inm (main body) . Specimen 3-5A, Sample 9 -33A

Fig. 7 *Baltisphaeridium erectum*. 36um (main body). Specimen 15-13A, Sample 89-34C

Fig. 8 *B. erectum*. 37um (main body). Specimen 6-7A, Sample 99-33D

Fig. 9 Same as above

Plate 5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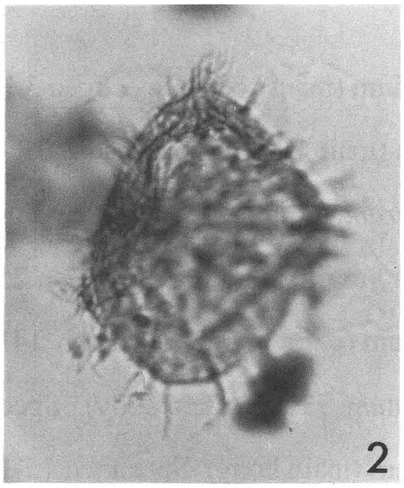
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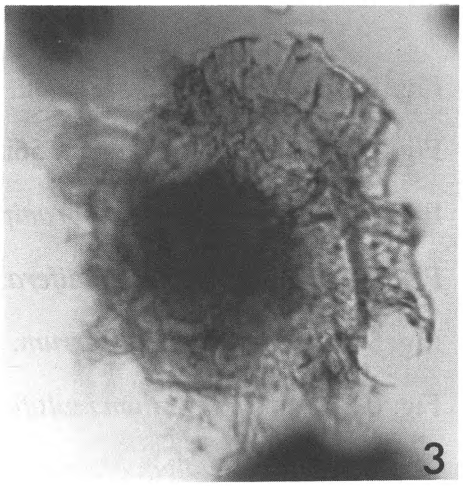
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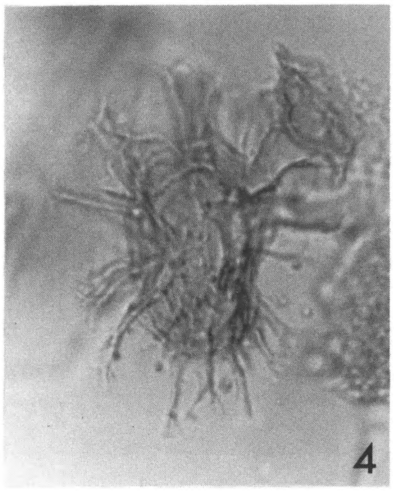
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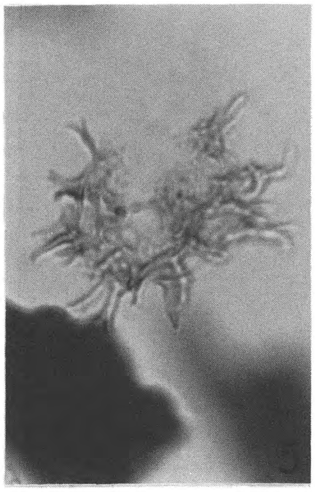

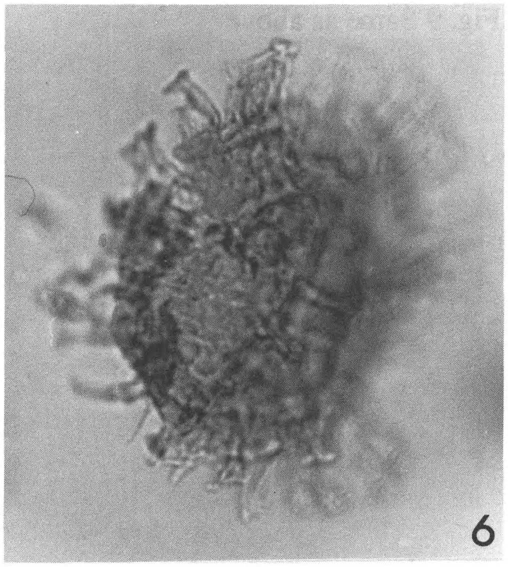
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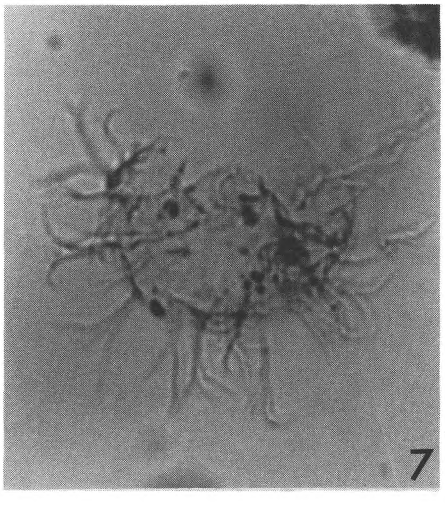
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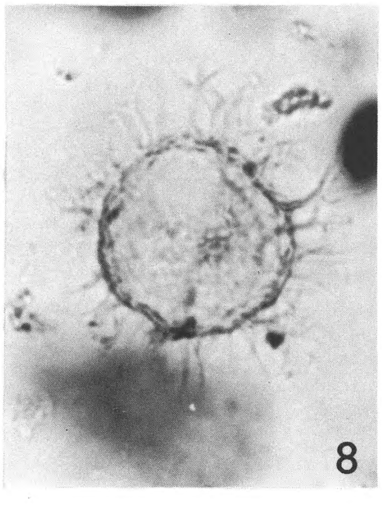
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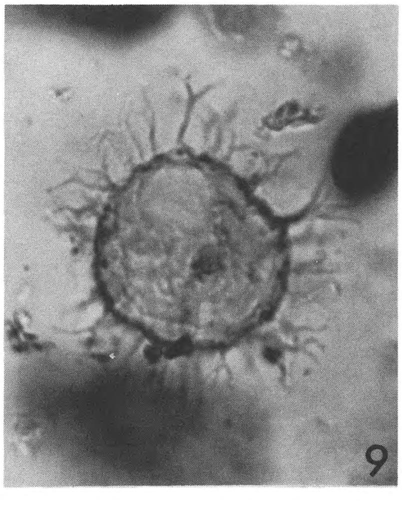
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PLATE 6

