UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Facies Analysis of the Lower Cycles of the Mesaverde Group (Upper Cretaceous) in Northwestern Colorado

By

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FACIES ANALYSIS OF THE LOWER CYCLES OF THE MESAVERDE GROUP (UPPER CRETACEOUS) IN NORTHWESTERN COLORADO

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ABSTRACT

The uppermost 180 m of the Mancos Shale and overlying 390 m of the Iles Formation of the Mesaverde Group in northwestern Colorado were deposited at the west margin of an epicontinental seaway that spanned North America 66-98 million years ago from the circumboreal seaway on the north to the Gulf of Mexico on the south. Sedimentation in the seaway was controlled by uplift in source areas to the west, subsidence in the basin, and eustatic sea level changes. Sedimentation rates were relatively high, averaging about 220m/million years; marine cycles of deposition occurred in northwestern Colorado that correspond to the Claggett, Judith River, and Bearpaw regressions of Montana.

The upper Mancos shale and lower Iles Formation can be subdivided into ten facies based on five criteria: (1) Lithology, texture, and thickness relations (geometry); (2) sedimentary structures and contacts; (3) trace and body fossils; (4) paleocurrent data; and (5) adjoining facies (underlying, overlying, and laterally). Each facies has distinct attributes which characterize a specific depositional environment. Environments represented by facies include (A) offshore shoreface transition (prodelta); (B) shallow marine sand bars; (C) destructional delta front; (D) constructional delta front (sheet sands and mouth bars); (E) beach foreshore-shoreface deposits; (F) interdistributary marsh and swamp deposits and fluvial floodplain; (G) distributary channels; (H) crevasse splays; (J) fluvial streams; and (K) tidally influenced distributary channel.

Facies analysis of outcrop data shows that transgressions and regressions occurred, some of which are related to major (eustatic) sea level changes and others that reflect only local causes. These events in northwestern Colorado are summarized in following chapters, and an attempt is made to show their relationship to broad regional patterns of sedimentation.

INTRODUCTION

Renewed activity in the exploration for hydrocarbons in the Sand Wash Basin of northwestern Colorado has established the need for detailed study of the Mancos Shale and Mesaverde Group--rock units which have been of interest to geologists since the late 1800's. Early geologic investigations in northwestern Colorado focused on development of the enormous, economically important coal resources of the region. It was during this era that the names Mancos Shale and Mesaverde Group were introduced from southwestern Colorado (Fenneman and Gale, 1906). The Mesaverde and the upper part of the Mancos later were determined to be substantially younger in northwest Colorado than at their type localities (Scott and Cobban, 1959; Weimer, 1959, 1960), but the names Mancos Shale and Mesaverde Group have been retained in northwestern Colorado, following the usage of many years. In 1923, an oil strike at Hamilton dome (Department of Interior, 1923) on the Axial Basin anticline (fig. 1) spurred new interest in exploration for hydrocarbons in the region, and since then, moderate quantities of oil and gas have been produced, primarily from low permeability lenticular sandstone reservoirs, in shallow parts of the basin. Numerous geologic studies have been made in the area since these early discoveries, but stratigraphic problems still exist because of diachroniety of units, and apparent scarcity of regional synchronous, mappable horizons. Nomenclatural changes in different areas further add to the complexity of the problem.

Besides being economically important as an area for energy development, northwestern Colorado provides a unique geologic setting for a detailed study of shelf and marginal marine clastic sequences in an area bordering the west margin of the Western Interior seaway. Continuous exposures of strata extend for up to 50 km along the flanks of anticlinal folds from Elk Springs (fig. 1) on the west to Oak Creek on the east. The main trend of outcrops crosses depositional strike, which trended northeast-southwest during early Mesaverde time; northward directed canyons nearly parallel depositional strike allowing three-dimensional views of geometry of units and bedding characteristics.

The area in northwestern Colorado is located in southern Moffat County where the upper Mancos and lower Mesaverde are exposed on the flanks of the Axial Basin anticline and in the Williams Fork Mountains between the towns of Hamilton and Pagoda (fig. 1). The area is bordered on the north by the Sand Wash Basin and on the southwest by the Piceance Basin (fig. 1).

Fossils collected from marine sections include zonal fossils (Gill and Cobban, 1966, Kauffman, 1975, 1977) which have been keyed to biostratigraphic zones in well-dated sections elsewhere in the Western Interior (Gill and Cobban, 1973; Obradovich and Cobban, 1975; Kauffman, Cobban, and Eicher, 1977; Izett and others, 1971). Utilizing the well-established biostratigraphy of the Western Interior region, a stratigraphic framework has been constructed for northwestern Colorado, which establishes a basis for regional correlation.

The combination of the above factors provides an ideal setting in which to define facies patterns. Careful tracing of facies in well dated sections has not only provided the key to correlation of units in the area, but has also allowed a reconstruction to be made of paleoenvironments and marine history, based on analogy to modern environments and subsurface mapping in the southeastern Sand Wash Basin and northern Piceance Basin (fig. 17). The summary of facies developed herein is not only locally significant, but may find broad application to other areas in the Western Interior.

Masters (1966, 1967) developed a model of intertonguing between eastward-pointing continental sequences and westward-pointing marine shale tongues in northwestern Colorado, and assigned offbeach, beach lagoon, swamp, and flood-plain environments to the rocks. Asquith (1970, 1974, 1975), working with subsurface sections mainly in Wyoming and northwestern Colorado, proposed a "wide shelf" deltaic model for the region. Collins (1976, 1977) studied equivalent sequences in the Grand Hogback (eastern Piceance Basin) to the south, and delineated repetitive sequences of marine to nonmarine rocks that he interpreted as the deposits of a southeastward-prograding delta. Cyclic sequences vary from seven, near the strandline, to three farther seaward. The present study tests earlier interpretations, and examines some of the causes of cyclic deposition in this area.

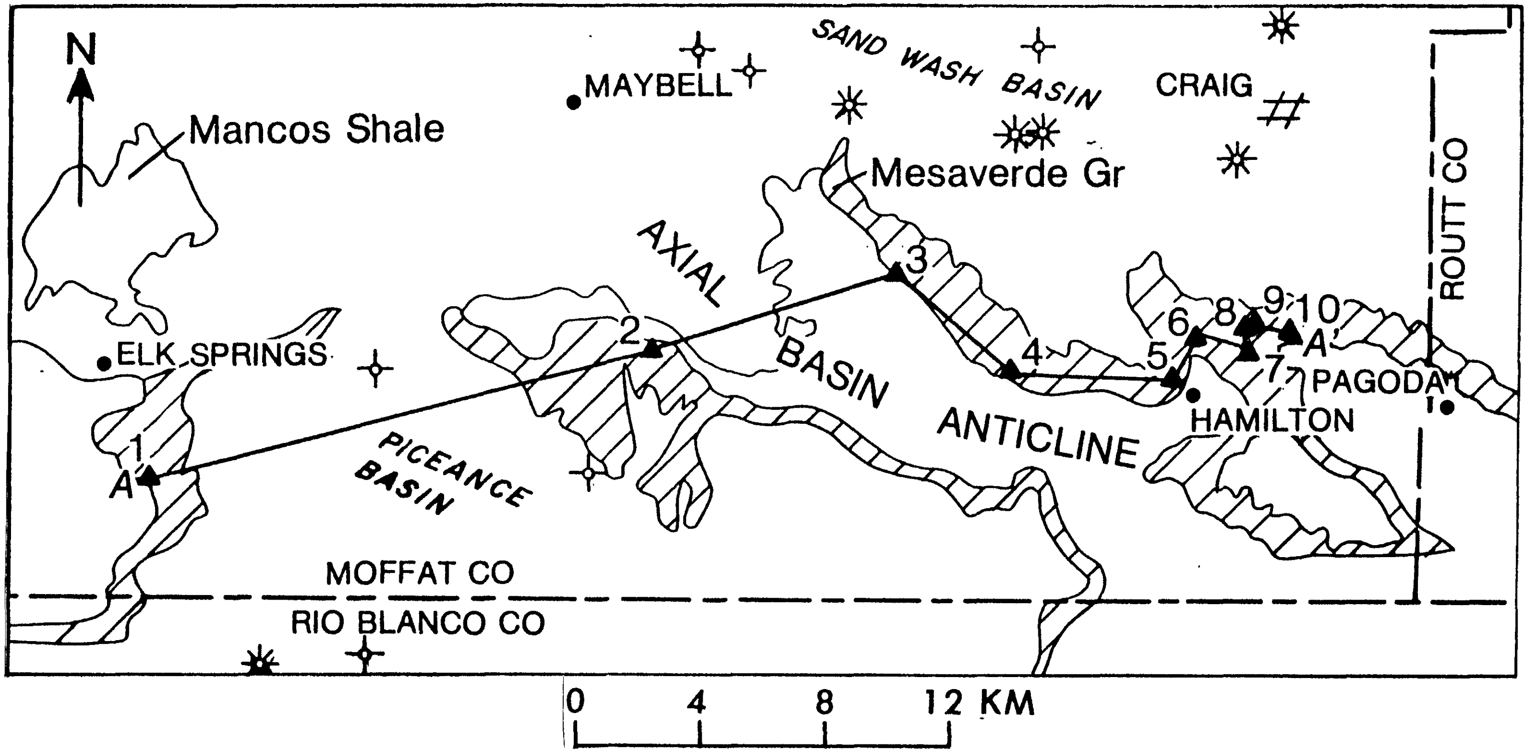


Figure 1. Index map showing area studied in northwestern Colorado. Cross section A-A′ shown by triangular symbols. Numbers indicate locations of measured sections: 1 Coal Creek, 2 Deception Creek, 3 Morgan Gulch, 4 Duffy Mountain, 5 Konishi, 6 Castor Gulch, 7 Bellering Cow, 8 Stock Pass Gulch, 9 Horse Gulch, 10 Poverty Gulch (Appendix).

METHODS OF STUDY

In this investigation subsurface data were supplemented by outcrop data because only 29 wells in the area penetrate rocks older than the Mesaverde Group. Ten outcrop sections averaging 300-400 m thickness were measured in a distance of 80 km along the southern margin of the Sand Wash Basin (fig. 1). Sections were spaced as much as 21 km apart in areas of good exposure but placed closer together (0.8-1.6 km) where exposure is poor or rapid facies changes occur. In all sections, detailed attributes of each facies were noted, and macroinvertebrates were collected wherever found. Shales and sandstones were sampled systematically for further petrographic work and analysis of microfossils. Facies were established after combining all data from each section measured (see Appendix) and determining lateral and vertical relationships. A facies diagram (fig. 2) was constructed which shows the lateral and vertical components of facies; environments were interpreted through comparisons with modern environments. Collectively these data allowed regional interpretation of paleoenvironments and marine history in the area.

Thin sections of sandstones from several selected facies were examined under the petrographic microscope, in order to determine texture and relative abundance of framework and matrix. Each sandstone was classified according to Folk (1974), based on a point count of 300 (fig. 10).

GEOLOGIC SETTING

The uppermost Mancos Shale and Iles Formation of the Mesaverde Group in northwestern Colorado were deposited 70-80 million years ago in a foredeep basin east of the tectonically active Sevier orogenic belt in west-central Utah (fig. 3). Cretaceous sedimentation began in this area on a nearly planar surface developed on old Precambrian positive elements overlain by a thin veneer of Paleozoic and older Mesozoic sedimentary rocks (Tweto, 1975). The thickness of the Cretaceous section, as much as 3,600 m, indicates that a considerable amount of subsidence occurred in this region during the Cretaceous alone.

Deposition of units occurred at a time when the north-south-trending epicontinental sea had retreated some distance to the east, as indicated by a thick regressive wedge that extended into the area from Utah on the west. Sedimentation rates were high in this region (average 220 m/million years) where clastics accumulated, but slow to the east (18-36 m/million years) where carbonates were deposited (Gill and Cobban, 1973). The slower rates to the east resulted form a lack of terriginous sediment supply from the west and relatively slow rates of pelagic carbonate accumulation.

The studied interval in northwestern Colorado accumulated in shelf regions adjacent to a basinal area to the east. The position of this basinal area, or trough, is somewhat controversial. Some (Eicher, 1969; Frush and Eicher, 1975; and Asquith, 1970, 1974) believe it was located in eastern Colorado and western Kansas, extending southward to the Big Bend area of Texas, wheareas others (Kauffman, 1969, 1970, 1977; and Kauffman, Powell, and Hattin, 1968) believe it was located farther west in central Colorado and Wyoming. Proponents of the "eastern trough zone" show evidence that carbonate deposition occurred at depths of 600-900 m, based on analysis of foraminifera in the Greenhorn Formation in Colorado and the Boquillas Formation in Texas.

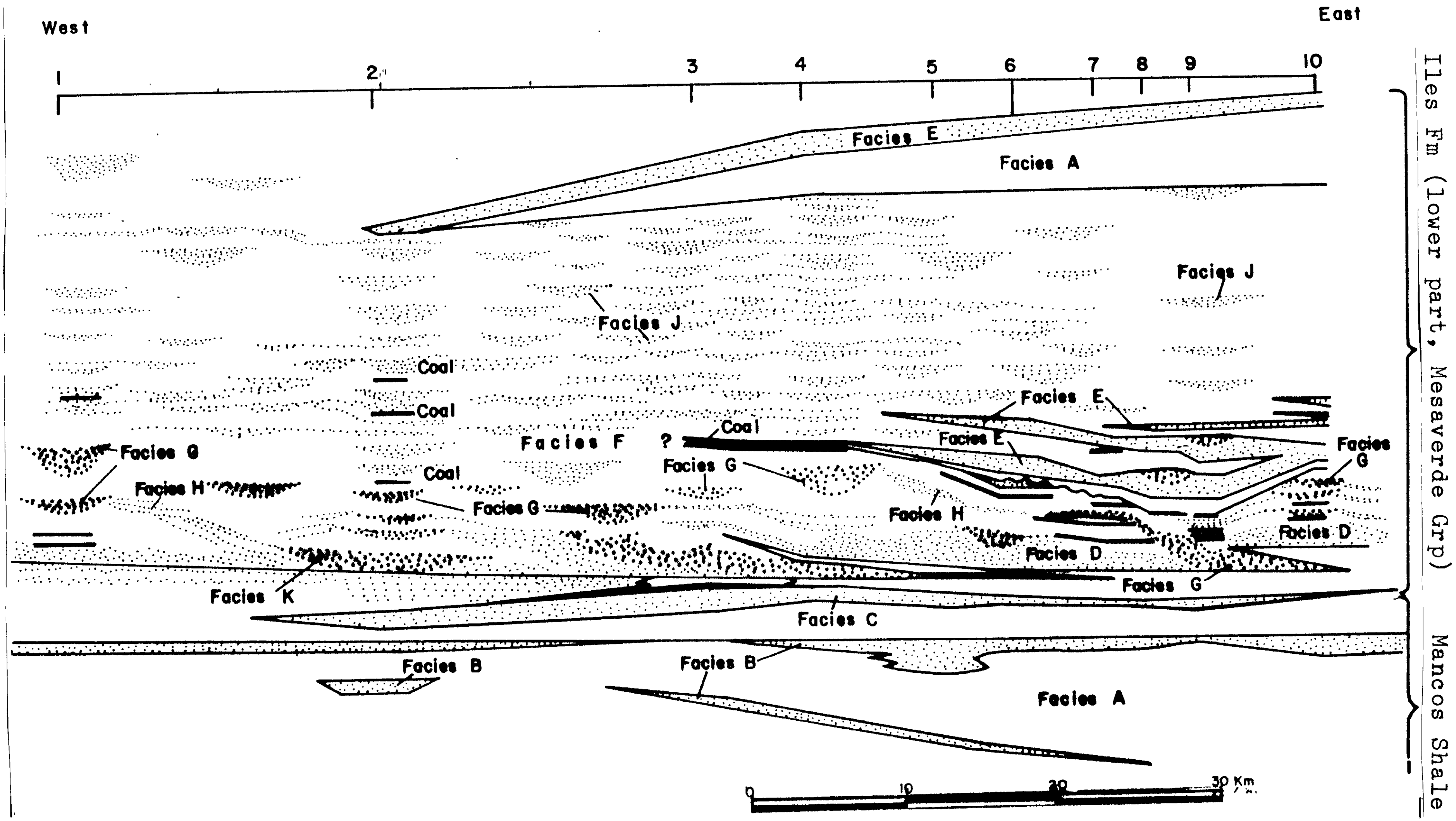


Figure 2. Facies diagram of the upper Mancos Shale and Iles Formation showing lateral and vertical relationships. For location of sections, refer to Index Map (fig. 2).

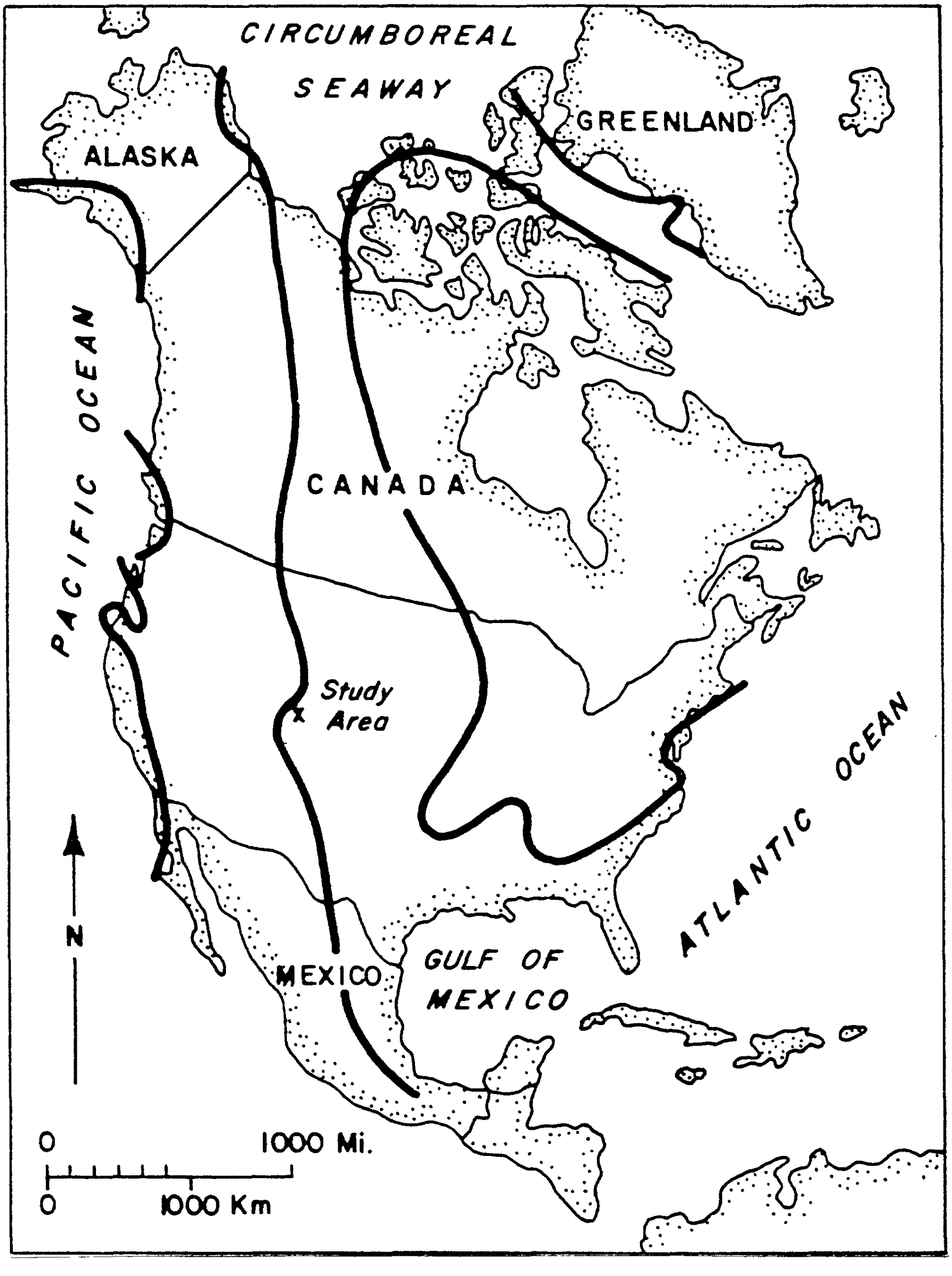


Figure 3. Western Interior seaway during late Campanian time, showing study area (x).