Fig. 1 *Deflandrea victoriensis*. 70um. Specimen 2-5L, Sample 89-32C

Fig. 2 *Deflandrea speciosa*. 110um. Specimen 3-48, Sample 99-33A

Fig. 3 *Deflandrea acuminata*. Il0um. Specimen 15-3K, Sample 89-34C

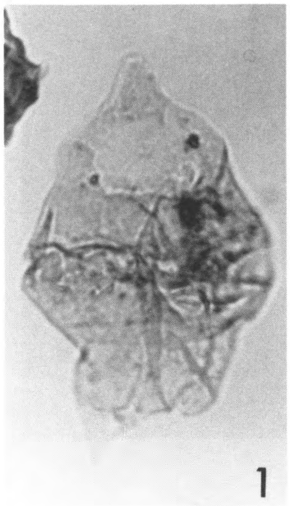
Fig. 4 *Deflandrea speciosa*. Il2um. Specimen 25-7J, Sample 99-37B

Fig. 5 *Gonyaulacysta* sp. Il9um. Specimen 3-1A, Sample 89-33A

Fig. 6 Fungal Spore A. 76um. Specimen 12-28, Sample 99-33J

Fig. 7 Fungal Spore B. 82um. Specimen 12-2A, Sample 89-33J

Plate 6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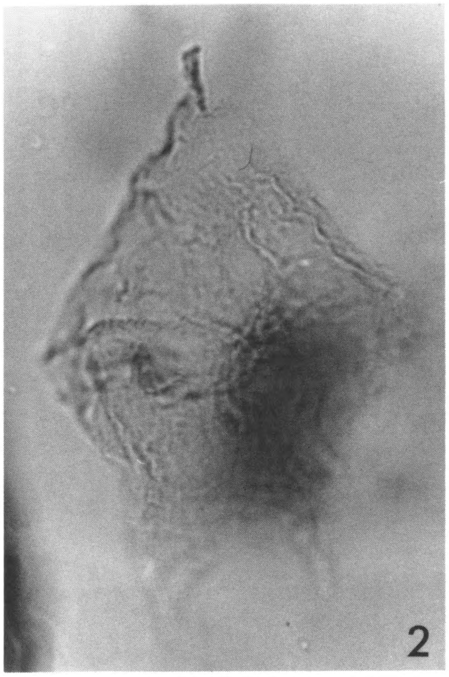
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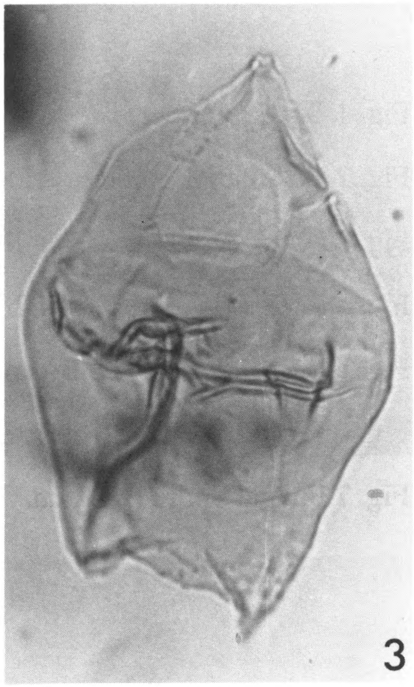
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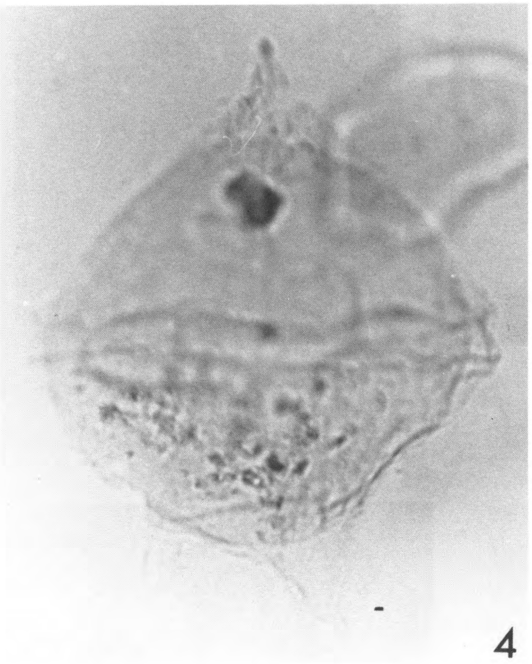
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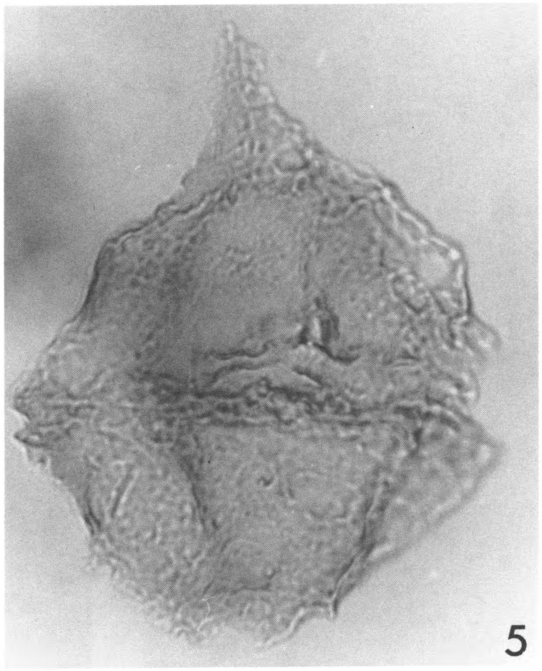
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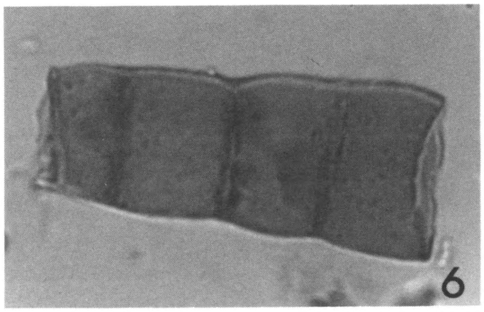
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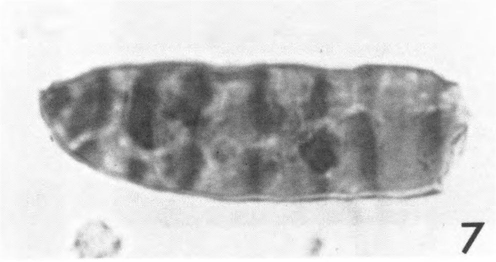
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PLATE 7

Fig. 1 *Senoniasphaera protrusa*. 99um. Specimen 3-6"O", Sample 89-33A

Fig. 2 *Senoniasphaera rotundata*. Il4um. Specimen 17-1M, Sample 89-34D

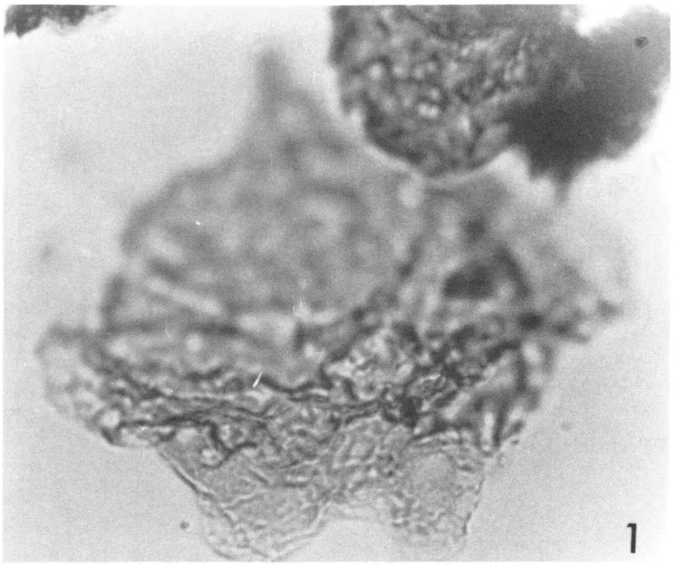
Fig. 3 *Canningia senonica*. 92um. Specimen 24-4A, Sample 89-378