This data is backed by calculations of stream gradients for the paleoslope upon which the initial transgression of the Late Cretaceous sea took place. Asquith (1970, 1974), working with subsurface sections in Wyoming, lends additional support to this evidence by demonstrating that isochronous surfaces in shale sections of the Upper Cretaceous slope gently eastward towards a basinal low. He shows that water depths were about 600 m deep from inner shelf to basin.

The proponents of the "west-central trough zone" (Kauffman, 1969, 1970, 1977; Kauffman, Powell, and Hattin, 1968) contend that the basin center was farther towards the area of maximum subsidence which was in western Colorado and Utah, based on preservation of complete cyclothems in this region, and paleoenvironmental analysis of constitute units. Kauffman (1977) suggests that water depths in this region did not exceed 200-300 m. This theory is further backed by the presence eastward of a major unconformity in the Niobrara (Hattin, 1975), and disconformities to the west (Kauffman, 1977).

Taking into account both sides of this controversy, this study proposes a wide-shelf marginal marine model that is in general compatible with the basin models proposed by Eicher, Frush, and Asquith (Eicher, 1969; Frush and Eicher, 1975; and Asquith, 1970, 1974, 1975). Extreme thickening of the Mancos-Mesaverde section in northwestern Colorado and presence of complete cyclothems, however, favors at least local subsidence-possibly related to early Laramide tectonic events as suggested by Kauffman and others (1968, 1969, 1970, 1977). These conclusions are based on several factors including interpretations of depositional environments, inferred water depths, and circulation in offshore areas.

STRATIGRAPHIC SEQUENCE

The total thickness of the Mancos Shale and Mesaverde Group in northwestern Colorado is about 2,700 m. The Mesaverde comprises eastward-thinning wedges of rocks of marginal marine and nonmarine origin that intertongue with westward-pointing wedges of marine Mancos Shale (fig. 4). The Mesaverde conformably overlies the Mancos Shale and is conformably overlain by the Lewis Shale. Unnamed marine shale tongues of the Mancos within the main body of the Mesaverde mark transgressive episodes.

The studied interval (fig. 5) includes the uppermost 180 m of the Mancos Shale and the basal 390 m of the overlying Mesaverde Group (*B asperiformis* to *E. jenneyi range* zones). The age of the interval is late Campanian (Zapp and Cobban, 1960; Izett and others, 1971). The upper part of the Mancos is composed of interbedded marine sandstone and shale that is transitional upward into predominately nonmarine sandstones, shales, and coals of the lower Mesaverde.

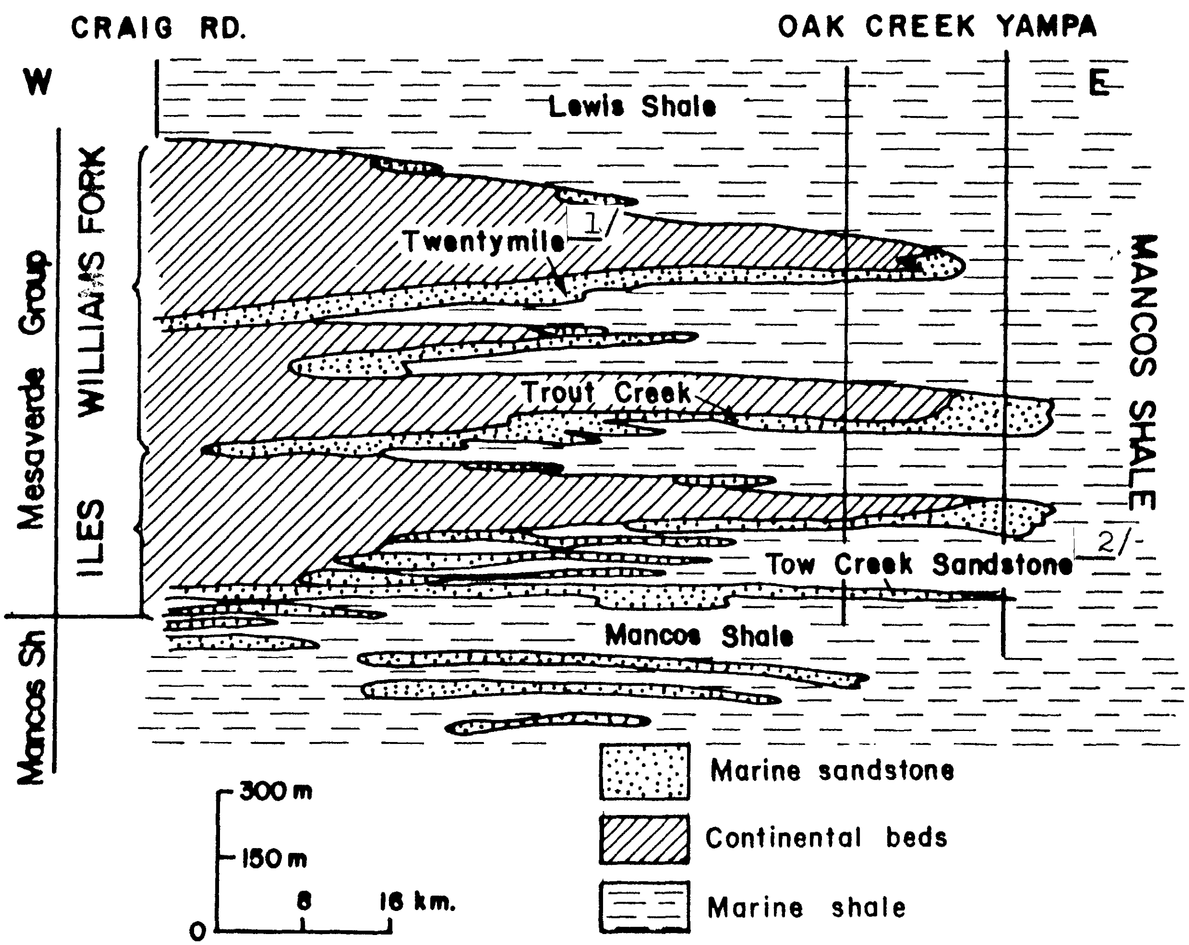


Figure 4. Mesaverde Group in northwestern Colorado showing eastward-thinning wedges of marine and nonmarine rocks, and westward-pointing wedges of marine shale. After Masters, 1967. [1]/Twentymile Sandstone Member of Williams Fork; [2]/Trout Creek and Tow Creek Sandstone Members of Iles Formation.

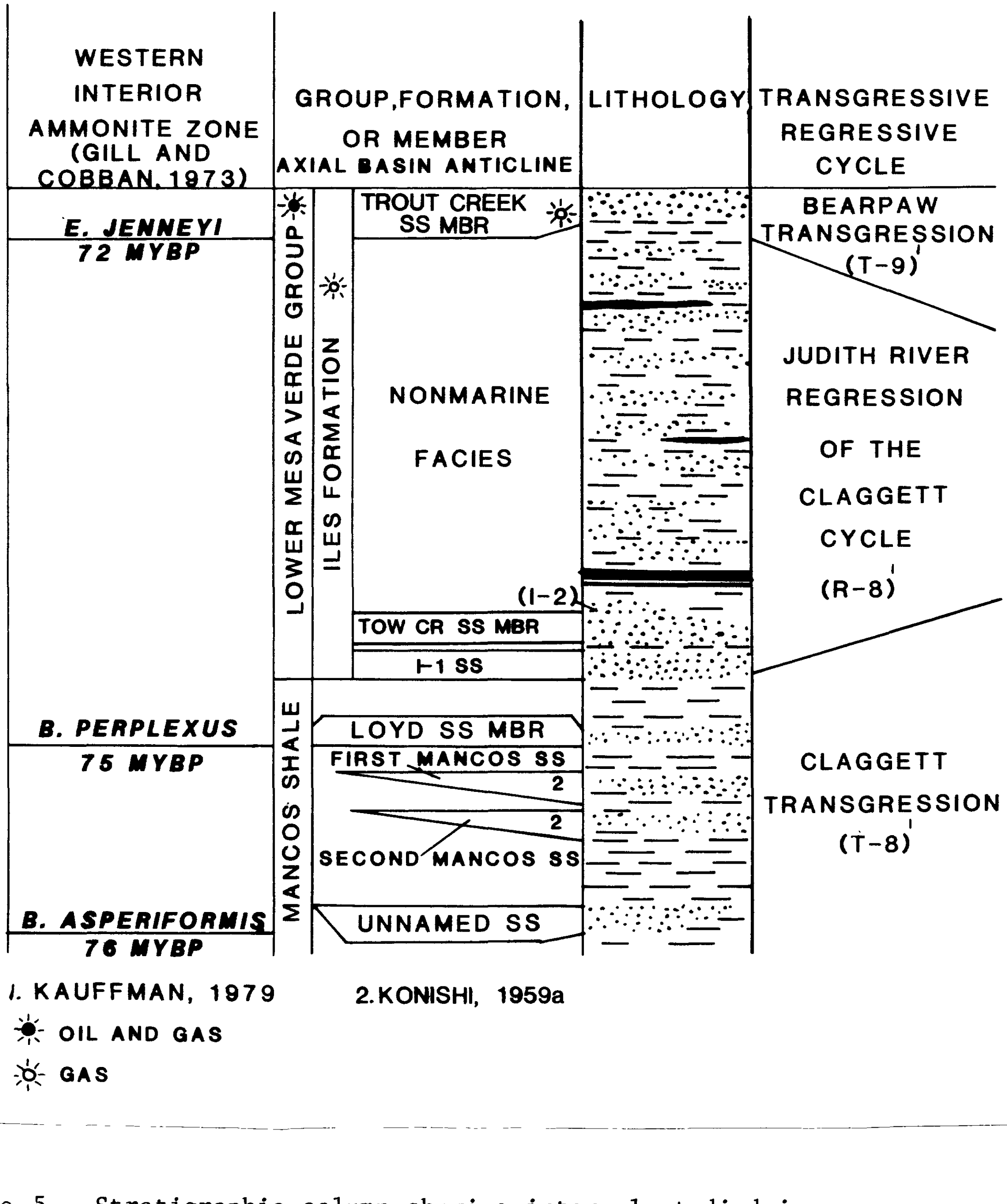


Figure 5. Stratigraphic column showing interval studied in northwestern Colorado. Western Interior ammonite zones of Gill and Cobban (1966) are keyed to K-Ar dates of Obradovich and Cobban (1975). Transgressive-regressive cycles of Gill and Cobban (1973) are keyed to global system of marine cycles of Kauffman (1977, 1979).

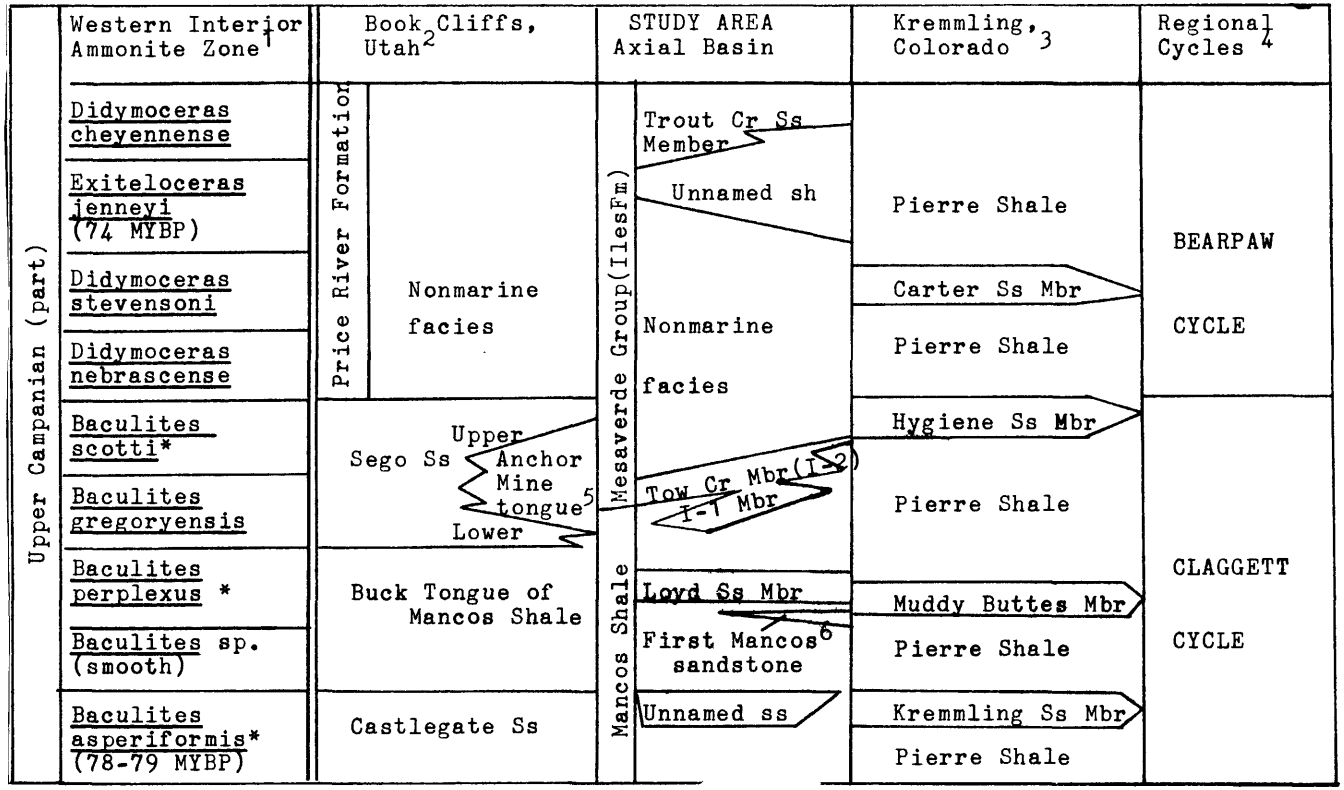
Hancock in 1925 subdivided the Mesaverde in this area into an upper and lower part and called the lower part the Iles Formation. The basal contact was placed at the base of a pair of marine sandstones, just above the Loyd Sandstone Member of the Mancos Shale. These paired sandstones he called "contact sandstone" (lowermost) and "Rim Rock" (uppermost). Later, Masters (1965) extended the Tow Creek Sandstone Member (Crawford, Wilson, and Perini, 1920) into the area in place of the uppermost sandstone. The Tow Creek is a persistent sandstone bed exposed on the Tow Creek anticline to the east; it forms the basal contact of the Iles where the "contact sandstone" of the study area is absent (Bass, Eby, and Campbell, 1955). For purposes of this study, the informal designations I-1 and I-2 have been applied to the "contact sandstone" and Tow Creek Member, respectively, and the basal contact of the Iles remains at the base of the I-1 sandstone, following Hancock's (1925) original definition. The I-1 and I-2 are distinct lithogenetic units, as determined by geometry and bedding characteristics, and as such are referred to informally for simplicity of discussion.

The upper boundary of the Iles Formation is at the top of the Trout Creek Member of Fenneman and Gale (1906) in the report area, as defined by Hancock (1925). The Trout Creek is widely distributed throughout both the Sand Wash and Piceance Basins. West of Deception Creek (loc. 2), however, the Trout Creek is replaced by fluvial strata and is indistinguishable as a separate unit. Where this change occurs, the Mesaverde is referred to as "Mesaverde Group, undivided."

The nonmarine facies of the Iles (fig. 5) overlying the Tow Creek Sandstone Member (I-2 sandstone) in the vicinity of Duffy Mountain changes eastward to marine sandstones and shales east of Hamilton (fig. 1). Where this change occurs, interbedded marine sandstones within the nonmarine facies are designated informally I-3 to I-7. The I-3 to I-7 sandstones, although not traceable for distances of more than a few kilometers, form reliable local marker beds within the otherwise nonmarine facies of the Iles near Hamilton.

With the exception of the Loyd Sandstone Member, units within the upper Mancos Shale are unnamed. The Loyd Sandstone Member was named by Konishi (1959a) because it is lithologically distinct, distributed widely, and contains numerous fossils, including the zonal fossil *Baculites perplexus*. The first Mancos sandstone (Konishi, 1959a) below the Loyd, and a second older one called the second Mancos sandstone (Konishi, 1959a: not examined in this study) are similar in appearance to the Loyd, but are more discontinuous. An unnamed sandstone containing *Baculites asperiformis* crops out to the west at Deception Creek (loc. 2, fig. 1), but cannot be traced for more than a few kilometers to the east or west.

The upper part of the Mancos and the Iles Formations in northwestern Colorado are equivalent (fig. 6) to the Castlegate Sandstone, Buck Tongue, Sego Sandstone, and Price River Formation of Utah, and to part of the Pierre Shale in Middle Park, near Kremmling, Colorado. Paleoenvironments of correlative sequences range from piedmont red beds and fluvial and delta front in Utah (Young, 1955, 1957; Hale, 1959; and Van de Graaff, 1972), and offshore marine near Kremmling (Izett and others, 1971).



[1]Gill and Coban (1966)
[2]W. A. Cobban (oral commun., 1978)
[3]Izett, Cobban, and Gill (1971)
[4]Gill and Cobban (1973)
[5]Of Mancos Shale
[6]Of Konishi, 1959a
*indicates fossil found in area of study

Figure 6. Chart showing nomenclature used in study area, ammonite zones of Western Interior Cretaceous, and correlations with other area.

FACIES

The field criteria upon which interpretations of facies are based include: (1) Lithology, texture, and thickness relations (geometry); (2) sedimentary structures and contacts; (3) trace and body fossils; (4) paleocurrent data; and (5) adjoining facies (underlying, overlying, and laterally). Field data are summarized in table 1 (App.). Ammonites were identified by W. A. Cobban and bivalves by E. G. Kauffman, each of whom provided paleoenvironmental interpretations for some species. Similar interpretations were provided by D. L. Eicher (Foraminifera), F. E. May (Pollen and Spores), and R. M. and E. B. Forester (Ostracodes). These are summarized along with field data in the following sections.

Ten facies have been delineated in the upper part of the Mancos Shale and Iles Formation based on field criteria and faunal and floral evidence. Each facies represents a distinct change in environment within the interval studied.

Mancos Shale

The upper Mancos Shale consists of two distinct facies, here designated A and B: facies A, olive-gray to medium-dark-gray mudstone containing thin sandstone interbeds composes the main body of the Mancos Shale; facies B, thick (>1.5 m) tabular to lenticular sandstone bodies enclosed in facies A includes the Loyd Sandstone Member, the first Mancos sandstone of Konishi (1959a), and the unnamed sandstone below the Loyd containing *Baculites asperiformis*. Facies B sandstones resemble one another in gross aspect, but they differ considerably in internal structure and, therefore, probably also in origin. Hence, each of the three B sandstone units is discussed separately.

Facies A

Olive-gray to medium-dark-gray mudstone of facies A is sandy and locally somewhat fissile. It contains abundant finely disseminated carbonaceous plant material. Bedding in the mudstones is commonly destroyed by intense bioturbation (fig. 7).

A single macroinvertebrate was identified from facies A at locality 1 (*Placenticeras intercalare*, W. A. Cobban, written commun., 1978). Microfossils included Foraminifera, *Spiroplectomania semicomplanata* (Carsey) and *Haplofraymoides excavatus* Cushman and Waters at locality 2 (units 2 and 6, measured sections, App.) (D. L. Eicher, oral commun., 1978), and one Ostracode, *Haplocytheridea* (E. B. Forester, written commun., 1978) from locality 2 (unit 6). Pollen and spores identified at locality 4 (unit 4) are *Deflandrea victoriensis, Trithyrodinium robustum, Aquilapollenites, Palaeonystrichophora infusorioides,* and *Proteacidites* (F. E. May, written commun., 1977).

Thin (<0.3 m) sandstone interbeds of facies A are very fine to fine grained and laminated to very thin bedded. In contrast to bedding in the mudstones, bedding in the sandstones is very well preserved, and contacts with underlying and overlying mudstones are sharp and parallel (fig. 7).

Figure 7. View of facies A at Deception Creek (loc. 2, unit 6, App.) showing bioturbation in mudstones and sharp basal and upper contacts of sandstone interbeds.

Sandstones are horizontally bedded to ripple bedded. Ripples are generally small asymmetric current ripples with rounded crests. The tops of current rippled beds are commonly covered by tracks and trails of *Gyrochorte, Crossopodia, Nereites*?, and starfish resting traces (Hantzschel and others, *in* Moore, 1962), and less commonly by sand-filled burrows of *Planolites*, the trace of a deposit feeder that inhabited the muddy interbed between sandstone layers.