Fig. 4 *Senoniasphaera protrusa*. 72um. Specimen 24-4C, Sample 89-378

Fig. 5 *Canningia cf. C. senonica*. 93um. Specimen 2-10A, Sample 89-32C

Fig. 6 *Apteodinium* sp. 79um. Specimen 3-2C, Sample 89-33A

Plate 7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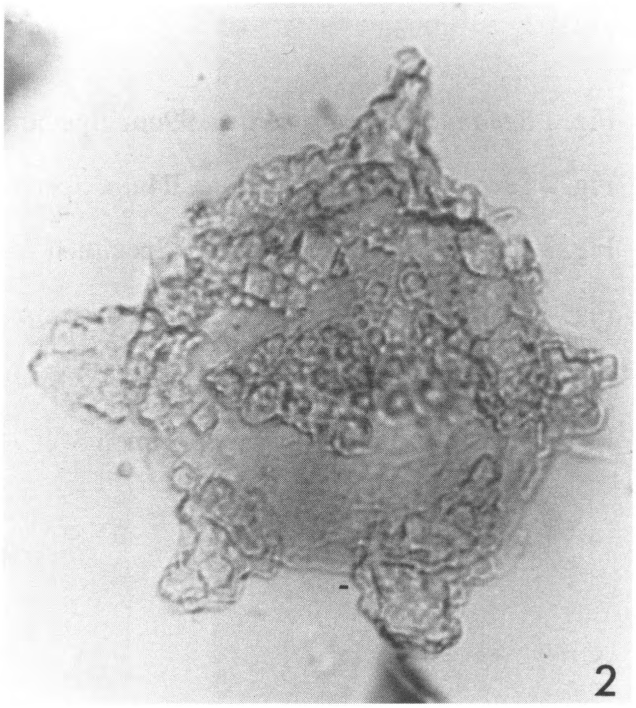
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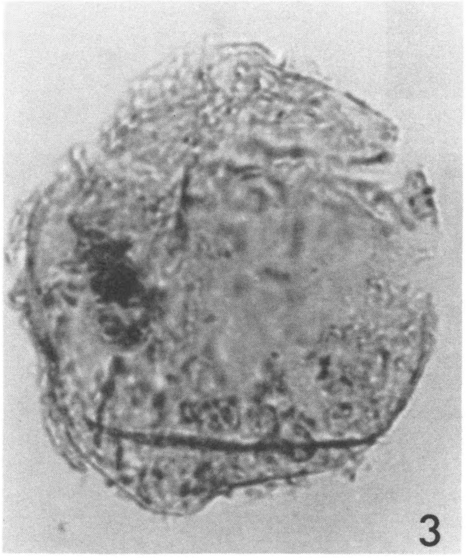
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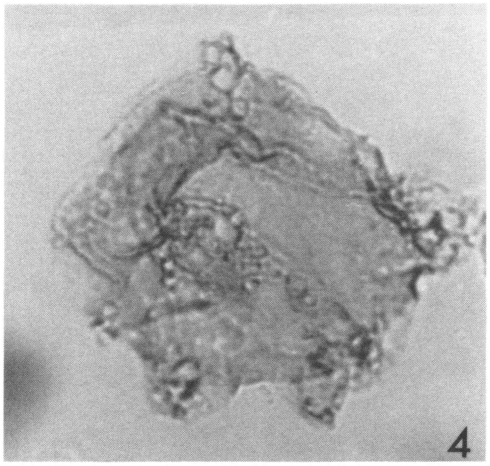
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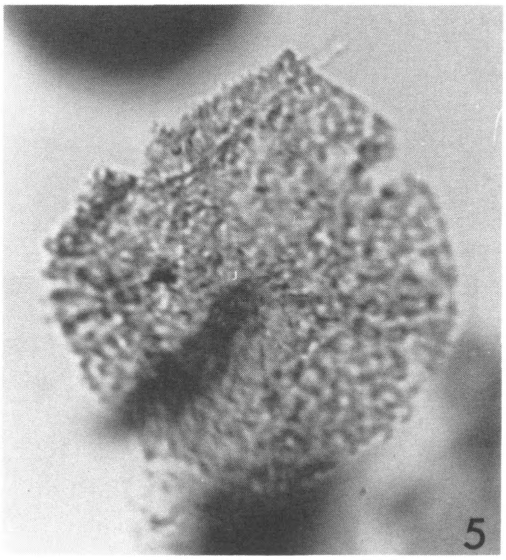
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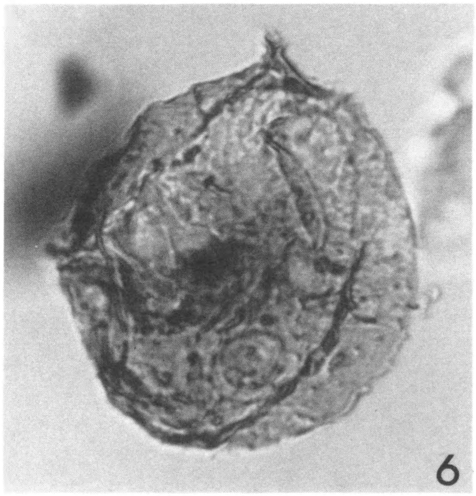
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PLATE 8

Fig. I *Odontochitina costata*. 107um. Specimen 25-7A, Sample 89-37B

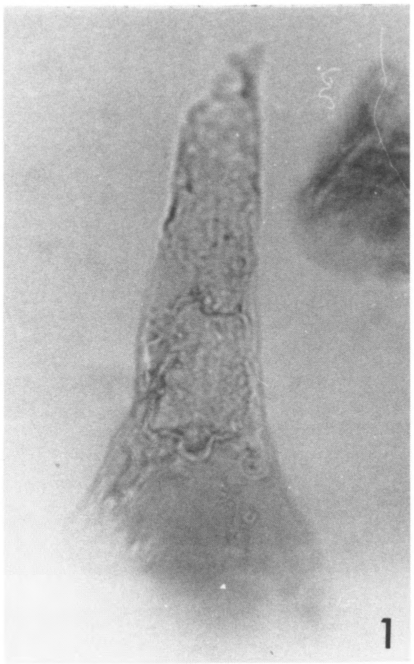
Fig. 2 *Odontohitina operculata*. 90um. Specimen 25-12A, Sample 89-37B

Fig. 3 *Pterospermopsis*. 63um. Specimen 2-9E, Sample 89-32C

Fig. 4 *Palambages morulosa*. 79um. Specimen 24-2A, Sample 89-37B

Fig. 5 *Pterospermopsis* sp. 143um. Specimen 2-9F, Sample 89-32C

Plate 8



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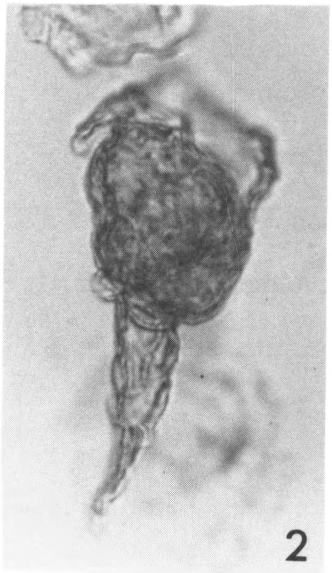

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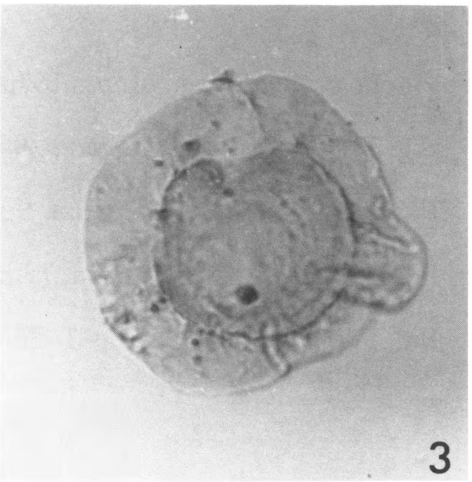

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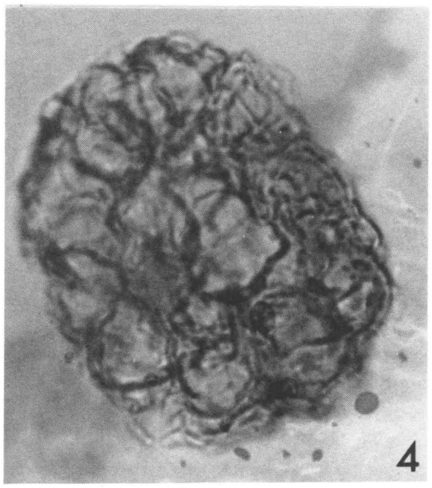

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EDELMAN, PERCIVAL and ASSOCIATES
BIOSTRATIGRAPHERS

700 S. Cockrell Hill Rd., Suite 114
Duncanville, Texas 75116
Telephone: (214) 617-2692
(214) 299-6832

April 30, 1990

Dr. Marjorie A. Chan
Department of Geology and Geophysics
College of Mines and Earth Sciences
The University of Utah
717 W.C. Browning Building
Salt Lake City, Utah 84112-1183

RE: PALYNOLOGICAL ANALYSIS
MANCOS SHALE OUTCROP SAMPLES
EAST-CENTRAL UTAH

Dear Dr. Chan:

At your request, six outcrop samples (UT89-33j, UT89-33e, UT89-33c, UT89-33b, UT89-37b, UT89-38b) from the Mancos Shale in east-central Utah were examined for palynomorphs. Recovery of palynomorphs from these samples was excellent. All six samples yielded abundant and diverse palynomorph assemblages of Late Cretaceous (Senonian) age.

Palynological age determinations, documentation, and approximate paleobathymetry for each of these samples are discussed below. Samples are listed by locality in descending stratigraphic order. Included in the summary for each sample is a list of the palynomorphs identified with the relative abundance of each species.

Locality UT89-33: Hatch Mesa. Sec. 32, T21S, R16E

UT89-33j: Senonian (probable Campanian)

Spores and Pollen:

Abietinaepollenites foveoreticulatus	VR
Acanthotriletes varispinosus	VR
Alisporites bilateralis	R
Alisporites grandis	F
Alisporites spp.	R
Aequitriradites sp.	R
Araucariacites limbatus	FL
Callialasporites dampieri	VR
Cedripites cf. C. canadensis	VR

Cicatricosisporites dorogensis	R
Cicatricosisporites spp.	F
Complexiopollis microverrucosus	R
Conbaculatisporites undulatus	A
Corollina torosus	F
Deltoidospora diaphana	A
Deltoidospora hallei	R
Deltoidospora psilostoma	C
Ephedripites sp.	R
Gleicheniidites senonicus	R
Hamulatisporis hamulatis	R
Inaperturopollenites dubius	R
Laevigatosporites ovatus	C
Laricoidites magnus	R
Liliacidites sp.	VR
Lycopodiumsporites sp.	VR
Monocolpites spp.	VR
Monosulcites scabratus	R
Phyllocladites mawsoni	F
Piceapollenites sp.	VR
Podocarpidites sp.	R
Polypodiisporites favus	F
Polypodiisporites spp.	R
Proteacidites retusus	R
Proteacidites thalmanii	F
Quadripollis krempii	F
Retitricolpites spp.	R
Rugubivesiculites floridus	F
Schizosporis parvus?	VR
Taxodiaceaepollenites hiatipites	F
Tricolpites psilascabratus	R
Tricolpites reticulatus	VR
Tricolpites cf. *T*. *anguloluminosus*	VR
Tricolpites spp.	R
Tricolpopollenites clavireticulatus	VR
Tricolporopollenites affluens	R
Triplanosporites sp.	A
undetermined bisaccates	C
undetermined trilete spores	C
Verrucosisporites sp.	VR
Zlivisporis novomexicanum	F

Dinocysts:

Cleistosphaeridium sp?	VR
undetermined dinocysts	R

Acritarchs:

Pterospermopsis sp.	VR

The rich palynomorph assemblage recovered from this sample includes numerous taxa reported by Anderson (1960), Newman (1964, 1965), Nichols and Jacobsen (1982), Stone (1973), and Thompson (1972) from Late Cretaceous (Senonian) strata throughout the Rocky Mountain region. Also represented are rare pollen grains assigned to the Normapolles genus *Complexiopollis*, which is well represented in rocks of Late Cretaceous age from the Atlantic and Gulf Coastal Plains (Christopher; 1979 , 1982) and Mississippi Embayment (Tschudy; 1973 , 1975). The few specimens of *Complexiopollis* observed in this sample are probably referable to *Complexiopollis microverrucosus*, reported by Tschudy (1973) from strata of Campanian to early Maastrichtian age in the Mississippi Embayment. The occurrence of *Complexiopollis microverrucosus* in this sample suggests that the sampled interval represents the upper (Campanian) part of the Mancos Shale. Deposition probably took place in a shallow marine (inner to middle neritic) environment.