Paleocurrent directions on ripple crests at locality 2 indicate that currents flowed towards the shore (northwest) at this locality; ripple crests generally parallel the paleoshoreline.

In some places locally thickened (0.3-1.5 m) sandstone lenses occur within facies A. These lenses somewhat resemble the thin rippled interbeds except for their greater thickness and the fact that bedding consists of bipolar-bimodal wedge crossbeds (loc. 4) or bimodal trough crossbeds (loc. 1). Transport of these sand bodies was bipolar-bimodal, parallel to elongation of the sand body (fig. 8). Paleocurrent directions at locality 1 are approximately parallel to the paleoshoreline trend; at locality 4 they are at right-angles. Mean variants indicate a general longshore direction of current flow (fig. 8).

Lithology, sedimentary structures, and fossils of facies A suggest deposition in the offshore-shoreface transition zone. The shoreface zone is the gently sloping zone between low tide and the transition to offshore marine muds. The transitional offshore is from effective daily wave base seaward to below storm wave base (Reineck and Singh, 1975, p. 286) (fig. 9). The Foraminifera, *Spiroplectomania semicomplanata* (Carsey) and *Haplofraymoides excavatus* Cushman and Waters occur in marine habitats (D. L. Eicher, oral commun. 1978), and the dinoflagellates, *Deflandrea victoriensis* and *Trithyrodinium robustum*, suggest marine environments (F. E. May, written commun., 1977).

Nereites, a deposit-feeding organism that passes sediment through its system, occurs below storm wave base in quiet-water (Chamberlain and Frey, 1976). *Gyrochorte*, a snail trail, is common in the offshore-shoreface transition (Howard, 1972). The sharp basal and upper contacts of sandstone interbeds suggest periodic storms and subsequent redeposition of sediment by settling from suspension. Well-preserved laminae within sandstone beds overlain and underlain by bioturbated mudstones indicate rapid sand deposition after storms and reoccupation of the substrate by deposit-feeding organism.

Asymmetric current ripples with rounded crests suggest that wave motion was predominant over current drift between storms (Harms and others, 1975, p. 58). Combined current-wave ripples, such as those at locality 2, with a consistent onshore migration direction reflect shoaling conditions. Wave ripples of this type are similar to ones described by Clifton and others (1971) in the asymmetric ripple facies (inner offshore).

A. $\underline{n}$ = 22

M.V. = 223°

dip_{av} = 11° SW

B. $\underline{n}$ = 5

M.V. = 239°

dip_{av} = 11° SW

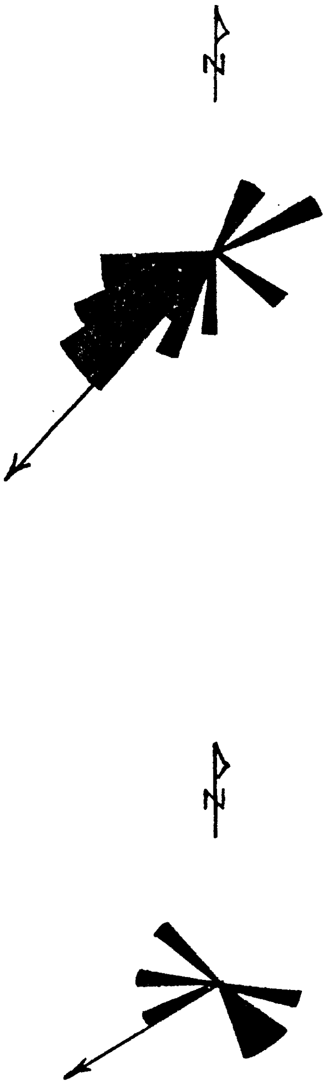


Figure 8. Paleoccurrent rose diagrams of facies A, tidal sand bodies, at (A) Coal Creek (loc. 1) and (B) Duffy Mountain (loc. 4), showing dip directions of crossbedding (M.V., mean vector, and average dip of crossbeds (dip_{av}). $\underline{n}$, number of readings.

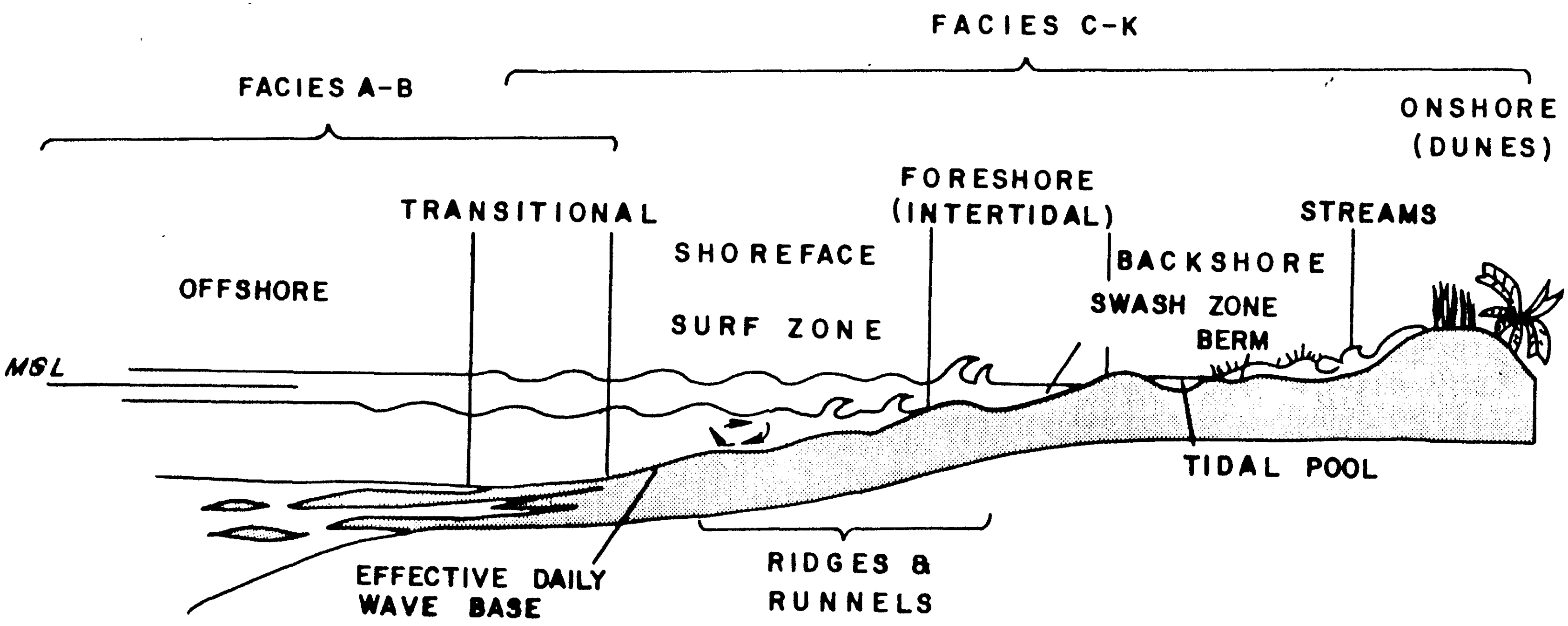


Figure 9. Generalized shoreline profile showing distribution of facies delineated by this study and environments referred to in this paper (Reineck and Singh, 1975).

The locally thickened sandstone lenses with bipolar-bimodal wedge and trough crossbeds are interpreted as "tidal sand bodies" (Klein, 1971). They possibly represent sand that bypassed a river mouth, and was reworked by tides, since they are preserved down-dip from an interpreted channel sand deposit. River-mouth bypassing occurs when sediment is flushed over river mouth shoals that normally constitute a barrier for fluvial sediment transport to the sea (Stanley and Swift, 1976). During peak flow, such as river floods or spring tides, fine sand may be flushed over these shoals as suspended sediment, either at high flood stage or as a result of ebb tidal jets, which occur when tidal flow passes seaward through a constricted river mouth. The seaward tidal flow generally is stronger than the landward flow due to reinforcement by river discharge. The fine sand then rains out either on the shoreface or farther seaward on the shelf (Stanley and Swift, 1976) and is reworked by ebb and flood tidal currents into elongate bars.

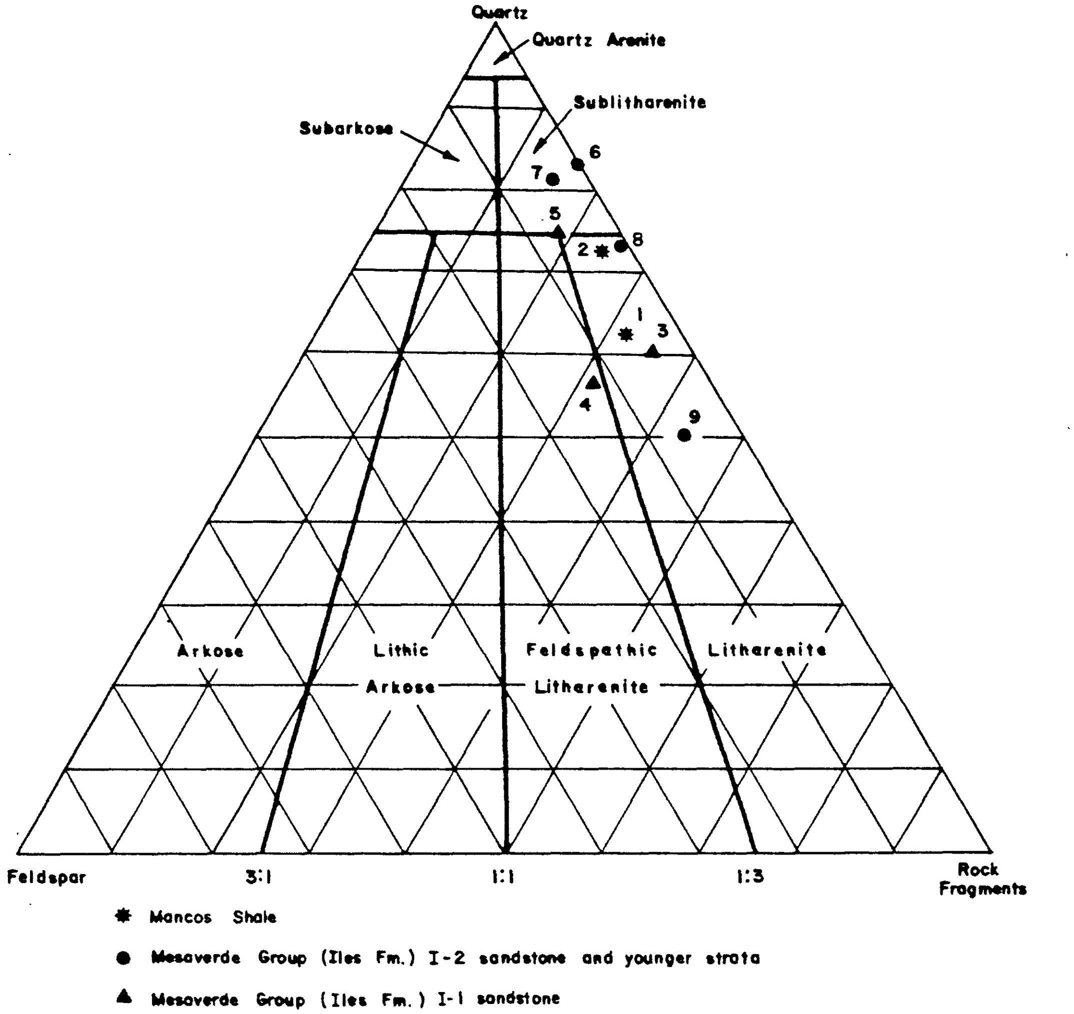
Facies B

Loyd Sandstone Member--In most places the Loyd Sandstone Member is 5-10 m thick, but at locality 5 (fig. 1) it reaches a maximum of 31.2 m. At locality 3, the Loyd is absent altogether. Wherever the Loyd occurs it contains *Baculites perplexus* (a middle form, W. A. Cobban, oral commun. 1980), an important stratigraphic marker.

The Loyd is a grayish-green sandstone that differs markedly in color from the yellowish-gray sandstones in the Iles Formation above. The green coloration appears to be due to chlorite, which, according to Porter and Weimer (1979), formed during early diagenesis in Late Cretaceous marine environments. The grain size ranges from very fine to fine sand and the sorting is moderate to poor. Grains are subangular to angular and consist of quartz, chert, K-feldspar, and rock fragments, with minor muscovite and plagioclase. The sandstone is classified as a litharenite (fig. 10). The Loyd contains as much as 40 percent calcite cement, more than occurs in other sandstone units in the Mancos or Mesaverde, and probably indicates dissolution of some of the contained marine shells.

Bedding in the Loyd is almost entirely absent, except for locally preserved horizontal or low-angle crossbedding. The rock appears homogeneous, a characteristic first recognized by Hancock (1925), who described the unit as "sugary" textured. Locally the Loyd contains calcareous concretions which range in diameter from a few centimeters to about 4 m. These concretions commonly form around nuclei of fossils.

Macroinvertebrates are abundant in the Loyd at almost all localities. In addition to *Baculites perplexus*, the ammonites *Hoploscaphites* sp. and *Placenticeras* sp. have been identified by W. A. Cobban (written comm., 1977) from the Loyd at locality 1. Bivalves identified by E. G. Kauffman (written commun., 1979) from the Loyd at localities 1, 2, 4, and 9, include the following:



(1) sample 77-LK-1 (Sec. 4, Unit 1, App.)
(2) sample 77-LK-2 (Sec. 4, Unit 3, App.)
(3) sample 77-LK-5 (Sec. 4, Unit 5, (top), App.)
(4) sample 77-LK-4 (Sec. 4, Unit 5, (base), App.)
(5) sample 77-LK-43 (Sec. 2, Unit 5, App.)
(6) sample 77-LK-7 (Sec. 4, Unit 9, App.)
(7) sample 77-LK-45 (Sec. 2, Unit 9, App.)
(8) sample 77-LK-9 (Sec. 4, Unit 11, App.)
(9) sample 77-LK-17 (Sec. 4, Unit 25, App.)

Figure 10. Classification (after Folk, 1974) of selected sandstone samples from the Iles Formation of the Mesaverde Group and Mancos Shale, northwestern Colorado (see Table 3, App.).

Locality 1, COAL CREEK, secs., 20, 21, T. 4 N., R. 98 W.

Unit 1

Bivalvia:
Anatina sp. indet.
A. n. sp. aff. *A. lineata*
Clisocolus dubius (Gabb)
C. moreauensis (Meek and Hayden)
Corbula sp. indet.
Crenella elagantula (Meek and Hayden)
Cymbophora? sp.
Granocardium (Etnmocardium) n. sp. aff. *G. (E.) whitei* (Dall) (=*G. (E.) speciosum* (Meek and Hayden)
Endocostea? barabini (Morton)
E. sp. cf. *E. barbini* (Morton) (s.s.)
"*Inoceramus*" cf. *balchii* (Meek and Hayden)
"*I*." *oblongus* trans. to *I. balchii* (Meek and Hayden)
"*I*." *regularis* d'Orbigny
I. proximus (Toumey) (s.s.)
I. proximus subcircularis (Meek) (?= *I. vanuxemi* Meek and Hayden, of Meek, 1876, pl. 14, fig. 2)
"*Lucina*" (=*Nymphalucina*) *subundata* (Hall and Meek)
Nucula sp. cf. *N. obsoletistriata* (Meek and Hayden)
Pseudoptera (juv.) aff. *P. subtortuosa* (Meek and Hayden)
Phelopteria linguiformis (Evans and Shumard)

Locality 2, DECEPTION CREEK, secs. 22, 23, 26, and 27, T. 5 N., R. 95 W.

Unit 3
Bivalvia:
cf. *Veniella* sp.
Clisocolus n. sp. aff. *C. dubius* and aff. *C. transversa* (Whitfield)

Locality 4, DUFFY MOUNTAIN, sec. 25, T. 5 N., R. 93 W., secs. 30, 19, 18, 17, T. 5 N., R. 92 W.

Unit 3
Bivalvia:
Cymbophora subtilis (Stephenson)
Cymella n. sp. aff. *C. montanensis* (Henderson)
Dosiniopsis deweyi (Meek and Hayden)
Large disc-like bivalve, cf. *Cyprimeria* sp.
Ostrea (Ostrea) sp. indet. (frags. only)
Mytilus (Mytilus) n. sp. cf. *M. quadratus* (Gabb)
cf. *Panopea* sp. indet.
Pinna sp. (frag.)
Phelopteria liguaeformis (Evans and Shumard)
Oxytoma (Hypoxytoma) n. sp. cf. *O. (H.) nebrascana* (Evans and Shumard)
Thyasira sp. aff. *T. bacca* (Kauffman) (worn)

Locality 9, HORSE GULCH, secs. 24, 13, T. 5 N., R. 91 W.

Unit 1
Bivalvia:
Corbula sp. juv.
"*Corbula*" sp.
Crassostrea? frags.
Cymbophora sp. cf. *C. warrenana* (Meek and Hayden)
Dosiniopsis sp. aff. *D. deweyi* (Meek and Hayden)
Granocardium (Ethmocardium) whitei (Dall)
Granocardium n. sp.
Oxytoma (Hypoxytoma nebrascana) (Evans and Shumard)
Pinna sp. (frag.)
Syncyclonema sp. cf. *S. dalli* (Gabb)
Thracia? sp.
Thyasira? sp.

In addition to these macroinvertebrates, the Loyd contains *Ophiomorpha*, large, horizontal, smooth-walled burrows (*Thalassinoides*?), *Chondrites*, and a few distinguishable *Planolites* (small smooth-walled burrows). The Loyd Sandstone Member was deposited at or above effective wave base (lower shoreface) in normal marine, intertidal to shallow subtidal environments. E. G. Kauffman (written commun., 1979) states that contained fossils indicate shallow, nearshore, normal marine environments where sands were deposited by active waves and currents. The assemblage is ecologically well balanced as indicated by strongly byssate epifaunal suspension feeders (*Phelopteria, Oxytoma*), thick-shelled cemented suspension feeders (*Ostrea*) semi-infaunal suspension feeders (*Pinna*), shallow (*Cymbophora, Dosiniopsis, Thyasira*), moderately deep (*Cyprimeria*) and deep burrowing (*Panope*) infaunal suspension feeders, and a marine infaunal microcarnivore (*Cymella*). A single valve of *Mytilus* suggests intertidal to very shallow subtidal environments. It is a byssate suspension feeder. This specimen has not been carried far from a strandline. The scarcity of deposit-feeding bivalves reflects a low organic content and probably high energy environment where sand was winnowed by waves and currents.

This diverse group of bivalves suggests normal marine nearshore conditions rather than brackish environments, especially among the inoceramids. Both infaunal and epifaunal forms are present, and suspension feeding as well as sparse detritus-feeding bivalves. These collectively indicate a widely habitable interface where open-marine conditions prevailed. A low representation by selective infaunal suspension feeders and the presence of *Nucula* and lucinoids may indicate occasional difficult infaunal sedimentary environments which were probably reducing. *Nucula* is an organic deposit feeder, but rare, so sediment was retaining at least local organic debris. Hard or firm substrates (maybe large shells) are suggested by the presence of some byssate inoceramids and *Phelopteria*. *Crenella* is a byssate hole or crevice dweller in firm substrates.

The occurence of *Baculites perplexus* in the Loyd at many localities indicates not only the age of the unit, but that sedimentation occurred seaward of a strandline. Ammonites occur most commonly in offshore areas, and only rarely as rafted material in brackish or intertidal environments. Intense bioturbation in the Loyd suggests deposition in an offshore environment, similar to that in modern shelves seaward of modern coastlines.

Ophiomorpha and *Thalassinoides* are relatively undiagnostic of depth inasmuch as they have been reported from modern lower foreshore environments (Weimer and Hoyt, 1964), from depths at or above storm wave base, but below daily wave base (Chamberlain and Frey, 1976), and from turbidites far below storm wave base (R. Hunter, written commun., 1979). No evidence has yet been found that the Loyd Sandstone Member was ever emergent.

In summary, the Loyd is interpreted as a widepsread shallow, nearshore (regressive) sheet sand deposit that was left (a palimpsest deposit, Swift and others, 1971) in offshore areas during a rise of sea level.

First Mancos sandstone of Konishi (1959a)--The First Mancos sandstone of Konishi (1959a), an informal unit, is exposed between localities 3 and 5 and reaches a maximum thickness of about 6 m at locality 4. This sandstone is a very fine to fine grained, coarsening upward, moderately well sorted sandstone with angular to rounded grains. Quartz, chert, K-feldspar, and rock fragments constitute the main detrital grains, with mica, chlorite, and heavy minerals comprising minor components. The sandstone is classified as a litharenite (Folk, 1974), similar to the Loyd.

Bedding in the First Mancos sandstone consists almost entirely of tabular planar crossbeds with minor symmetrically filled trough crossbeds and with ripples on upper surfaces. Rounded ironstained clay clasts occur on some bedding surfaces, as well as fragments of oysters and sharks' teeth. Two macroinvertebrates were identified in the first Mancos sandstone at locality 4; these were a *Baculites* sp. indet. and an *Inoceramus* (s.l.) fragment cf. *I. proximus* Toumey (W. A. Cobban, written commun., 1978-79).

Burrows and trails in the First Mancos sandstone include *Asterosoma* form *Cylindrichnus, Ophiomorpha, Planolites, Chondrites*?, *Gyrochorte, Thalassinoides*, and *Scolithus*?. The tops of beds are commonly bioturbated.

Paleocurrents at locality 4 (fig. 11) were essentially unimodal (unidirectional) longshore at 228° parallel to the elongation of the sand body. Some readings indicate a 180° reversal of current, and others (obtained from trough axes) indicate a secondary southerly flow, at a slight angle to the trend of the main current.

The First Mancos sandstone (fig. 5) represents deposition of a shallow offshore marine ridge. *Asterosoma*, a vertical, upward-flaring burrow, and *Gyrochorte*, a snail trail, at locality 4 indicate conditions similar to those in the offshore to lower shoreface environments represented in Upper Cretaceous beds in the Book Cliffs in Utah (Howard, 1972). The presence of predominately suspension feeders in limited numbers such as *Ophiomorpha, Thalassinoides, Asterosoma*, and *Scolithus* in the sandstone suggests that organic detritus was low and energy was relatively high (Howard, 1972).

The well-preserved bedforms in the First Mancos sandstone also indicate the predominance of physical processes over biologic activity. Unidirectionally oriented tabular planar crossbedding (in sets as thick as 14 cm) and upward coarsening indicate accretion of the sand ridge by sand-wave migration. Sand waves migrated toward the southwest, or longshore; minor 180° reversals to the northeast suggest reversing current flow. Trough

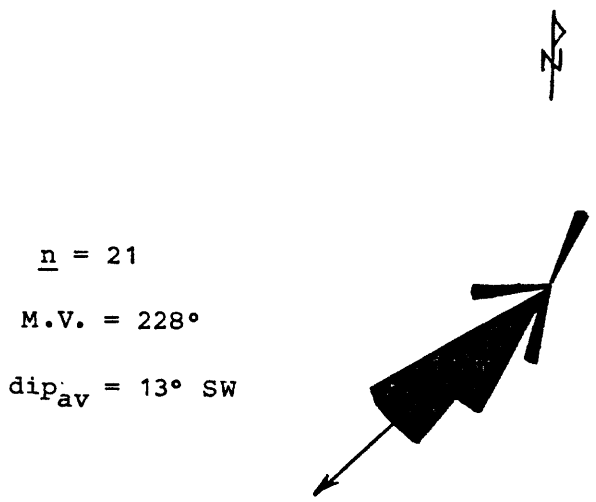


Figure 11. Paleoccurrent rose diagram of facies B, shallow marine bar at Duffy Mountain (loc. 4), showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip_{av}). n, number of readings.

crossbedding which trends obliquely to tabular sets, indicates that dunes formed during periods of increased mean flow velocities (Harms and others, 1975). Rounded claystone pebbles on some bedding surfaces are evidence that reworking and redeposition of shelf muds occurred periodically, probably as a result of severe storms.

Processes that deposited the First Mancos sandstone of Konishi (1959a) may have been similar to those forming modern linear sand ridges (Duane and others, 1972) on the Atlantic shelf off the East Coast of the U.S., or in the North Sea off Holland (Houboult, 1968; McCave, 1971). Modern linear sand ridges extend for tens of kilometers diagonally across the shelf and are spaced at intervals of about 3 km; deposition of the ridges can result from either storms or tides (Walker, 1979). According to Walker (1979), storm-controlled sand ridges *should* be expected to exhibit medium-scale dune bedforms. Bedforms of tide-controlled ridges are incompletely known, but those in the tide-dominated North Sea consist of "megaripples" (terminology of McCave, 1971) with "sand waves" on their backs; elongation of the North Sea ridges parallels the tidal current direction (Houboult, 1968). The "megaripples" are up to 1.5 m high and "sand waves" are up to about 7 m high (McCave, 1971).

Even though the largest sets of crossbeds ("sand waves" in this report) in the First Mancos sandstone are only about 14 cm thick, the morphology of the unit closely resembles that of the North Sea sand ridges. Reversing (tidal) currents apparently were weak during deposition of the First Mancos sandstone, but reversing rectilinear tidal currents in modern seas commonly have a single dominant flow direction which causes asymmetry of bedforms (Stride, 1963; Belderson and Stride, 1966, *in* Johnson, 1977). When the dominant tidal current is reinforced by wind-drift or storm surge currents, this asymmetry increases (Johnson and Stride, 1969; Swift, 1974, *in* Johnson, 1977).

Occasional storm-related features such as dunes and rounded claystone pebbles indicate that the morphology of ridges was probably modified by occasional storms.

Unnamed sandstone containing *Baculites asperiformis*--The unnamed sandstone containing *B. asperiformis* was found only at locality 2 where it is 10.4 m thick. This sandstone apparently is not continuous with others in the region (Michael Brownfield, oral commun., 1978), but it is of the same age as the Castlegate Sandstone of Utah.

The unnamed sandstone is pale greenish yellow, dominately fine grained and thick bedded. Grains are well rounded, and sorting is moderate to good. Bedding consists of very large scale (>6.0 m) gently dipping foresets and trough crossbedded units. The upper contact is sharp and appears to "truncate" gently dipping foresets in a seaward direction (southeast): the basal contact appears somewhat gradational, although exposure is poor. Trace fossils in the unnamed sandstone include *Ophiomorpha* and *Thalassinoides* near the top, and *Siphonites* and *Chondrites*? near the base.

Paleocurrents flowed southwest (longshore), but some flowed to the east and west (fig. 12).

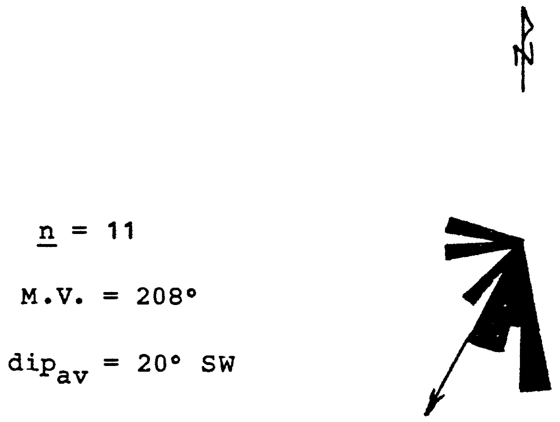


Figure 12. Paleoccurrent rose diagram of facies B, shallow marine bar, at Deception Creek (loc. 2), showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip_{av}). $\underline{n}$, number of readings.

The unnamed sandstone containing *B. asperiformis* is interpreted as the seaward slope of a submarine bar. The well-rounded, well-sorted fine grains suggest high-energy conditions and efficient winnowing of clay-sized material. The large-scale bedforms resemble those in the zone of shoaling waves. Low-angle foreset beds in modern sediments, for example in Kouchibouguac Bay, New Brunswick, Canada (Davidson-Arnott and Greenwood, 1976), are deposited in relatively shallow water at medium to high current velocities. Apparent truncation of the upper surface of the gently dipping foresets in the unnamed sandstone reflects either a seaward decrease in the rate of sediment transport in deeper water (Davidson-Arnott and Greenwood, 1976, p. 154), or submarine erosion of the bar due to rising sea level.

Ophiomorpha and *Thalassinoides* at the top indicate that the bar probably was not subaerially exposed, but that the top of the bar was in the low intertidal zone. *Chondrites*? and *Siphonites* in moderate numbers near the base indicate slow sedimentation (Sellwood, *in* Crimes and Harper, 1970).

Iles Formation

The Iles Formation consists of eight facies, designated C to K. Basic characteristics of each facies are summarized in table 1 (App.). Sandstones of facies C, D, and E are believed to be marginal marine deposits; facies F, G, H, J, and K represent brackish and nonmarine deposits.

Facies C

This facies is represented by a lenticular sandstone, the I-1, that is present only between localities 2 and 10. The I-1 sandstone has a maximum thickness of 17.1 m at locality 3; it disappears both to the east and west and is thin to absent locally along the length of the outcrop. At locality 10, the I-1 sandstone has been replaced by highly burrowed siltsone and interbedded olive-gray mudstone of the Mancos Shale; at locality 1, it is entirely missing owing to non-deposition.

Sandstone in the I-1 is yellowish gray but weathers to light gray at the top in areas where coal or carbonaceous shale overlie the unit. Grain size ranges from very fine at the base to fine grained at the top; grains are subangular at the base to well rounded at the top. The I-1 contains a diverse assemblage of rock fragments that constitute as much as 36 percent of the sandstone. The unit is classified as a litharenite on the system of Folk (1974). Dolomite cement occurs abundantly in the basal part of the sandstone but is virtually absent in the upper part.

The I-1 includes very large-scale (>6.0 m), low-angle dipping foresets and tabular and wedge planar crossbeds in the upper part, and low-angle to horizontal bedding and small- to medium-scale trough crossbeds in the lower part. The basal and upper contacts of the I-1 sandstone are sharp. Fossil bivalve shell detritus (oysters and inoceramids) is found at several horizons within the sandstone. At locality 2, oyster-filled channel-type depressions occur at the top of the sandstone (fig. 13), and pockets filled with rafted coal and woody plant debris occur within the sandstone. Structures of *Ophiomorpha* are numerous in the basal three-fourths of the sandstone at localities 3 and 4, but are rare to absent in the upper one-fourth where vertical root traces occur (fig. 14). In a seaward direction, *Ophiomorpha* and *Thalassinoides* are gradually replaced by *Planolites* and indeterminate bioturbation structures.

Figure 13. Oyster-filled channels at top of I-1 sandstone (facies C) at Deception Creek (loc. 2) in secs. 22, 23, 26, and 27, T. 5 N., R. 95 W. Basal contact of channel with underlying sandstone is indicated by person's finger.

Figure 14. Root zone at top of I-1 sandstone (facies C) at Duffy Mountain (loc. 4) in sec. 25, T. 5 N., R. 93 W.

Inoceramus convexus was found earlier by Konishi (1959b) in the I-1 sandstone at locality 3; *Crassostrea* sp. aff. *C. subtrigonalis* (Evans and Shumard) and rare borings of the sponge *Clione* in shells were identified from the I-1 at locality 2 (E. G. Kauffman, written commun., 1979). Pollen and spores from a carbonaceous shale at the top of the I-1 sandstone at locality 4, were identified as *Laevigatosporites, Cyathidites, Alnipollenites, Betulaepollenites, Proteacidites,* and *Ephedrapites* (F. E. May, written commun., 1977).

The I-1 sandstone overlies rocks of marine facies A and B of the Mancos Shale and is overlain by either a thin sequence of continental beds (locs. 3 and 4) or rocks of facies A (locs. 2 and 5-10). The facies A deposits overlying the I-1 sandstone at locality 2 consist of highly bioturbated mudstones and sandstones (fig. 15) with fragmental shell debris (mainly oysters). The I-1 sandstone gradually changes to facies A mudstone both to the east and west.

Transport directions at locality 4 (fig. 16b) show a bimodal pattern, to the west-northwest and east-southeast; patterns at locality 3 appear from limited data (4 readings), to be bimodal north-northeast to south-southwest (fig. 16a). Mean variants indicate that current flow was opposed in each of these localities.

The I-1 sandstone is interpreted as the deposit of a prograding destructional delta front facies. The maximum distance of progradation of this delta front environment did not exceed about 20 km (between locs. 2 and 4) as measured perpendicular to the depositional strike. The subaerial portion of the delta was located near locality 3 (Morgan Gulch) where maximum development of coal occurs above well-developed foreshore-shoreface environments. This shoreline apparently curved westward and southwestward towards the Deception Creek area (loc. 2) where it was fronted by a barrier island-lagoon complex (fig. 17).

Several subenvironments have been recognized in the I-1 sandstone, and these together comprise the destructional delta front facies. These include a strandplain beach foreshore-shoreface deposit (loc. 3), reworked distributary mouth bars (loc. 4), an interdistributary bay (between locs. 2 and 3), and a barrier island-lagoon complex (loc. 2). Reworked distributary mouth bars at locality 4 resemble delta front sheet sands (described in a later section), but differ in that they are laterally discontinuous and directly overlie offshore shelf muds. There basal contacts are sharp and probably erosional. They were deposited by ebb and flood currents in submarine channels slightly offshore from the main strandplain (beach foreshore) located adjacent to the river mouth. Sandstones further west with longshore drift components represent longshore bars or barriers located downdrift from the beach foreshore.

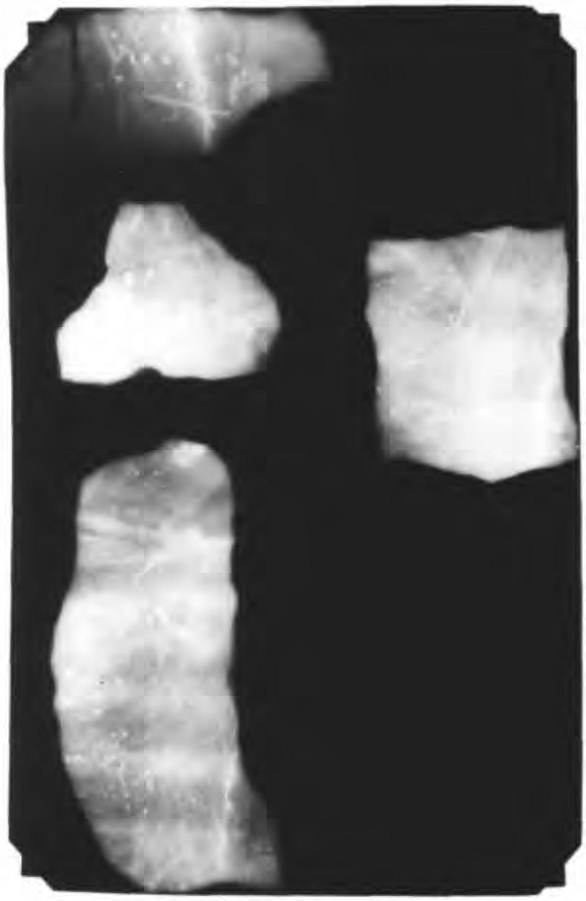
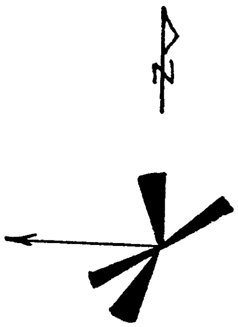


Figure 15. X-ray radiograph of unit 7 at Deception Creek (loc. 2, App.) in secs. 22, 23, 26, and 27, T. 5 N., R. 95 W., showing burrowing. Actual size.

A. $\underline{n}$ = 4

M.V. = 282°

dip_{av} = 11° SE



B. $\underline{n}$ = 16

M.V. = 96°

dip_{av} = 12° SE

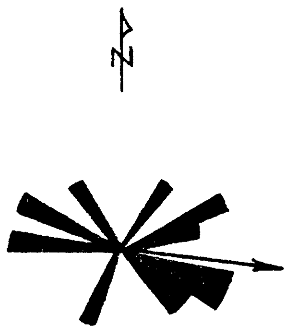


Figure 16. Paleoccurrent rose diagrams of facies C, barrier island, at (A) Morgan Gulch (loc. 3) and (B) Duffy Mountain (loc. 4), showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip_{av}). $\underline{n}$, number of readings.

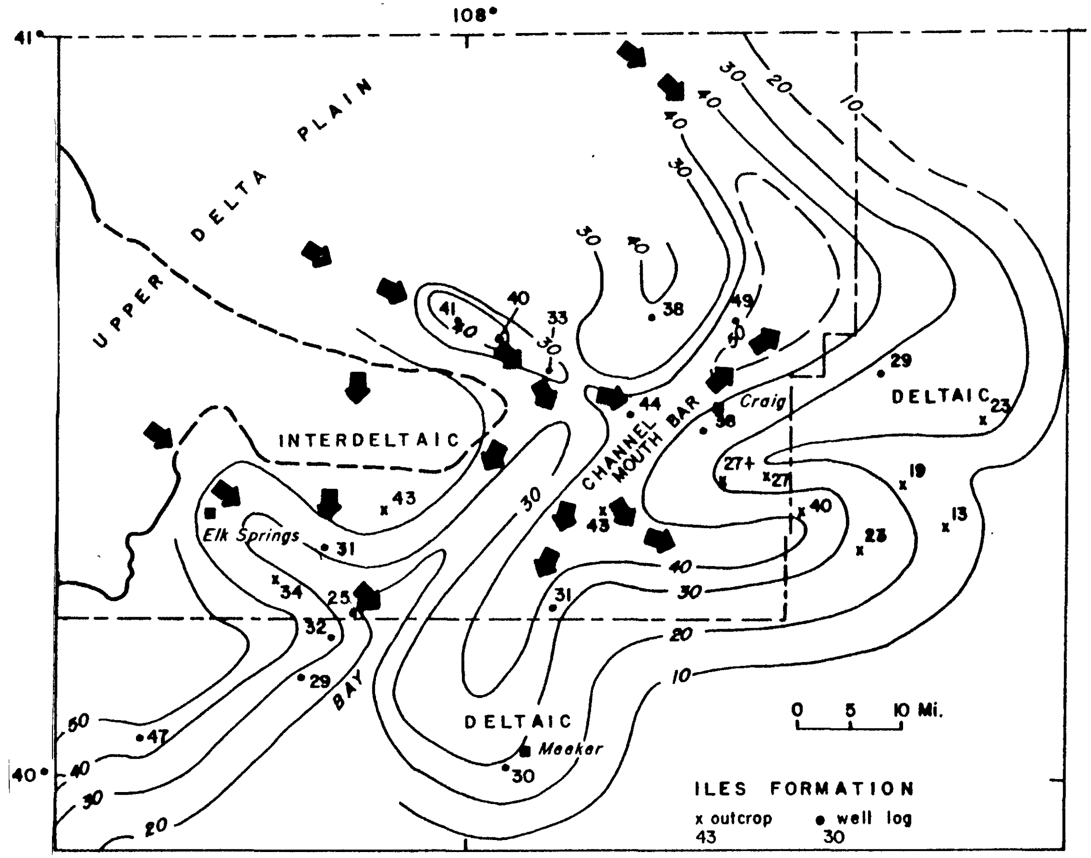


Figure 17. Percentage of sand in the Iles Formation, based on outcrop and subsurface sections. General paleogeographic interpretations shown. (Map follows method of LeRoy and LeRoy and others, 1977, p. 244-284).

Within the length of the outcrop along the north flank of the Axial Basin anticline, sandstones of the I-1 undergo a complete transition from reworked distributary mouth bars on the east to beach foreshore-shoreface at Morgan Gulch (loc. 3). At Deception Creek (loc. 2) on the south flank of the Axial Basin anticline the I-1 is represented by a true barrier bar. It is for this reason that in a landward direction at Deception Creek increasingly more brackish-water indicators are present; i.e., low-diversity, highly burrowed, oyster-bearing mudstones and sandstones overlying the I-1, whereas seaward these indicators are absent. The oysters, identified as *Crassostrea* that have been bored by the marine sponge, *Clione* (E. G. Kauffman, written commun., 1979) clearly indicate marginal bay or lagoonal invironments.

In summary, with the exception of Morgan Gulch, where a thick coal occurs, the top of the I-1 sandstone is capped either by only a very thin interval of carbonaceous shale, or by burrowed sandstone. There is only rare indication of any channeling at the top of the sandstone. At localities 2 and 5-10 deposition of the I-1 occurred in a shoreface zone (as indicated by burrowed sandstone at the top); at localitie 3, however, approximately the uppermost 5 m of the sandstone was subaerially exposed. Offshore shales with storm-deposited sandstones overlie the unit at localities 4-9; at loc. 3 continental beds are present above the sandstone, and at locality 2 lagoonal shales overlie the unit.