UT89-33e: Senonian (probably Campanian)

Spores and Pollen:

Abietinaepollenites foveoreticulatus	R
Acanthotriletes varispinosus	R
Alisporites bilateralis	C
Alisporites grandis	F
Alisporites spp.	R
Araucariacites limbatus	A
Callialasporites dampieri?	VR
Cedripites cretaceus?	VR
Cedripites cf. *C*. *canadensis*	VR
Cicatricosisporites dorogensis	R
Cicatricosisporites sp.	VR
Cingutriletes sp.	VR
Complexiopollis microverrucosus	FL
Complexiopollis spp. indet.	F
Conbaculatisporites undulatus	F
Corollina torosus	F
Cupanieidites cf. *C*. *reticularis*	R
Cycadopites sp.	VR
Deltoidospora diaphana	C
Deltoidospora hallei	R
Deltoidospora psilostoma	C
Dictyophyllidites sp.?	VR
Gleicheniidites senonicus	A
Hamulatisporis hamulatis	R
Inaperturopollenites dubius	R
Ischyosporites sp.?	R
Laevigatosporites ovatus	F
Laricoidites magnus	R
Lycopodiumsporites sp.	VR

Monosulcites scabratus	F
Phyllocladites mawsoni	R
Podocarpidites spp.	R
Polypodiisporites favus	C
Polypodiisporites spp.	R
Proteacidites thalmanii	F
Quadripollis krempii	R
Retitricolpites spp.	R
Rugubivesiculites floridus	F
Taxodiaceaepollenites hiatipites	C
Todisporites minor	VR
Tricolpites spp.	C
Tricolpopollenites compactus?	VR
Tricolpopollenites microreticulatus	VR
Tricolporopollenites affluens	F
Triplanosporites sp.	FL
undetermined bisaccates	F
undetermined trilete spores	C
undetermined triporates	R
Zlivisporis novomexicanum	VR

Dinocysts:

Achomosphaera sp.?	VR
Chichaouadinium densispinatum	R
Cleistosphaeridium sp.?	VR
Isabelidinium acuminata	R
Isabelidinium cooksoniae	C
Spiniferites sp.	VR
undetermined dinocysts	F

Acritarchs:

Pterospermopsis sp.	VR

Sample UT89-33e, like sample UT89-33j, contains a rich and varied palynomorph assemblage of Late Cretaceous (Senonian) age. Included within this assemblage are abundant specimens of the palynomorph Complexiopollis microverrucosus, which has thus far been reported only from strata of Campanian to early Maastrichtian age. Also present are rare specimens of the dinocyst Chichaouadinium densispinatum, which has been reported only from rocks of Campanian to Paleocene age in western North America. C. densispinatum has thus far been reported from the Almond Formation (late Campanian to Maastrichtian) of Wyoming (Stone, 1973), the Navarro Group (Maastrichtian) of Texas (Zaitzeff, 1967), the upper Moreno Formation (Danian) of California (Drugg, 1967), and the Cannonball Member of the Fort Union Formation (Paleocene) of South Dakota (Stanley, 1965). The occurrence of both Complexiopollis microverrucosus and Chichaouadinium densispinatum in sample UT89-

33e suggests that this sample represents the upper (Campanian) part of the Mancos Shale. The dinocyst assemblage recovered from this sample suggests that deposition took place in a shallow marine (inner to middle neritic) environment.

UT89-33c: Senonian (probably Campanian)

Spores and Pollen:

Abietinaepollenites foveoreticulatus	VR
Abietinaepollenites sp.?	VR
Acanthotriletes sp.?	VR
Alisporites bilateralis	F
Alisporites grandis	R
Alisporites cf. A. microsaccus	VR
Alisporites spp.	R
Appendicisporites cf. A. cristatus	VR
Araucariacites limbatus	A
Callialasporites dampieri	VR
Cedripites cretaceus	R
Cedripites cf. C. canadensis	VR
Cicatricosisporites spp.	R
Cingutriletes sp.	R
Complexiopollis microverrucosus	C
Conbaculatisporites undulatus	F
Corollina torosus	R
Cupanieidites cf. C. reticularis	VR
Deltoidospora diaphana	C
Deltoidospora hallei	R
Deltoidospora psilostoma	F
Densosporites sp. (recycled)	VR
Ericaceoipollenites rallus?	VR
Gleicheniidites senonicus	A
Hamulatisporis hamulatis	R
Ischyosporites sp.	R
Inaperturopollenites dubius	R
Laevigatosporites ovatus	C
Laricoidites magnus	R
Kuylisporites waterbolki	VR
Osmundacidites sp.	VR
Phyllocladites mawsoni	R
Polypodiisporites favus	A
Polypodiisporites spp.	R
Proteacidites retusus	F
Proteacidites thalmanii	F
Quadripollis krempii	R
Retitricolpites spp.	R
Rugubivesiculites floridus	R
Schizosporis parvus	VR

Taxodiaceaepollenites hiatipites	F
Tsugaepollenites sp.?	VR
Tricolpites spp.	C
Tricolpopollenites compactus	VR
Tricolporopollenites affluens	R
Triplanosporites sp.	A
undetermined bisaccates	F
undetermined trilete spores	C
undetermined triporates	R
Zlivisporis novomexicanum	VR

Dinocysts:

Achomosphaera sp.	R
Chichaouadinium densispinatum	F
Cyclonephelium sp.?	VR
Dinogymnium sp.	VR
Hystrichostrogylon sp.?	R
Isabelidinium acuminata	R
Isabelidinium cooksoniae	A
Spiniferites sp.	VR
Surculosphaeridium cf. *S. longifurcatum*	VR
undetermined dinocysts	C

Algae:

Tasmanites sp.	VR

The probable Campanian age assigned to sample UT89-33c is based on the occurrence of the palynomorph *Complexiopollis microverrucosus* and the dinocyst *Chichaouadinium densispinatum*, both of which have not been reported from strata older than Campanian in age. Deposition probably took place in a shallow marine (inner to middle neritic) environment.