The upper part of the I-1 sandstone at locality 3 consists of well-rounded grains of well-sorted sandstone apparently deposited in the high-energy environment of a beach foreshore. The foreshore is defined as that part of a beach between the crest (or beach berm) and the low tide mark (Thompson, 1937) (fig. 9). Very long (>6 m) seaward-dipping low-angle foreset bedding in the upper part of the I-1 sandstone results from wave swash in the foreshore zone (Thompson, 1937; Hunter and others, 1972). Upper foreshore deposits in the I-1 are recognized by the absence of *Ophiomorpha* and the presence of root structures. Pollen identified in a carbonaceous shale sample at the top of the I-1 at locality 4 includes a mixture of several populations from various climatic zones--high, moist mountains; moist, humid woodlands; and arid climates (F. E. May, oral commun., 1978). Climate in northwestern Colorado during deposition of the Iles Formation is thought to have been warm during part of the year when vegetation grew rapidly, and cool enough during other parts of the year for extensive formation of peat bogs (Collins, 1976).

Oyster-filled tidal inlet channels and rafted coal and woody debris in the upper I-1 sandstone at locality 2 indicate the part of the I-1 that was marginal to the bay and lagoonal environments.

Tabular and wedge planar sets below the top of the I-1 sandstone at Morgan Gulch resulted from migrating sand waves in the lower foreshore to upper shoreface zones. *Ophiomorpha* burrow systems are usually concentrated in this zone. Horizontal bedding and trough cross-bedding in the lower portion of the sandstone at the same locality suggest deposition by breaking waves and currents in a bar-and-trough system (Hunter and others, 1972, p. 6). Fossil debris and shelly layers in the sandstone represent thin deposits of single severe storms or hurricanes (Dickinson and others, 1972) or lags in bar-and-trough systems.

Direction of transport near the base of the I-1 at locality 3 (fig. 16A) is longshore, to the southwest. Bimodal east-to-west directed transport in the I-1 at locality 4 (fig. 16B), slightly offshore from the mainland beach, indicates tidal influence in submarine channels that were present in that area.

The barrier that produced the I-1 sandstone at Deception Creek probably resembled modern analogues along the Texas coastal plain between the Brazos River delta and the Rio Grande delta (Hunter and others, 1972; Dickinson and others, 1972). Barriers along the Texas coast are called spits (peninsulas) or islands depending upon whether they are attached to the shoreline or separated along trend by tidal inlets. Modern analogues of the remainder of sub-environments in the destructional delta front facies, with the exception of the beach foreshore-shoreface, are not well known at the present time. The beach foreshore-shoreface, in contrast, has been well documented by Thompson, 1937 and Clifton and others, 1971.

Facies D

Facies D in the area of study is represented by one sandstone bed, the Tow Creek Member (I-2) between localities 3 and 8 (fig. 2). The most obvious characteristic of the I-2 sandstone is that it varies greatly in thickness, sometimes within very short distances (10-20 m). The minimum thickness is about 10 m and the maximum about 34 m (fig. 18). At locality 9 the I-2 is absent either because it has changed facies to marine shales (facies A) or because it has been eroded away by a younger channel complex.

The I-2 sandstone is a yellowish-gray to light gray, very fine to fine grained sandstone with subangular to subrounded, moderately well sorted grains. The sandstone consists of quartz, chert, K-feldspar, and plagioclase, with minor biotite, muscovite, and heavy minerals. Quartz content is about 83 percent whereas in the I-1 sandstone it is only 56-60 percent.

Bedding of the I-2 varies from structureless in thicker parts to tabular, wedge planar and trough crossbedded in thinner parts. Samples from structureless sandstone, when X-rayed, show very low-angle foreset laminations, and burrows (fig. 19). Seaward-dipping foreset bedding is sometimes visible in the field in the upper few meters of the I-2. The base of thick structureless parts of the I-2 sandstone are characterized by broad shallow troughs (fig. 20), 0.3-0.6 m deep by about 1.8-2.4 m wide. Basal contacts of these troughs with underlying shale or siltstone are sharp and erosional. Internally these troughs contain pale greenish-gray mudstones with comminuted plant debris, burrowed siltstones, carbonaceous shale, and rounded claystone pebbles (fig. 20).

Ophiomorpha occurs in a distinct zone about 4-5 m above the base of thick structureless parts of the I-2, and in about the lower half of thinned sequences. Vertical root traces occur at the top of the I-2 sandstone. Fragments of *Inoceramus* and *Ostrea* occur at various horizons within the sandstone, but no specifically identifiable macroinvertebrates were found.

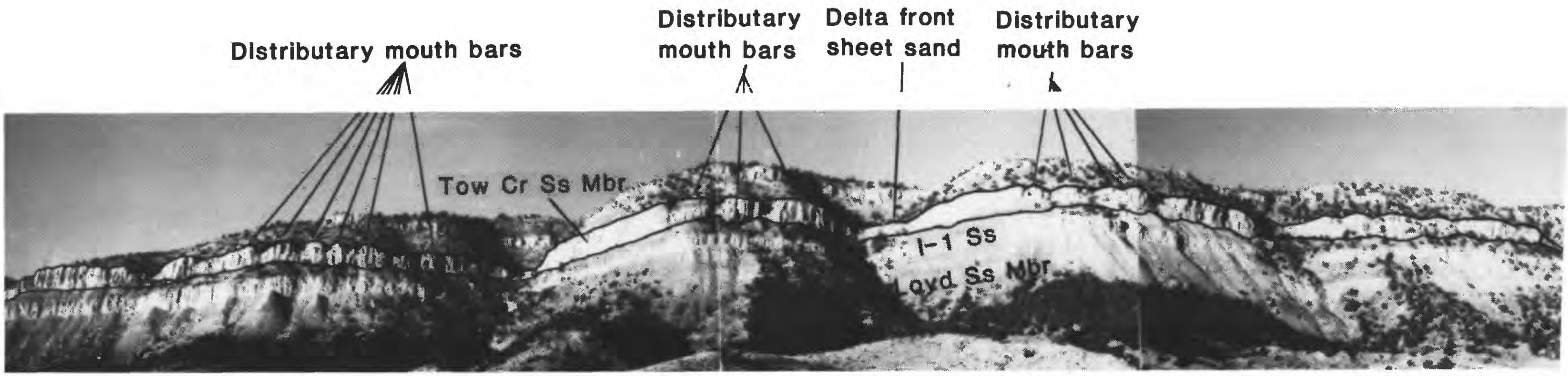


Figure 18. Panorama of south face of Iles Mountain in sec. 31, T. 5 N., R. 91 W., and secs. 35-36, T. 5 N., R. 92 W., showing, in ascending order, Loyd Sandstone Member, unnamed shale, I-1 sandstone and Tow Creek Sandstone Member (I-2). Depositional environments represented include a shallow marine sand sheet (Loyd Sandstone Member); barrier island (I-1 sandstone); and delta front sheet sands and mouth bars (Tow Creek Sandstone Member, I-2), sheet-like deposition. Note thickening and thinning along strike.

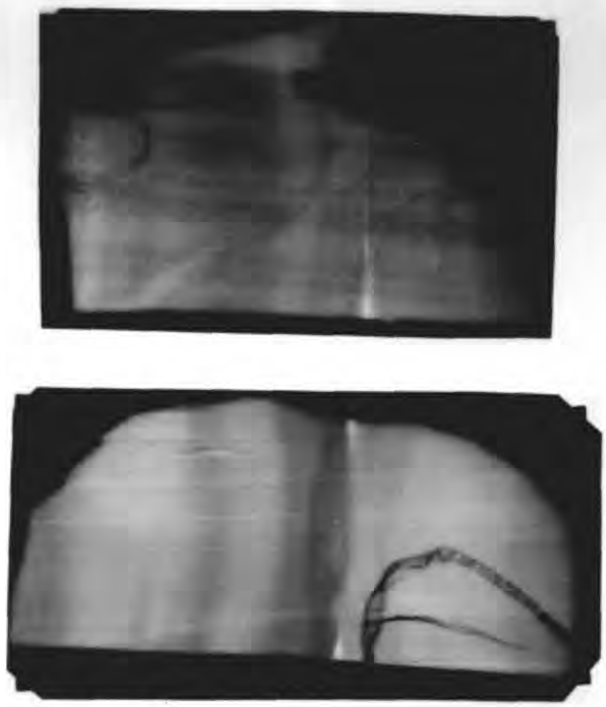


Figure 19. X-ray radiographs of proximal (upper photo) and distal (lower photo) distributary mouth bars in the I-2 (Tow Creek Sandstone Member) at locality 6 showing low-angle dipping parallel laminations and, in upper photo, an upward-curving burrow trace. Actual size.

Figure 20. Broad, medium-scale, symmetrically filled trough at base of the I-2 (Tow Creek Sandstone Member) at Duffy Mountain (loc. 4).

The I-2 sandstone overlies facies A, and is overlain by brackish and nonmarine sequences; laterally the unit changes to facies A seaward, and to continental (fluvial) sequences landward (fig. 2). Paleocurrent measurements indicate bipolar-bimodal flow to the northeast and southwest (longshore) at locality 4 where the unit exhibits tabular, wedge planar, and foreset bedding (fig. 21).

Facies D is interpreted as the constructional phase of a delta that built seaward into shallow water over organic-rich muds and thin interbedded sandstones (facies A) of the prodelta. Sheet sands are represented in the thinner parts of the I-2 sandstone, and distributary mouth bars in the thicker parts (fig. 18). Small channels preserved as troughs at the bases of the distributary mouth bars (fig. 20) may have been formed by seaward-flowing currents in front of the advancing delta. Their orientation perpendicular to the paleoshoreline indicates fluvial dominance over longshore drift.

Distributary mouth bars result from shoaling of riverborne sediment due to a decrease in velocity and carrying power of the stream as it leaves the confines of the river (Coleman and Gagliano, 1965, p. 145). Depending upon proximity to a distributary channel, a distributary mouth bar may be multidirectionally trough cross-laminated, wave and current rippled, or parallel laminated (Coleman and Gagliano, 1965). The dominance of gently seaward-dipping parallel laminae in the distributary mouth bars in the I-2 sandstone suggest that the sediment was affected more by wave action rather than by currents. Yet the excellent preservation of the mouth bars (fig. 18) indicates a river-dominated delta system.

Ophiomorpha in a zone about 4-5 m above the base of thick structureless distributary mouth bars in the I-2 sandstone may indicate the approximate position of mean sea level during deposition of the bar (Weimer and Hoyt, 1964). Build-up of sand above the zone where the *Ophiomorpha* occur locally reaches as much as 27 m, a thickness that is much greater than the apparent shallow depth of the water into which the mouth bar was building. It follows that the sediment above the level of the *Ophiomorpha* zone must have been river-derived, since additional material supplied from the sea can only build up to the zone of shoaling waves which is slightly above the *Ophiomorpha* zone. The large amount of sediment above the *Ophiomorpha* accumulated as the distributary mouth bar prograded seaward. After channels became filled with sediment and subsidence began, the uppermost 4-5 m of the mouth bar was reworked by waves and currents into a normal foreshore zone. This would account for the low-angle foreset bedding, leached zones and root structures at the tops of mouth bars in the I-2 sandstone.

Delta front sheet sands result from reworking of distributary mouth bars by wave and longshore currents, hence sedimentary structures reflect normal marine wave and tidal action, similar to that along beaches. The ancient sheet sands in the I-2 are differentiated from destructional delta front facies (facies C) or normal beaches (facies E) primarily by their lateral continuity with thick distributary mouth bars.

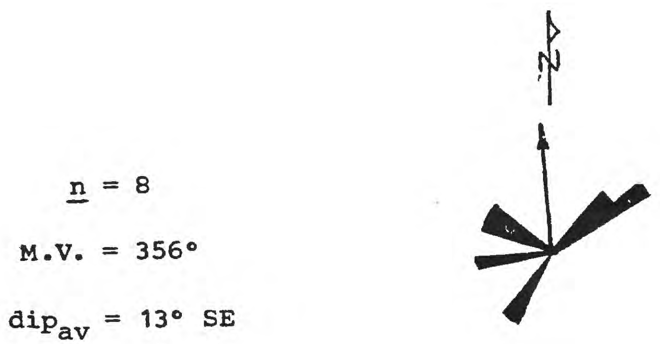


Figure 21. Paleoccurrent rose diagram of facies D, delta front sheet sands and mouth bars at Duffy Mountain (loc. 4), showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip$_{av}$). n, number of readings.

Facies E

Sheet sandstones with gradational bases occur in the extreme eastern and western parts of the study area, and at several stratigraphic positions within the Iles Formation. In eastern localities, facies E sandstones are designated I-3 to I-7; in the west at locality 1, facies E comprises only the basal unit of the undivided Mesaverde Group and is unnamed. Facies E sandstones range in thickness from about 3 m up to 13.1 m.

Sandstones of facies E weather yellowish gray to light gray. They are very fine to fine grained (coarsening upward) quartzose sandstones. Grains are subrounded to rounded and very well sorted.

Bedding consists of horizontal or low-angle foreset laminations throughout except for medium-scale (0.3-6.0 m) trough crossbedding in a thin zone at, or somewhat above, the middle of the unit. In general, numerous *Ophiomorpha* occur below this trough crossbedded zone and only rarely above it. The basal 1.5-3.0 m of the unit, which is gradational into underlying mudstones, consists of sandstone, containing *Ophiomorpha*, and thin intercalations of mudstone. Many *Ophiomorpha* have long branches which parallel bedding surfaces. Vertical root traces are common in the top of facies E sandstones.

Facies E overlies olive-gray mudstone (facies A) and is overlain by continental beds or by coal. Seaward, the sandstone changes to olive-gray mudstone (facies A), and landward, to continental sequences. Where the sandstones pinchout into continental sequences, they are characterized by thinning (3-7 m) and poor sorting, and they contain many marine fossils. Bedding in the poorly sorted sandstones is either not well developed or absent due to bioturbation. Where bedding is visible, however, it consists of horizontal or low-angle cross laminae. Some poorly sorted sandstones are capped by 0.4-0.6 m of shell debris and oxidation and weathering is apparent (fig. 22). A collection of macroinvertebrates from one of these erosional surfaces yielded the following faunal assemblage (E. G. Kauffman, written commun., 1979):

Locality 10, POVERTY GULCH, sec. 19, T. 5 N., R. 90 W.

Unit 21
Bivalvia:
Crassostrea fragments
cf. *Dosiniopsis* sp.
Granocardium sp.
Inoceramus fragments
inoceramid cf. *Endocostea typica* (Whitfield)
cf. *Phelopteria* sp.
Pseudoptera subtortuosa (Meek and Hayden)
Thracia n. sp. (large form)
Turritella sp.
naticid gastropod
fish scales

Figure 22. Shell lag deposit and oxidized and weathered zones at erosional surface at top of I-5 sandstone at Poverty Gulch (sec. 19, T. 5 N., R. 90 W.).

"Inoceramus" (Endocostea?) barabini (Morton) (E. G. Kauffman, written commun., 1979) was found in interbedded sandstones and shales (unit 20, loc. 10) beneath this sandstone.

Poorly sorted facies E sandstones directly overlie continental facies, and are overlain by either lagoonal mudstones or by continental beds.

Facies E sandstones are interpreted as normal beach foreshore and shoreface deposits which developed in interdeltaic areas. The beach foreshore zone is represented in the upper one-fourth to one-half of the unit; the shoreface is represented by the lower half to three-fourths of the unit.

The upper foreshore deposits in the upper part of facies E consist of horizontal to gently seaward-dipping laminations that developed from swash and backwash of waves (Thompson, 1937). These deposits are the same as those of the inner planar facies of Clifton and others (1971, fig. 7). The trough crossbedded sandstones underlying the upper foreshore deposits represent the "plunge zone at the foot of the beach" (Howard, 1972, p. 223), which corresponds to the inner rough facies of Clifton and others (1971). The inner rough facies on a gently sloping beach is characterized by troughs separated by broad flat ridges (Clifton and others, 1971). Alternatively, trough crossbedded sandstones in facies E may correspond to the deposits in the swash-trough transition (Hunter and others, 1979, fig. 12) which result from longshore currents and waves in a barred nearshore zone.

The shoreface beds of facies E sandstones are characterized by horizontal laminae. These deposits correspond to the outer planar facies of Clifton and others (1971, p. 114). A lunate megaripple facies that Clifton and others (1971) recognized at the base of the shoreface is, however, unrecognizable in facies E sandstones, suggesting that waves were small and of short period, sand grain size was too fine for development of lunate megaripples (Clifton, 1976), and (or) that bedforms have been destroyed by burrowing infauna.

Ophiomorpha structures in the surf zone of facies E have a predominant vertical component and are lined with pellets, indicating relatively high energy conditions.

The landward terminus of the normal beach deposits, consisting of thin poorly sorted fossiliferous sandstone, is interpreted as the transgressive deposition of sand directly onto underlying continental beds as sea level rose. Shell hash and oxidation and weathering at the tops of the sandstones indicates alternate periods of submergence and emergence as sea level oscillated back and forth. Fossils identified from one of these sandstones indicate a mixed (brackish) environment suggesting deposition within an interdistributary bay between active distributaries. For this reason Chandeleur island-type beach build-ups are postulated for the facies E sandstones. The vertical stacking of several facies E sandstones suggests that subsidence of the underlying delta did not occur at a constant rate, but rather was intermittent. This is further substantiated by sea levels that apparently fluctuated within a single cycle.

Facies F

Interbedded carbonaceous shale, medium- and light-gray mudstones, and coal make up facies F in the main body of the Iles Formation. The basal Iles consists of about 75 percent organic-rich fine sediments and 25 percent sandstone, whereas the upper Iles is composed of mudstone and sandstone in about equal proportions.

Coal beds are up to 1.5 m thick and laterally persistent in the lower 140± m of the Iles but are thin and discontinuous in the upper part of the Iles. Carbonaceous shales are moderate brown to dark yellowish-orange on weathered surfaces and are fissile owing to a high content of alined plant fragments. Medium and light-gray mudstones are silty and contain coalified plant fragments. Few fossils are found in these rocks, but in places they contain plant impressions, possibly *Charophyte* vegetative parts (R. Forester, written commun., 1978) and *Crassostrea*.

Facies F deposits overlie marginal marine sandstones and are overlain to the east by marine shale of the Mancos and to the west by continental beds of the Williams Fork Formation. Facies F beds interfinger with fluvial, brackish, and marine beds in the Iles Formation.

Carbonaceous shales, medium- and light-gray mudstones, and coals apparently accumulated in swamps and marshes between distributary and fluvial channels.

Carbonaceous shales containing aligned plant fragments accumulated where vegetation was mostly non-woody -- probably in marshes where grass progenitors and reeds grew. In modern coastal areas, marshes form in the lower delta plain where clay-sized material brought in by distributaries, wind, or tidal currents gradually builds up above the level of the water table and plant growth becomes established (Kolb and Van Lopik, 1966). Marshes were generally saline to brackish, but may be bordered by a band of fresh-water marsh at the transition to the swamplands. A fresh-water marsh is distinguished from a swamp by an absence of trees.

Medium- and light-gray mudstones in the Iles, containing coalified debris, suggest swampy areas where trees grew. Swamps formed in the same way as marshes but normally occurred landward from the mean high tide line, whereas the marshes are seaward of this line in brackish and saline waters. The possibility of intermixing of swamp and marsh is also possible, however.

Swamps in the modern Atchefalaya Basin in Louisiana occur in basin areas between river channels where reducing conditions predominate. They are characterized by highly organic black clays with thin laminations of silt and syngenetic iron inclusions such as pyrite, vivianite, and siderite (Coleman, 1966).

The thick coals in the lower part of the Iles represent the area of maximum accumulation of peat in the lower delta plain. These coal beds are the lateral equivalents of the I-3 sandstone, a normal beach facies, farther east (fig. 2), and both together mark the final abandonment of the delta in the lower Iles. The area of maximum accumulation of peat in modern deltas is in the transitional zone between brackish- and fresh-water marsh or swamp (depending upon the vegetative cover), where organic matter content may reach as high as 80-90 percent. Probable *Charophyte* vegetative parts of fresh-water algae were found in dark-gray mudstone above the thick coal beds in the Iles at locality 4. This dark-gray mudstone probably was deposited in a fresh-water environment. Coal beds above the top of the *Charophyte*-bearing bed are thin and discontinuous, which is typical of modern fresh-water swamp environments.

Facies G

Facies G in the lower part of the Iles is composed of lenticular sandstones with sharp scour bases. Lag deposits of comminuted plant material and logs occur in the lower portions of the sandstones above the sharp lower contacts. These sandstones vary in thickness from about 9 m to about 30 m. They are yellowish gray to light gray on outcrop and consist of fining-upward sequences of very fine- to medium-grained sandstone. Grains are subrounded to rounded and moderately well sorted. Quartz, chert, and rock fragments are the major detrital grains; K-feldspar is present as a minor component. Matrix in facies G consists of compressed rock fragments and authigenic clays as pore filling; cement is quartz, as overgrowths, and authigenic clay (J. Webb, written commun., 1979).

Bedding in facies G consists entirely of trough crossbeds with local rippled or climbing ripple bedding. Medium-scale (0.3-6 m) and large-scale (>6 m) troughs occur where the sandstone is very thick (30 m), and small- (<0.3 m) to medium-scale asymmetrically filled troughs occur where facies G is comparatively thin (fig. 23). The basal part of the sandstone is commonly convoluted, and claystone pebbles and clay drapes occur along bedding planes. *Teredolithus* Bartsch (Moore, 1969), the borings made by marine bivalves in wood (e.g., modern "shipworm" borings; fig. 24), occur in fossil wood fragments near the base of the sandstones. Local masses of structureless, probably bioturbated, siltstone and claystone occur in the lower half of the sandstones.

At localities 1-4, facies G is overlain by about 3 to 4.5 m of interbedded carbonaceous shale, silty sandstone, and thin coals capped by a 1- to 2-m bed of mottled gray and dark-yellowish-orange, very fine grained, silty sandstone. The silty sandstone bed is characterized by iron staining, wavy or contorted bedding or ripple laminae, and coaly plant material.

Facies G sandstones are underlain and overlain by facies F carbonaceous shales, gray mudstones, and coals. Locally they grade laterally into thin tabular sandstones with ripple laminae. Locally facies G rocks are interbedded with facies A mudstones and sandstones of the upper Mancos shale, where facies G has eroded older strata (fig. 2).

Transport directions obtained from several facies G sandstones (fig. 25) indicate unidirectional southeastward-flowing currents. Summation of all mean vectors of facies G yields a grand mean vector of 144° (S. 36° E.).

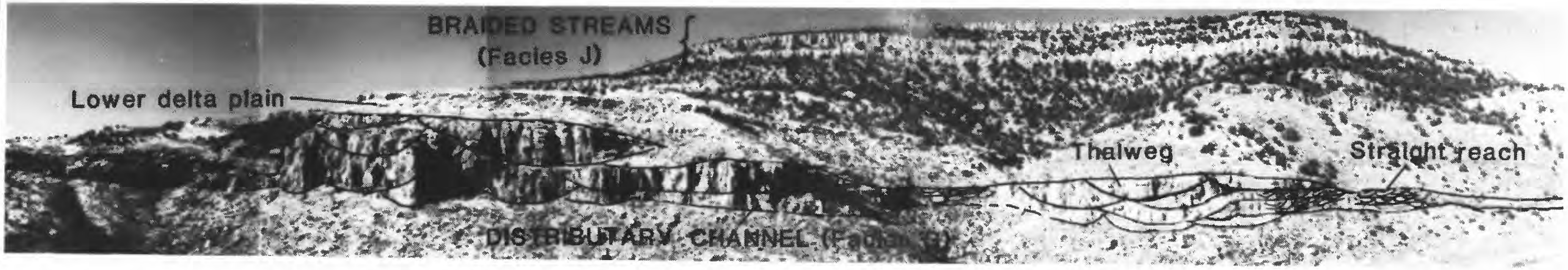


Figure 23. Panorama of Duffy Mountain looking northwest in Milk Creek Canyon (secs. 19 and 30, T. 5 N., R. 92 W.) showing details of bedding of facies G. Medium- to large-scale trough crossbedding characterize thalwegs; small- and medium-scale asymmetrically filled troughs characterize straight reaches.

Figure 24. Teredolithus-bored wood in facies G at Horse Gulch (loc. 9, unit 5, App.).

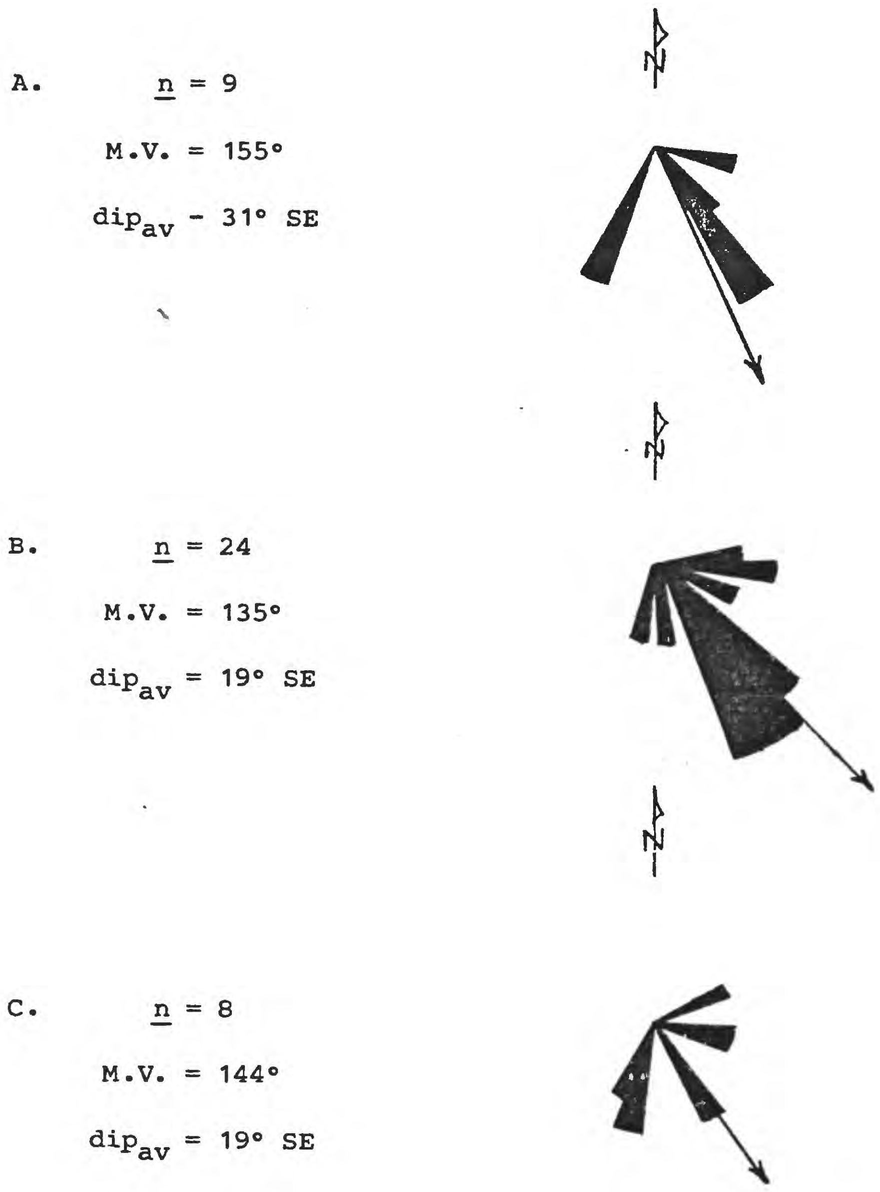


Figure 25. Paleocurrent rose diagrams of facies G, distributary channels, at (A) Deception Creek (loc. 2), (B) Duffy Mountain (loc. 4), and (C) near the Hamilton Store in NE 1/4 sec. 21, T. 5 N., R. 91 W., showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip_{av}). n, number of readings.

Facies G sandstones are interpreted as predominantly active channel fill in distributaries in the lower delta plain. Some distributaries were as deep as 30 m, and flanked by levees (locs. 1-4); others were smaller, radially branching channels. The presence of numerous branching distributaries is characteristic of a delta that built out into shallow water or "shoalwater" deltas such as the pre-modern deltas of the Mississippi River (Kolb and Van Lopik, 1966).

A distributary channel is defined by Coleman and Gagliano (1965) as a "natural flume which accommodates and directs a portion of the discharge and transported sediment from the parent stream." When a distributary channel begins to shoal and broaden at its mouth, it loses its identity as a channel, and a distributary mouth bar forms. At that point, currents move in varying directions (Coleman and Gagliano, 1965), and both bedload and suspended load are deposited. Distributary channels are initiated where seaward building channels split around mouth bars or by crevassing upstream (Kolb and Van Lopik, 1966). Two stages of development characterize the distributaries represented in the Iles: (1) active flow, represented by very fine to medium-grained, rounded, moderately well sorted sandstone, and (2) abandonment of the channel, represented by interbedded carbonaceous shale, silty sandstone and thin lenticular coal at the top of active channel fill. Abandonment of the channel results from avulsion upstream, and initiation of a new channel.

Active channel filling in distributaries of the Iles deposited sandstones with medium- and large-scale trough crossbeds in apparent deep portions (thalwegs) of the channels, and left small-and medium-scale assymmetrically filled trough crossbedding in sands of shallow reaches. Trough crossbeds indicate deposition by migrating dunes (Harms and others, 1975). Medium- and large-scale troughs in the thalweg in modern rivers represent elongate depressions within a dune field that were scoured by jets of water issuing from dune crests immediately upstream (Harms and Fahnestock, 1965). Small- and medium-scale asymmetrically filled troughs are similar to bedforms in straight reaches and represent point bar accretion in a sligthly sinuous, low-gradient channel. Lag deposits indicate rapid flow, probably while the river was in flood stage. Ripples and climbing ripples indicate decreased flow rates.

Deposits of carbonaceous shale, silty sandstone and coal accreted in still-standing water after channels were abandoned. Basal contacts of abandoned channel fill are sharp, indicating rapid abandonment of the channel.

Biogenic structures such as *Teredolithus* Bartsch and masses of probably bioturbated siltstone and claystone in the active channel fill may indicate mixing of marine and fresh water within the channel by tidal exchange. *Tereaolithus* Bartsch are structures that are similar to those made by marine clams which can tolerate a wide range of salinites (Siemers, 1976). Bioturbated masses of siltstone and claystone probably resulted from up-river migration of marine burrowing infauna in a saline wedge, such as commonly occurs in density-stratified estuaries.

Natural levees are believed to have bordered major distributaries at localities 1-4. Natural levees in the Iles, preserved as 1-2 m mottled silty sandstone at the top of abandoned channel fill, were well vegetated as indicated by intense root mottling and iron staining.

Where a distributary channel sandstone is found directly overlying and underlying facies A mudstones and sandstones, such as at localities 3 and 9 (fig. 2), it is interpreted as the ancient analogue of a bar-finger sand. The bar fingers at these two localities seem to coincide with the initiation of new delta cycles in the I-2 above. This fact suggests that wave and current action was not strong during the initial stages of delta progradation in the river dominated systems. This leads to the further conclusion that either sea level dropped at a rate that exceeded the rate of subsidence, or slopes became steeper due to tectonism in nearshore areas. Although it is difficult to determine the relative interaction of these two mechanisms, the former is favored because of the fact that the time of deposition of the I-2 coincided with the major Late Campanian fall in sea level that occurred in the Western Interior. Further discussion of this major sea level change will be offered in a later section dealing with "Sedimentary tectonics and eustatic fluctuations."

Facies H

Facies H consists of thin tabular sandstone and siltstone beds with sharp upper and lower contacts. These units occur in the lower part of the Iles in association with beds of facies F and G. Thickness of the facies H beds ranges from 0.3 m to 1.8 m and averages about 1 m.

Tabular sandstones and siltstones of facies H are light gray or dark yellowish-orange on outcrop. Grain size of the sandstones ranges from very fine to fine. The grain size in facies H decreases from sand-sized at localities 1-4 (landward) to dominantly silt-sized at localities 5-10 (seaward).

Facies H sandstones and siltstones are laminated to very thin bedded. The main bedding types are current ripples (fig. 26) or low-angle planar bedding. Claystone pebbles and clasts occur along bedding planes. Coalified plant material and plant impressions are common. Tops of beds are sometimes marked by vertical root traces.

Facies H sandstones and siltstones are underlain and overlain by carbonaceous shales, gray mudstones, or coal beds (facies F). They occur in positions lateral to facies G sandstones.

Thin tabular sandstones and siltstones with sharp upper and lower contacts are interpreted as crevasse splay deposits. Initial breakthrough of a crevasse splay results in a gradual increase in flow by successive flooding until a peak of maximum discharge and deposition is reached at which point flow wanes and crevassing becomes inactive (Coleman and Gagliano, 1964). Grain size increases from predominantly silt near the distal end to sand and silt proximal to the river channels where initial breakthrough occurs. Climbing ripples found at Duffy Mountain (unit 16, Appendix) commonly formed in systems with large amounts of suspended load and therefore imply an early stage in the formation of a crevasse splay. Clay rip-up clasts in the same beds probably came from erosion of the natural levee.

Figure 26. Facies H sandstone at locality 1 (unit 19, App.) secs. 20-21, T. 4 N., R. 98 W.

Current ripples or low-angle planar bedding in crevasse splays in the Iles indicate that currents alternated between low and high flow rates. When very fine to fine sand (>0.1 mm to about 1.0 mm) is subjected to increasing mean flow velocities in flume experiments, the sequence of bed forms produced is no movement to ripples to upper flat bed (Harms and others, 1975). Ripple bedding forms during non-flood periods, and low-angle planar bedding during flood periods. Convolute bedding indicates temporarily high flow rates. Vertical root traces at the tops of crevasse splays indicate plant growth was reestablished after abandonment of the crevasse.

Facies J

Tabular sandstones with sharp scoured basal contacts in the upper part of the Iles at locality 4 (fig. 1) constitute facies J. The facies J sandstone ranges in thickness from about 4 to 6 m, and extend laterally for distances of up to 1-2 kilometers. The sandstones are yellowish-gray to grayish-orange and fine upward. Grains are angular to rounded and poorly sorted. They consist chiefly of quartz, chert, and rock fragments with minor amounts of K-feldspar (5 percent), accessory mica and heavy minerals (1 percent). Carbonate detrital grains compose up to 12 percent of the rock. No cement is present, and matrix consisting of compressed rock fragments and solution welded interstitial material is present in only minor amounts (John Webb, written commun., 1978).

Bedding consists of thick sets of plane parallel laminae (fig. 27) and medium- and large-scale trough crossbeds with rippled upper surfaces (fig. 28). Rounded claystone pebbles, ironstone concretions, and comminuted plant fragments occur along bedding planes. Plant impressions are found on some bedding surfaces.

Figure 27. Thick planar laminated sandstone in facies J at Duffy Mountain (loc. 4).

Figure 28. Medium- and large-scale trough crossbedding, ripple bedding, and claystone lag pebbles in facies J at Duffy Mountain (loc. 4). Jacob staff is 1.5 m long.

Facies J sandstones are similar to facies G sandstones but differ in the following particulars:

FACIES J	FACIES G
angular to rounded grains poor sorting of grains	subrounded to rounded grains moderate to good sorting of grains
predominantly quartz, chert, rock fragments with 5% K-feldspar; low matrix	predominantly quartz, chert, and rock fragments with 1% K-feldspar; some matrix (authigenic clays)
units 4-6 m thick	units 6-30+ m thick
claystone lags	claystone lags +wood lags
almost 100% sandstone	sandstone and interbedded siltstone and claystone
interbedded with dominantly non-organic fine clastic sequences	interbedded with organic-rich fine clastic sequences

Facies J sandstones in the upper Iles represent the deposits of fluvial streams-possibly braided. Streams apparently covered broad areas in late Iles time. Tabular sandstones are underlain and overlain and lateral to dominantly non-organic fine clastic sequences. Channel widths of up to 2 km, were measured in the upper Iles at locality 4. Basal contacts of the tabular sandstones are erosional into underlying mudstones. Accumulations of rounded claystone pebbles or ironstone concretions on bedding surfaces within troughs in facies J (fig. 28) suggest that repetitive cycles of scour and fill occurred. Upper contacts are also sharp and ripple bedding is sometimes visible. The absence of siltstone or claystone within facies J sandstones implies large bedload and small amounts of suspended load as is to be expected in braided streams.

Bedding in facies J sandstones reflects deposition in streams that alternated between low and high flow regimes, as indicated by thick sets of upper flow regime plane parallel laminations (fig. 27), and trough crossbeds (fig. 28) with ripples. Bedforms in sandstones interpreted as fluvial stream deposits in the Iles resemble those in the Donjek River in the Yukon (Williams and Rust, 1969)despite the fact that grain size differs considerably, and parts of the Rio Grande in Texas (Harms and Fahnestock, 1965) where grain size is similar to that in the upper Iles. Thick plane parallel laminated bedding resembles that found in migratory sand bars with avalanche faces (facies D of Williams and Rust, 1969, p. 66, and 74) in the Donjek River. These types of sand bars cover broad areas in channels. Migratory sand bars in the Donjek River are characterized by rippled upper surfaces, downcurrent faces inclined at 10-30^{o}, and downstream scoured surfaces floored by "ellipsoidal" scours (Williams and Rust, 1969, p. 60, 66). Medium- and large-scale trough crossbeds in facies J sandstones in the Iles are analogous to elliptical scours downstream from migratory bar-avalanche faces in the Donjek River (Williams and Rust, 1969, p. 60-61).

Harms and Fahnestock (1965, p. 103) have described large bar forms in the Rio Grande near El Paso, Texas. Large-scale troughs represent erosional scours that are elongate parallel to stream flow. These may be either symmetrically or asymmetrically filled. Dimensions of trough crossbeds in facies J in the Iles are similar to those described in the Rio Grande River (Harms and Fahnestock, 1965, p. 104).

Facies K

A lenticular trough crossbedded sandstone near the base of the Iles Formation at locality 2 is designated facies K because of unique characteristics that set it apart from either a distributary channel (facies G) or braided stream environment (facies J).

The sandstone at locality 2 is 13.4 m thick and pinches out to the northeast and southwest. It is fine-grained, moderately well sorted, with subangular to rounded grains. Quartz and chert make up 81 percent of the sand, K-feldspar and rock fragments most of the remainder. Minor quantities of plagioclase, muscovite, tourmaline, and heavy minerals also occur. Quartz grains are tightly packed and rimmed with micaceous fragments; there is almost no matrix (John Webb, written commun., 1978).

Bedding in facies K consists of medium-scale (0.3-6.0 m) trough crossbeds. Rounded, locally large claystone pebbles and cobbles occur along bedding planes. The basal contact is sharp. Although marine shells and burrows are not obvious on outcrop, examination of a thin section of this sandstone confirms that burrowing infauna were present (John Webb, written commun., 1978). *Scolithus* and *Planolites* were identified in rippled silty sandstones adjacent to facies K.

Facies K overlies dark-gray and olive-gray mudstones and thin interbedded sandstones (facies A) that are intensely burrowed by low-diversity infauna. The sandstone is overlain by and is partly laterally bounded by interbedded rippled and burrowed silty sandstones (fig. 29), mudstones, carbonaceous shales, and thin coals (facies F).

Paleocurrent measurements indicate bimodal northeast to southwest flow; northeastward-directed flow was dominant (fig. 30).

Facies K is interpreted as a tidally influenced distributary channel, based on lateral and vertical facies relationships, bimodal-bipolar nature of crossbedding and trace fossils. The basal contact of the sandstone body is erosional on underlying mudstones and thin interbedded sandstones that have been thoroughly burrowed by infauna. These rocks are interpreted as lagoon-bayfill deposits, based on their relationship to other facies. Rippled silty sandstones and mudstones, carbonaceous shales, and coal seams overlying the sandstone represent sediments deposited in backshore areas.

Figure 29. Rippled silty sandstones and mudstones adjacent to facies K (below and to right out of picture) at Deception Creek loc. 2. Distributary channel sandstone above (note sharp contact).

$\underline{n} = 27$

M.V. = 143°

dip_{av} = 20° SE

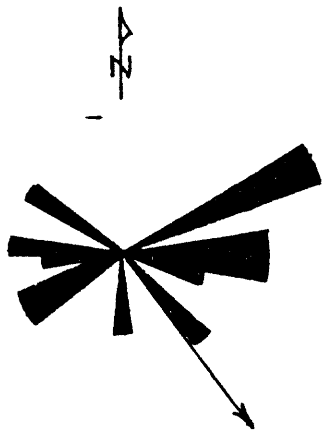


Figure 30. Paleocurrent rose diagram of facies K, tidal channel, at Deception Creek (loc. 2), showing dip directions of crossbedding (M.V., mean vector), and average dip of crossbeds (dip_{av}). $\underline{n}$, number of readings.