UT89-33b: Senonian (probably Campanian)

Spores and Pollen:

Abietinaepollenites foveoreticulatus	VR
Acanthotriletes varispinosus	VR
Alisporites bilateralis	F
Alisporites grandis	R
Alisporites spp.	R
Appendicisporites sp.	VR
Araucariacites limbatus	A
Callialasporites dampieri	R
Cedripites cretaceus	R
Cedripites cf. *C. canadensis*	R
Cingutriletes sp.	VR

Complexiopollis microverrucosus	VR
Corollina torosus	VR
Deltoidospora diaphana	F
Deltoidospora psilostoma	VR
Gleicheniidites senonicus	F
Hamulatisporis hamulatis	R
Laevigatosporites ovatus	VR
Laricoidites magnus	R
Liliacidites leei	VR
Monosulcites scabratus	R
Pityosporites alatipollenites?	VR
Polypodiisporites favus	R
Proteacidites retusus	F
Proteacidites thalmanii	F
Quadripollis krempii	F
Retimonocolpites sp.?	VR
Retitricolpites spp.	R
Rugubivesiculites floridus	R
Taxodiaceaepollenites hiatipites	F
Tricolpites spp.	R
Triplanosporites sp.	C
undetermined bisaccates	R
undetermined trilete spores	C
Verrucosisporites sp.?	VR

Dinocysts:

Achomosphaera sp.?	VR
Alterbia sp.?	VR
Chichaouadinium densispinatum	R
Dinogymnium undulosum	VR
Exochosphaeridium sp.?	R
Surculosphaeridium cf. *S. longifurcatum*?	VR
undetermined dinocysts	F

The occurrence of the palynomorph *Complexiopollis microverrucosus* and the dinocyst *Chichaouadinium densispinatum* suggest a Campanian age for this sample. The dinocyst assemblage present in this sample suggests that deposition took place in a shallow marine (inner to middle neritic) environment.

Locality UT89-37: Floy Canyon. Sec. 3, T22S, R16E

UT89-37b: Senonian (probably early to mid Campanian)

Spores and Pollen:

Abietinaepollenites sp.?	VR
Alisporites grandis	R
Apiculatisporis sp.?	VR

Araucariacites limbatus	VR
Cedripites cretaceus?	R
Complexiopollis microverrucosus	A
Complexiopollis spp. indet.	C
Conbaculatisporites undulatus	R
Inaperturopollenites dubius	VR
Laricoidites magnus	F
Phyllocladites mawsoni	VR
Proteacidites thalmanii	F
Proteacidites spp.	R
Schizosporis parvus	R
Taxodiaceaepollenites hiatipites	R
Tricolpites spp.	F
Tricolpopollenites compactus	VR
Triplanosporites sp.	VR
undetermined bisaccates	F
undetermined trilete spores	C
undetermined triporates	F
Zlivisporis novomexicanum	R

Dinocysts:

Achomosphaera sp.?	R
Alterbia cf. *A*. *acutula*	R
Alterbia sp.?	VR
Chatangiella sp.?	R
Chichaouadinium densispinatum	F
Diconodinum sp.	C
Dinogymnium heterocostatum	C
Dinogymnium undulosum	VR
Dinogymnium sp.	VR
Isabelidinium acuminata	R
Isabelidinium cooksoniae	FL
undetermined dinocysts	C

Acritarchs:

Pterospermopsis sp.	R

Sample UT89-37b from Floy Canyon, like the preceding samples from Hatch Mesa (Locality UT89-33), contains the palynomorph *Complexiopollis microverrucosus* and the dinocyst *Chichaouadinium densispinatum*. The occurrence of these two taxa suggests a Campanian or younger age for the section exposed at Locality UT89-37. The presence of the dinocyst *Dinogymnium heterocostatum* (late Coniacian to mid Campanian) indicates that sample UT89-37b is no younger than mid Campanian in age. Dinocysts recovered from this sample suggest deposition in a shallow marine (inner to middle neritic) environment.

Locality UT89-38: Floy Canyon. Sec. 3, T22S, R16E

UT89-38b: Senonian (probable early to mid Campanian)

Spores and Pollen:

Alisporites sp.	VR
Araucariacites limbatus	F
Cedripites sp.?	VR
Complexiopollis microverrucosus	FL
Complexiopollis spp. indet.	C
Corollina torosus	R
Cupanieidites cf. *C*. *reticularis*	VR
Laevigatosporites ovatus	VR
Laricoidites cf. *L*. *giganteus*	C
Laricoidites magnus	C
Monosulcites sp.	VR
Proteacidites retusus	VR
Proteacidites thalmanii	R
Proteacidites spp.	R
Quadripollis krempii	VR
Quercoidites sp.?	VR
Rugubivesiculites floridus	VR
Tricolpites clavireticulatus?	VR
Tricolpites spp.	C
Triplanosporites sp.	VR
undetermined bisaccates	F
undetermined tricolporate	VR
undetermined trilete spores	R
undetermined triporates	R

Dinocysts:

Chichaouadinium densispinatum	R
Deflandrea sp.?	VR
Dinogymnium heterocostatum	F
Dinogymnium undulosum	VR
Dinogymnium cf. *D*. *euclaense*	VR
Dinogymnium sp.	VR
Isabelidinium acuminata	R
Isabelidinium cooksoniae	FL
undetermined dinocysts	C

Acritarchs:

Pterospermospsis sp.	VR

Sample UT89-38b yielded a palynomorph assemblage of probable early to mid Campanian age. The occurrence of the palynomorph *Complexiopollis microverrucosus* and the dinocyst *Chichaouadinium* densispinatum suggest a Campanian or younger age for this sample. The presence of the dinocyst Dinogymnium heterocostatum (late Coniacian to mid Campanian) indicates that it is no younger than mid Campanian in age. Deposition probably took place in a shallow marine (inner to middle neritic) environment.

The palynological slides utilized in this study have been returned to you under separate cover. Unused samples will be returned via surface UPS.

We appreciate the opportunity to be of service. If we may be of further assistance, or answer any questions, please do not hesitate to contact us.

Sincerely yours,

D.W. Edelman

D.W. Edelman

DWE/sle
Enclosure

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NOMENCLATURE FOR RELATIVE ABUNDANCES:

VR = Very Rare (1 specimen)

R = Rare (2 - 4 specimens)

F = Few (5 - 9 specimens)

C = Common (10 - 19 specimens)

A = Abundant (20 - 49 specimens)

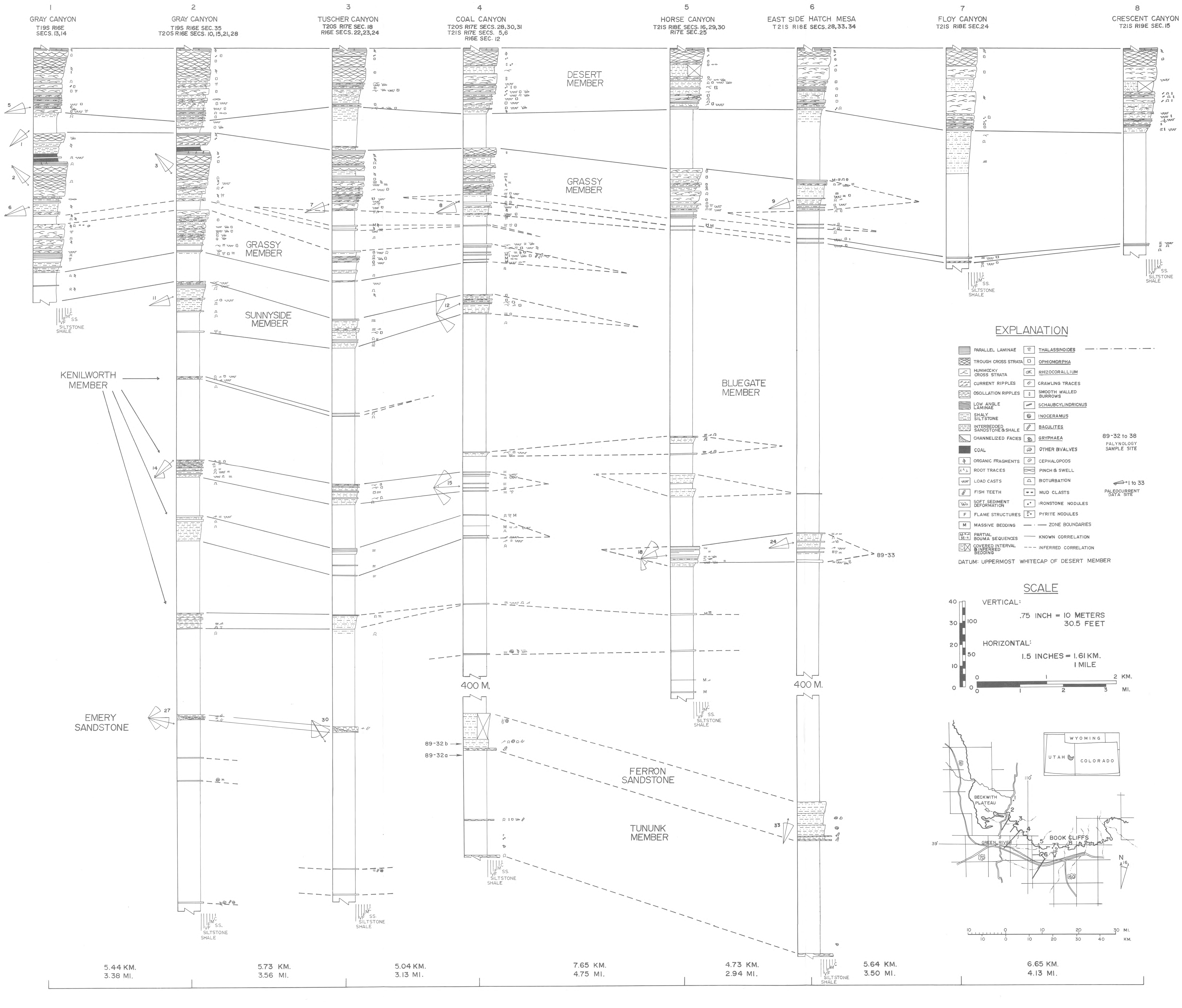
FL = Flood (> 50 specimens)

MEASURED STRATIGRAPHIC SECTIONS OF THE CRETACEOUS BLACKHAWK FORMATION AND MANCOS SHALE BETWEEN THE GREEN RIVER AND CRESCENT CANYON, EAST-CENTRAL UTAH

PLATE 1

M.A. CHAN and S.L. NEWMAN

(field sections measured by S.L. Newman)



MEASURED STRATIGRAPHIC SECTIONS FROM THE HATCH MESA AREA, EAST-CENTRAL UTAH

M.A. CHAN and S.L. NEWMAN

(field sections measured by S.L. Newman)

PLATE 2