Bipolar trough cross-stratification in the sandstone resulted from tidal exchange within the channel. The bipolar trough crossbeds resemble those in a modern meandering estuary in Georgia (Land and Hoyt, 1966) in which trough (festoon) crossbedding represents migrating dunes with lee sides oriented landward or seaward depending upon ebb (seaward-flowing) or flood (landward-flowing) tidal currents. Paleocurrent readings (fig. 30) indicate that flood tidal flow was dominant in facies K.

Rippled silty sandstones and mudstones lateral to and overlying the channel reach a maxium thickness of 5 m. They apparently were deposited during flood and non-flood periods of the river as sediment was supplied to backshore areas. Ripples on sandy interbeds are sinusoidal (Jopling and Walker, 1968) reflecting low flow regimes and continuous addition of sediment containing high amounts of suspended load (fig. 29). Burrows of *Scolithus* and *Planolites* in a thin, 1.2-1.5 m zone of the rippled silty sandstone and mudstone suggest deposition in an intertidal to subtidal zone. *Scolithus* resemble traces made by a polychaete (worm) in the bottom of tidal channels (Dorjes, 1970). They are found in channel margin deposits adjacent to tidal flats in the Dakota Sandstone west of Denver (Chamberlain and Frey, 1976).

In summary, the K facies sandstone in the basal Iles at locality 2 has characteristics that suggest both fluvial and marine processes similar to those forming in sands in the meandering estuary in Georgia studied by Land and Hoyt (1966). Rounded claystone pebbles and cobbles and well-preserved bedding suggest a dominance of fluvial processes within the channel. Bimodal trough crossbedding within the channel is, however, indicative of tidal exchange. Burrows in rippled silty sandstones and mudstones adjoining the facies suggest periodic low current velocities and intertidal to shallow subtidal conditions in sediments deposited at the margins of the channel. It therefore seems reasonable to conclude that facies K was deposited as a tidal channel or tidally-influenced distributary channel under similar conditions as those in the modern fluvial-estuarine channel in Florida.

SUMMARY OF DEPOSITIONAL ENVIRONMENTS

Paleoenvironmental interpretations of the upper Mancos shale and Iles Formation in northwestern Colorado are summarized in following sections and presented in block diagrams in figures 31-33.

Mancos Shale.--Olive-gray mudstones and thinly interbedded sandstones (facies A) in the Mancos Shale were deposited in quiet-water offshore to lower shoreface environments (fig. 31). Thick sandstone beds (Loyd Sandstone Member, unnamed sandstone containing *B. asperiformis*, and First Mancos sandstone of Konishi (1959a)) underlain and overlain by facies A, were, however, deposited in several high-energy environments that were unlike the quiet-water environments of the surrounding mudstone.

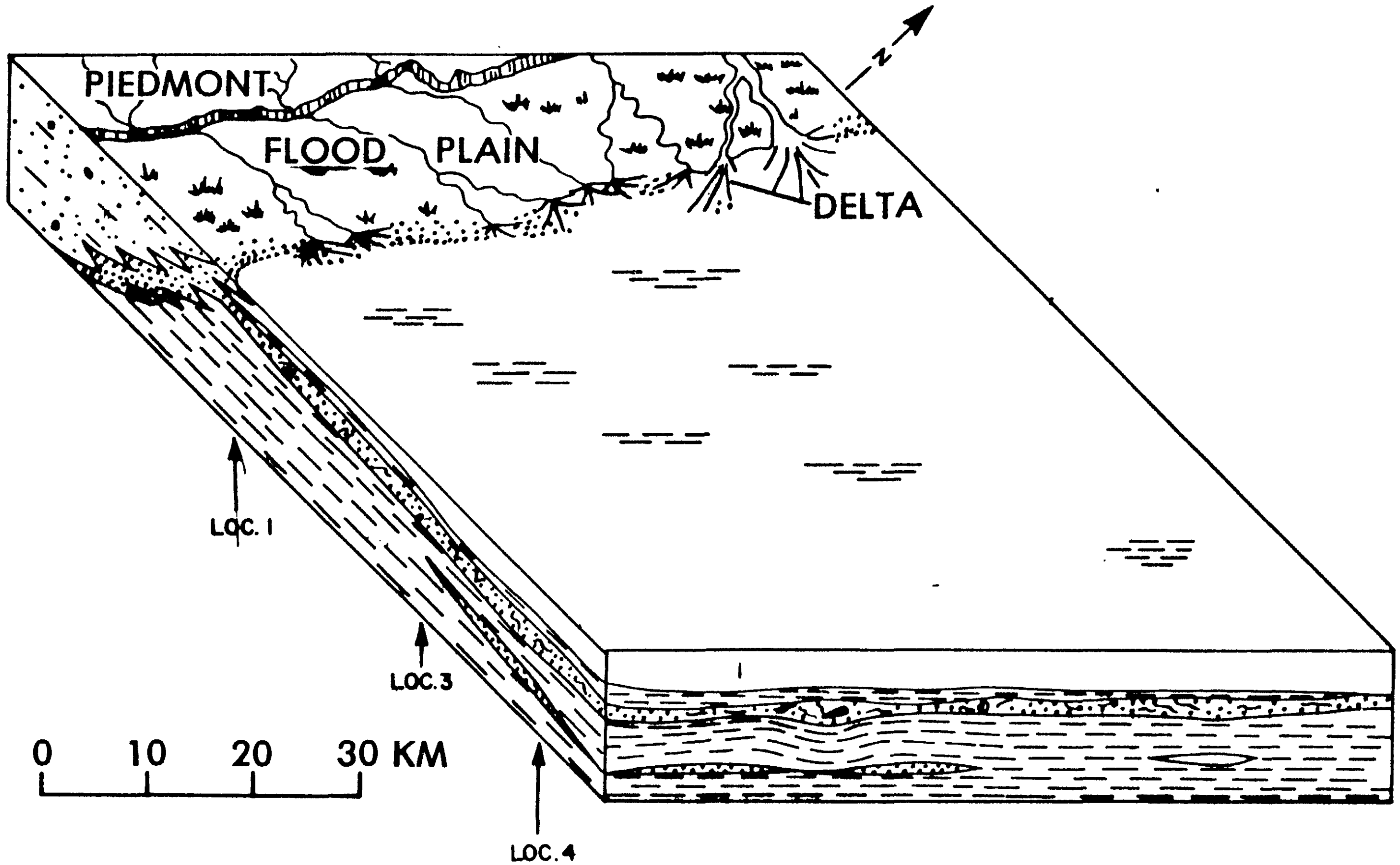


Figure 31. Diagram showing inundation of the area by a widespread marine transgression, and deposition of shallow marine bars offshore.

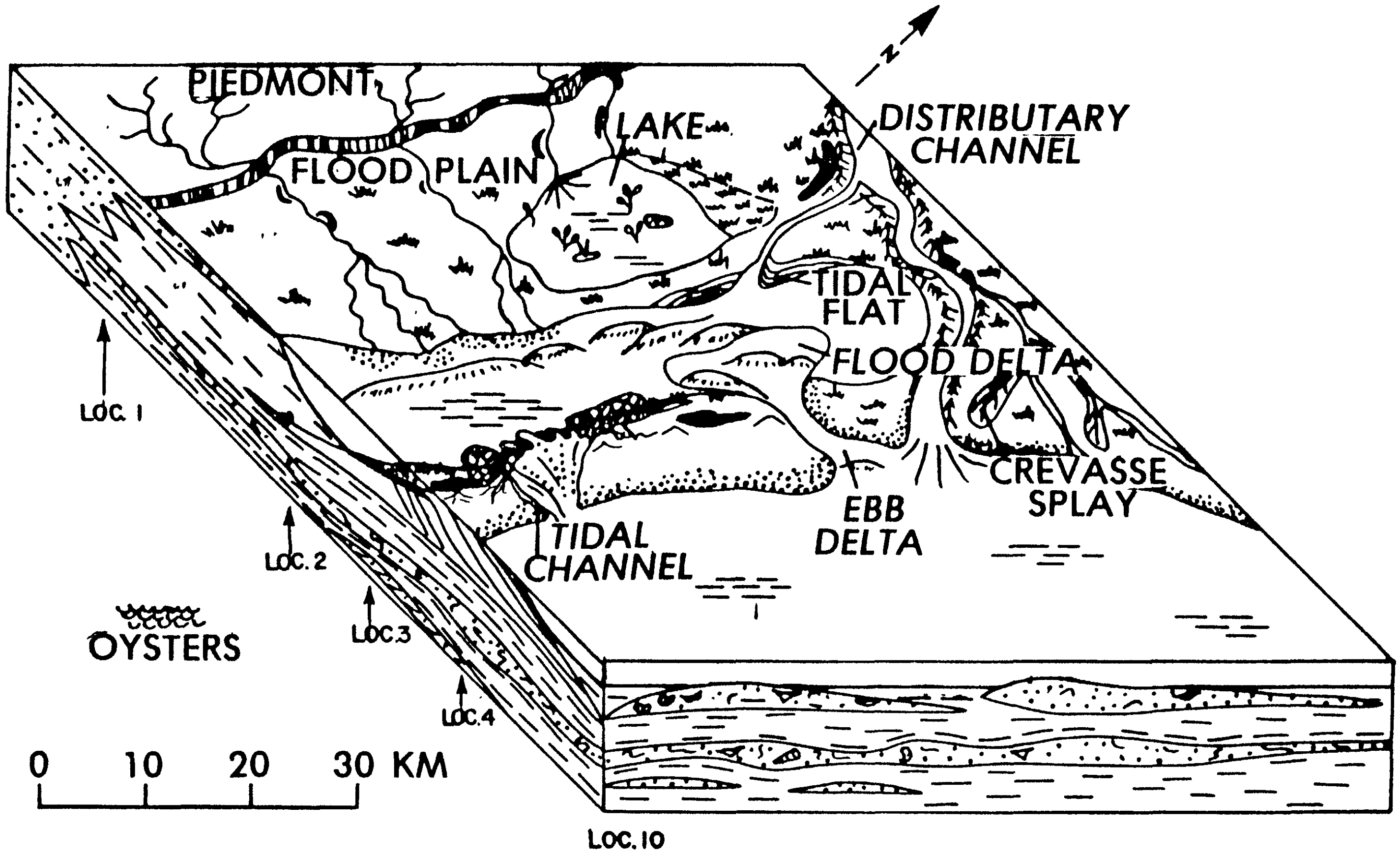


Figure 32. Diagram showing progradation of delta destructional facies into northwestern Colorado in earliest Mesaverde time.

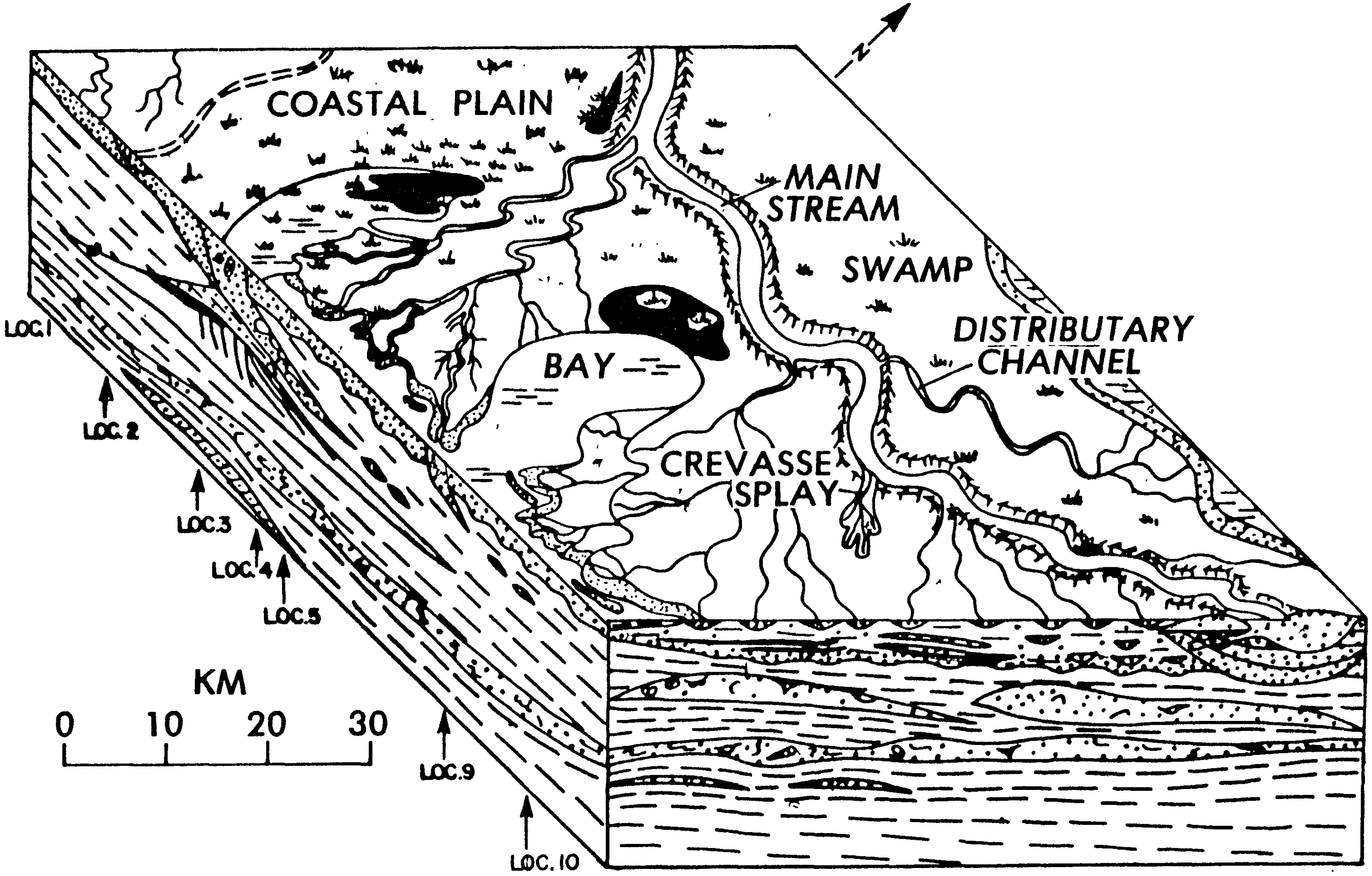


Figure 33. Diagram showing progradation of high-constructive delta into northwestern Colorado. Abandonment of delta lobes occurred as streams shifted to new sites.

The Loyd and the unnamed sandstone, deposited in normal nearshore marine environments with active waves and currents, represent ancient probably shoreface deposition of shallow marine sand bars or sheet sands that represent regressive phases preceding the main regression of the Mesaverde Group. Part of the original records of the regression may be missing, however, due to reworking and erosion in the shoreface zone (ravinement) as sea level rises during the subsequent transgression. The top of the unnamed sandstone, for example, appears to be beveled, a feature which may have resulted from either a seaward decrease in the rate of sediment supply to deep water, or submarine erosion during transgression.

The First Mancos sandstone of Konishi (1959a), in contrast, represents a shallow, probably shelf sand body that resembled linear sand ridges off the east coast of the United States or in the North Sea off Holland (Duane and others, 1972; Houboult, 1968; and McCave, 1971). These types of sand bodies result from reworking and redeposition of previously deposited material by tides and storms.

Iles Formation.--Interbedded sandstones, shales, and coals in the Iles Formation were deposited in marginal marine environments that were mainly of deltaic origin (beach, barrier, reworked distributary mouth bars, and mouth bars and sheet sands, and brackish to nonmarine environments (fluvial and deltaic coastal plain). Shorelines in the lower Iles in northwestern Colorado (fig. 32) resembled modern deltaic coastlines in the South Texas coastal plain. Reworked distributary mouth bars were present adjacent to beach and barrier island-bordered coastal plains. Barriers resembled Matagorda Peninsula or Padre Island (McGowan and others, 1977; Dickinson and others, 1972; and Hunter and others, 1972). Lagoons or bays were common behind the barriers, and distributary channels brought sediment into coastal areas. This early destructional delta phase was characterized by little or no development of lower delta plain sediments and minimal progradation. Later development of a constructional delta front environment is evidenced by distributary channels that were slightly sinuous and flanked by levees, or radially branching small straight channels with no levees. Much thicker lower delta plain sediment was deposited and back-beach areas were well vegetated, low, and poorly drained. Small shoal-water deltas (Fisk, 1955), building into shallow marine areas, formed high-constructive deltas (Fisher, 1969) characterized by sheet sands and mouth bars. Interpretation of high-constructive deltas in this area is based on several criteria: (1) over-all coarsening-upward sequence (Oomkens, 1967); (2) a predominance of fluvial or fluvially influenced facies; (3) pronounced coastal progradation; (4) thick delta plain sequences that are vertically distinct from thin destructive facies: (5) lobate (rounded) shape of delta lobes; and (6) low sand to mud ratio (fig. 17). Delta lobes were often constructed adjacent to and overlapping abandoned lobes, indicating shifting of distributaries to new depositional sites, local compaction and subsidence, and basin tectonics.

Normal beaches were deposited in the eastern (seaward) part of the area (fig. 33) above interdistributary bay muds; they were similar to the Chandeleur Island-type beaches (Fisher and others, 1969). The landward terminus of these small beach deposits lies directly on continental beds in the main body of the Iles.

SEDIMENTARY TECTONICS AND EUSTATIC FLUCTUATIONS

Table 3 interprets the depositional history of the Mancos Shale and Iles Formation in northwestern Colorado and infers cycles of local transgressions and regressions vs. regional transgressive-regressive patterns based on analysis of the local facies and correlations with other areas. A comparison of these cycles in northwestern Colorado with those in Montana and Wyoming (Gill and Cobban, 1973) suggests that most of the sea-level changes were eustatic in the Western Interior seaway as suggested earlier by Kauffman (1979), but that superimposed local transgressions and regressions also occurred which infer local tectonic controls. Global eustatic sea-level changes in the Late Cretaceous have been attributed to periods of sea-floor spreading (plate tectonics) by Hays and Pitman (1973), Kauffman (1977, 1979), and Vail and others (1977) and are most completely preserved in the continental interior when sea level is rising. As sea-floor spreading slows down or ceases, altogether, coastal off-lap occurs and much of the record may be lost due to erosion.

Deposition of the Mancos Shale below the Mesaverde coincided with the regional Claggett transgression in Montana, but a local regressive-transgressive cycle (Table 3, steps 2 and 3) that occurred just prior to deposition of the Iles appears to have no regional counterparts. The regression resulted in deposition of a widespread nearshore, normal marine intertidal to shallow subtidal sheet sand (Kauffman, written commun., 1979) that was thoroughly bioturbated by macroinvertebrates (Loyd Sandstone Member). This unit probably represents a "condensed zone" or rapid fall in sea level just preceding the time of the main Judith River regression (R 8). The peak of the subsequent transgression (step 3) (= peak Calggett) was marked by deposition of longshore drifted, laterally reworked distributary mouth bars and barriers in the lower Iles (locs. 2-10, and fig. 2) adjacent to nearshore marine beach sands (loc. 2, fig. 2). This only slightly prograding marine-dominated delta front envionment was marginal to a large bay which opened seaward to the southeast, and was located near locality 2 (fig. 2).

An extensive regression which was represented in the lower Iles by the Tow Creek Sandstone Member (I-2 sandstone) (step 4), coincided with the beginning of the Judith River regression, recognized in Montana (Gill and Cobban, 1973), and elsewhere in the Western Interior (Kauffman, 1977). This regression in northwestern Colorado occurred simultaneously with a basinwide lowering of sea level and consequent seaward shift of longshore drift currents. Because of this shift of strong currents seaward delta front sheet sands and mouth bars were elongated east-west and systems were river-dominated.

Normal beach deposition above the Tow Creek (to the east) and equivalent coal bed deposition to the west above the I-2 sandstone (fig. 2) marks a transgression (step 5) that occurred in the lower Iles. Shales marking this early phase of the major Bearpaw transgression (Tg) apparently are widespread throughout northern Colorado and may represent the initial landward movement of the sea as it encroached from the east.

Extensive eastward progradation in the upper Iles (step 6) is not evident in Montana where coastlines were in retreat during the Bearpaw transgression (Gill and Cobban, 1973) and therefore reflects a local period of uplift. The subsequent transgression (step 7) is marked by the shale tongue below the Trout Creek which is widespread only in northwestern Colorado. This transgression , although local on extent, occurred near the peak of the Bearpaw transgression in Montana.

CONCLUSIONS

This study, based on a detailed analysis of facies patterns in the Mancos and Mesaverde in northwestern Colorado, shows the complex interrelationships of environments that developed in this area of relatively high sedimentation rates. The depositional environments show cyclic repetition; major cycles appear to be related to controls that operated uniformly within the entire basin of deposition. Minor transgressions and regressions superimposed on these major cycles indicate times when local tectonics altered patterns of sedimentation. The study suggests that a definite relationship exists between sedimentary cycles and basin-wide sea level changes, which were probably eustatic, and resulted from displacement of water onto or away from the continents during periods of sea-floor spreading (Hays and Pitman, 1973, Kauffman, 1977, 1979, Vail and others, 1977).

The depositional environment of sandstones interpreted as beach foreshore and shoreface were easily recognized because thorough descriptions of internal structures of modern analogues have been available for some time (e.g., Thompson, 1937; McKee, 1957; Clifton and others, 1971; Dickinson and others, 1972; Hunter and others, 1972; etc.). Environments of associated facies were not as easily identified because work on modern analogues, particularly core descriptions, is just now beginning to emerge. Sandstones and shales in the Mesaverde in northwestern Colorado interpreted as distributary channels, mouth bars, delta front sheet sands, crevasse splays, and interdistributary marsh and swamp deposits, represent an attempt to describe such ancient features in the Upper Cretaceous based mainly on "process-response" models developed by Coleman, Gagliano, Ferm, Kolb, Van Lopik, and several others (see References Cited), primarily from study of the Mississippi River delta. "Reworked distributary mouth bars" represent a newly coined phrase for which there are few described modern analogues. Fluvial (braided) streams and tidally influenced distributary channels similarly were based on limited data from the modern environment. Small-scale features, such as crevasse splay deposits, are more easily discerned than others because the geometry of the unit can be detected nearly completely in the field or from the air.

The genesis of many of the shales and some of the sandstones that lack recognizable internal structures was difficult to determine, even utilizing vertical relations of facies. Further work in this area is essential for more detailed understanding of transgressive-regressive history. The most difficult of the environments to interpret was the shallow offshore facies, partly because of difficulties encountered with interpretation of shales and partly because there are few modern analogues comparable to those found in the Cretaceous. More work in modern shelf environments would greatly benefit future studies of Cretaceous shallow marine sand bodies.

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APPENDIX 1

Measured Sections

MEASURED SECTIONS

1. COAL CREEK SECTION, C E1/2 sec. 20, C sec. 21, T. 4 N., R. 98 W., Elk Springs 15 min. Quadrangle, Moffat County, Colorado. Section from Units 1 through 24 measured with Jacob Staff and tape by J. R. Dyni and R. R. Cunningham, Sept. 5, 1962, and remeasured and annotated by L. W. Kiteley, assisted by Jason Ota, July and August 1977. Section from Units 25 through 43 measured with Jacob Staff and tape by L. W. Kiteley and E. B. Forester, September 1977. Megafauna identified by E. G. Kauffman, U.S. National Museum, and W. A. Cobban, U.S. Geological Survey.

Mesaverde Group: Iles Formation:	Feet	Meters
43. Trout Creek Sandstone Member equivalent: Sandstone, light-gray (N7); weathers "whitish"; fine to medium grained (at base to calcareous at top); subrounded, cherty, noncalcareous at base to calcareous at top	77.0	23.5
42. In part covered, claystone, gray; contains ironstone concretions; and interbedded thin silty lenticular sandstone; fine-grained	130.0	39.16
41. Covered	163.0	49.7
40. Sandstone, silty, dark-yellowish-orange, (10YR 6/6), very fine to fine grained, poorly sorted, slightly calcareous; medium bedded (up to 1 ft, 0.3 m); weathers massive	29.0	8.8
39. Claystone, gray, and thinly interbedded sandstone; ironstone concretions (poorly exposed)	164.0	50.0
38. Sandstone, lenticular, clayey, light-gray (N7) to dark yellowish-gray (10YR 6/6), fine-grained, cherty, trough crossbedded; contorted in places	4.0	1.2
37. Claystone, gray, mostly covered; very calcareous	15.0	4.6

[1]Prepared in cooperation with the U.S. Department of Energy (NVOO).

COAL CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
36. Sandstone, similar to 38, fine-grained fining upward to silt-sized; trough and wedge planar crossbedding; sharp scour base over shale with ironstone concretions	10.0	3.0
35. Claystone, gray, and interbedded carbonaceous shale, ironstone concretions, and thin siltstones (up to 3 ft, 0.9 m) near top	38.0	11.6
34. Sandstone, shaly, light-gray (N7) to dark-yellowish-orange (10YR 6/6); very fine grained at base to silt sized at top; small-scale trough crossbeds (ca. 0.5 ft (0.15 m) in length); very thin clay "drapes"	18.0	5.5
33. Claystone, gray, and interbedded carbonaceous shale (fissile because of alined plant fragments); interlaminated coal stringers	10.0	3.0
32. Sandstone, clayey, light-gray (N7), very fine grained; large-scale foresets with very thin clay "drapes"' vertical root traces in basal 4 ft (1.2 m)	10.0	3.0
31. Mudstone, grayish-brown (5YR 3/2), noncalcareous, slightly coaly	7.0	2.1
30. Sandstone, lenticular, wedges out against overlying sandstone, light-gray (N7), dark-yellowish-orange (19YR 6/6)-weathering, very fine to fine-grained at base to dominantly fine-grained at top; large-scale foresets; sharp scour base	17.0	5.2
29. Claystone, lenticular, medium-gray (N5)	5.0	1.5
28. Sandstone, lenticular; wedges out against overlying sandstone; light gray (N7), fine grained at base to silt sized at top; ripple laminated clay "drapes"; sharp scour base	11.0	3.4

COAL CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
27. In part covered with upper 7 ft (2.1 m) better exposed; claystone, medium-dark-gray (N4) and interbedded siltstone, medium-gray (N5) to dark-yellowish-orange (10YR 6/6); carbonaceous plant debris; root traces (?) or possibly burrowed(?) near top	67.0	20.4
26. Sandstone, clayey, "salt and pepper", light-gray (N7) to dark-yellowish-orange (10YR 6/6) ("root mottled"), very fine grained fining upward to silt-sized, ripple-laminated; sharp scour base	6.0	1.8
25. In part covered; shale, carbonaceous; lower two-thirds brown, dark brown weathering, upper one-third weathers "whitish"	11.5	3.5
(Offset due west to Point C on Photo 161 of J. Dyni; following section measured by J. R. Dyni, R. R. Cunningham, 1962, annotated by L. W. Kiteley, assisted by J. Ota, 1977)		
24. Sandstone, yellowish-tan and light-tan fine- to medium-grained, slightly calcareous; medium-scale trough crossbedded (6-8 ft, 1.8-2.4 m in width), asymmetrically filled, grading upward to ripples at tops of troughs; claystone pebbles and light-gray clay "drapes"; upper 22 ft (6.7 m) contains small spheroidal calcareous sandstone concretions that weather out on outcrop	98.0	29.9
23. Shale, sandy, carbonaceous; weathers gray	16.0	4.9
22. Sandstone, shaly, mottled gray and yellow-tan ("root mottled"), very fine to fine-grained; thinly laminated; contorted; root markings near top	6.3	1.9

COAL CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
21. Shale, carbonaceous; interbedded sandstone, light-gray (N7), very fine grained; and coal	16.0	4.9
20. Sandstone, light-gray, yellowish-tan weathering, fine-grained (a few medium grains), slightly calcareous; small scale crossbedded; clay pebbles and thin clay "drapes"; interbedded siltstones and claystones (up to 2 ft, 0.6 m thick) in basal part	55.0	16.8
19. Largely covered; shale, carbonaceous, sandy; interbedded gray carbonaceous sandstone	26.5	8.1
18. Coal	1.2	0.4
17. Same as unit 15	18.0	5.5
16. Coal	0.4	0.1
15. Shale, carbonaceous; interbedded sandstone and siltstone; weathers light gray. Sandstone and siltstone, lenticular, very thin bedded, carbonaceous; current rippled	1.1	0.3
13. Shale, carbonaceous, and interbedded claystone, gray	5.5	1.7
12. Coal; basal few cm is very organic-rich carbonaceous shale (paleo-soil?)	1.0	0.3
11. Sandstone, very light gray to tan in basal one-third, very fine to fine grained, well-sorted; trough crossbedded near base (inferred "swash zone"); flat bedded in upper one-third; *Ophiomorpha* abundant in lower part, fewer in upper half	27.0	8.2

COAL CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
10. Sandstone; interbedded gray shale (0.8 ft, 0.2 m) at base. Sandstone, light-gray (N7), very fine grained; weathers massive and rounded; laminated (1.0 cm) horizontally bedded near top; *Ophiomorpha* throughout	4.0	1.2
9. Sandstone, light-tan, very fine to fine-grained, calcareous; thinly interbedded siltstone (bioturbated); dominantly flat bedded; *Ophiomorpha*, some parallel to bedding	10.4	3.2
Total thickness Iles Formation	1,110.9	338.6
Mancos Shale (part): Buck Tongue, upper part:		
8. In part covered, shale, sandy, gray; forms slope	10.0	3.0
7. Sandstone; interbedded sandy shale; tan (base) and light gray (upper half). Sandstone fine-grained, subrounded, moderately well sorted, trough crossbedded; some flat bedding at top; medium bedded (up to 20 cm); bioturbated in places	13.5	4.1
6. Sandstone, silty, tan, very fine to fine-grained, very thin bedded to laminated (1.0 cm) (at top); trough crossbedded. One foot (0.3 m) shale layer at top	4.1	1.2
5. Claystone; thinly interbedded siltstone (near top), greenish gray, thin bedded; a few selenite crystals; forms slope	15.5	4.7
4. Sandstone, tan, fine-grained, calcareous; large *Ophiomorpha* parallel to bedding	5.5	1.7

COAL CREEK SECTION-(cont.)

Mancos Shale (part)-(cont.) Buck Tongue, upper part-(cont.)	Feet	Meters
3. In part covered; sandstone, shaly, tan, fine-grained, subangular, thick-bedded	11.0	3.4
2. Shale, sandy, mostly olive gray, in part tan and yellowish-brown, subfissile; some selenite gypsum crystals and a few rusty brown clay ironstone concretions; forms slope Ammonite: *Placenticeras intercalare*	165.0	50.3
Total thickness Buck Tongue, upper part	224.6	68.4
1. Loyd Sandstone Bed: Sandstone, gray, brown-to orangish-brown -weathering, very fine to fine -grained; calcareous, low-angle crossbedded to flat-bedded; very large (about 10-15 ft (3-4.5 m) diameter) spheroidal fossiliferous limy sandstone concretions: *Ophiomorpha* throughout; pelecypod on uppermost bedding surface	29.0	8.8

Bivalvia:

Inoceramus sp. cf. *I. barabini* Morton (s.s.) equally rugate form
Inoceramus proximus Toumey (s.s.)
Inoceramus proximus subcircularis Meek (?= *I. vanuxemi* Meek and Hayden, of Meek, 1876, pl. 14, fig. 2)
Inoceramus barabini Morton s.l. (of Meek, 1876, pl. 13, fig. 1a-c), finely unequally ribbed variant.
Nucula sp. cf. *N. obsoletistriata* Meek and Hayden
Phelopteria linguiformis (Evans and Shumard)
**Lucina* (=Nymphalucina) subundata* (Hall and Meek)
Crenella elegantula Meek and Hayden
Granocardium (Ethmocardium) n. sp. aff. *G. (E.) whitei* (Dall) (=*G. (E.) speciosum* Meek and Hayden)
Corbula sp. indet
Clisocolus dubius (Grabb)?
C. moreauensis (Meek and Hayden)
C. dubius (Gabb)

	Feet	Meters
Total Thickness Mancos Shale (part)	253.6	77.3

COAL CREEK SECTION-(cont.)

Mancos Shale (part)-(cont.)	Feet	Meters

Cymbophora? sp. (mold)
Endocostea? barabini (Morton)
"*Inoceramus*" *regularis* d'Orbigny
"*I.*" cf. *balchii* Meek and Hayden
"*I.*" *oblongus* trans. to *I. balchii* Meek and Hayden
Anatina
A. n. sp. aff. *A. lineata*
Pseudoptera (juv.) aff. *P. subtortuosa* (Meek and Hayden)

Ammonites:

Baculites perplexus Cobban
Hoploscaphites sp.
Placenticeras sp.

2. DECEPTION CREEK SECTION, W1/2 sec. 23, NW1/4 sec. 26, SE1/4SE1/4 sec. 22, N1/2 sec. 27, T. 5 N., R. 95 W., Citadel Plateau 15 min. Quadrangle, Moffat County, Colorado. Section measured with Jacob Staff and tape by L. W. Kiteley and J. R. Peterson, July 1977. Microfauna identified by D. L. Eicher and E. B. Forester; megafauna identified by E. G. Kauffman, U.S. National Museum, and W. A. Cobban, U.S. Geological Survey.

Mesaverde Group: Iles Formation:	Feet	Meters
48. Trout Creek Sandstone Member: Sandstone, silty near base, light-gray (N7), uniformly fine grained, well-sorted, subrounded, cherty, very thin bedded (2 cm), flat-bedded to very low angle crossbedded; a few *Ophiomorpha*	25.0	7.6
47. Mostly covered; probably carbonaceous shale	18.0	5.5
46. Sandstone, silty, very fine to fine-grained, ripple-laminated	13.0	4.0
45. Mostly covered; claystone, light-gray (N7)	5.0	1.5
44. Sandstone, light-gray (N7), very fine to fine-grained (fining upward), thin-bedded; weathers massive	26.0	7.9
43. Covered; probably mostly claystone	55.0	16.8

DECEPTION CREEK SECTION-(cont.)

Mesaverde Group-(cont.)
Iles Formation-(cont.)

	Feet	Meters
42. Sandstone, light-gray (N7), very fine to fine-grained (fining upward), well-sorted; laminated to very thin bedded (0.5-2 cm); trough crossbedded in lower half, medium-scale foresets (locally thick bedded, 30 cm) at top; contorted bedding near base	30.0	9.1
41. Claystone, light-gray (N7), and interbedded thin lenticular sandstones	50.0	15.2
40. Sandstone, silty, light-gray (N7) to dark-yellowish-orange (10YR 6/6), fine-grained; claystone pebbles (up to 3 cm diameter); contorted bedding; weathers massive	48.0	14.6
39. Sandstone, grayish-yellow (5Y 8/4); similar to unit 40	11.0	3.4
38. Claystone, light-gray (N7); interbedded siltstones	30.0	9.1
37. Poorly exposed; sandstone, light-gray (N7) to dark-yellowish-orange (10YR 6/6), very fine-grained; carbonaceous plant debris and plant impressions on sandstone	12.0	3.7
36. Claystone, light-gray	5.0	1.5
35. Siltstone, dark-yellowish-orange (10YR 6/6); wood imprints at top; weathers massive	10.0	3.0
34. Sandstone, silty, light-gray (N7) to yellowish-orange (at top), very fine grained; plant debris at top; interbedded light-gray claystone; gradational lower contact	25.0	7.6
33. Sandstone, very fine to medium-grained biotite mica, chert; weathers massive flat bedded to ripple bedded; clay pebbles	37.0	11.3
32. Poorly exposed; claystone; interbedded siltstones	15.0	4.6

DECEPTION CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
31. Sandstone, silty, light-gray, very light gray (N8) weathering, very fine grained, medium-scale (up to 2 ft, 0.6 m) trough crossbedded; ironstone concretions near base	3.0	0.9
30. Poorly exposed; siltstone, light-gray (N7); interbedded claystone, medium-gray (N5), carbonaceous	20.0	6.0
29. Sandstone, yellowish-gray (5Y 7/2) to dark-yellowish-orange (10YR 6/6); ripple laminated, some low angle crossbedding; clay pebbles; sharp scour base	30.0	9.1
28. Claystone, gray; interbedded thin coal, sandstone, and carbonaceous shale	52.0	15.8
27. In part covered; claystone; interbedded sandstone, fine- to medium-grained; abundant chert; contorted; weathers massive	25.0	7.6
26. Sandstone, yellowish-gray (5Y 7/2) to dark-yellowish-orange (10YR 6/6), fine- to medium-grained, friable, ripple-laminated; clay pebbles; sharp scour base	5.0	1.5
25. Claystone, medium light-gray (N6), carbonaceous debris; interbedded siltstone, yellowish-gray (5Y 7/2); large ironstone concretions in claystone	30.0	9.1
24. Sandstone, light-gray (N7), fine-grained, moderately well sorted, thin-bedded; trough crossbedding, cuspate rippled at tops of beds; clay pebbles	41.0	12.5
23. Covered; probably claystone	20.0	6.1
22. Sandstone, yellowish-gray (5Y 7/2), very fine to fine-grained, cherty, moderately well sorted; medium-scale foreset bedding and some ripple bedding	26.0	7.9

DECEPTION CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
21. Claystone, light-gray (N7); interbedded carbonaceous shale, coal (2 ft, 0.6 m thick) and minor sandstone; ironstone concretions	40.0	12.2
20. Sandstone, yellowish-gray (5Y 7/2), dark-yellowish-orange-weathering (10YR 6/6), very fine to fine-grained; "bleached" white at top; trough crossbedded and ripple laminated; contorted bedding; carbonaceous plant debris at top	26.0	7.9
19. Covered; claystone, light-gray	20.0	6.1
18. Sandstone, yellowish-gray (5Y 7/2), fine-grained; small-scale trough crossbedded; carbonaceous debris; sharp scour base	2.0	0.6
17. Shale, medium-gray (N5) and dark-yellowish-orange (10YR 6/6), slightly fissile; iron-stone concretions; carbonaceous debris	16.0	4.8
16. Sandstone, silty, light-gray, fine-grained, well-sorted, well-rounded; trough cross-bedded; sharp scour base; siltstone inter-beds near base; *Toredolitnus* at base	30.0	9.1
15. Claystone, medium-gray; interbedded carbonaceous shale	7.0	2.1
14. Sandstone, very fine to fine-grained, well-sorted; medium scale trough crossbeds (festoon); sharp scour base	30-35.0	9.1-10.6
13. Sandstone, light-gray (N7); thinly interbedded claystone, medium-gray (N5). Sandstone, silty, very fine-grained, very well sorted; pre-dominantly ripple bedded with broken clay clasts and rounded clay pebbles on bedding surfaces; *Scolithus*	16.0	4.9
12. Coal	0.25	0.07
11. Claystone, brownish-gray, carbonaceous	6.5	2.0

DECEPTION CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
10. Sandstone, silty interbedded claystone. Sandstone entirely medium scale trough crossbedded	21.5	6.5
9. Sandstone, light-gray (N7) fine-grained, quartz, some chert; weathers "bleached" white at top, medium-scale (up to 2 ft, 0.6 m) trough crossbeds; sharp scour base over thin sandstone or thinly interbedded shale and sandstone	44.0	13.4
8. Shale; thinly interbedded sandstone	21.5	6.6
7. Sandstone, light-gray (N7) to yellowish-gray (5Y 7/2), very fine grained laminated to very thinly bedded (1 cm) horizontally bedded; long straight crested, very shallow ripples at top; basal contact sharp (hummocky surface); *Ophiomorpha*, *Ostrea* (disarticulated), on upper surface, bioturbation structures	10.0	3.0
6. Shale; thinly interbedded sandstones and siltstones at 35 ft (10.7 m) above base. Sandstone (up to 1 ft (0.3 m) thick); long sinuous crested ripples on tops of sandstones; tracks, trails, and burrows include *Gyrochorte* (biserial trails), *Crossopodia* (central furrow with "segments" forming a broad dense fringe on either side), *Nereites?* (meandering feeding trails with central axis and laterally spaced leaf-or lobe-shaped protrusions), starfish resting trace, and *Planolites* (meandering sand- and silt-filled, smooth walled, deposit feeding burrows)	70.0	21.3

Ostracode:
Haplocytheridea

Foraminifera:
Haplophragmoides excavatus Cushman and Waters

DECEPTION CREEK SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
5. I-1 sandstone; Sandstone, light-gray (N7 to yellowish-gray (5Y 7/2), fine- to medium-grained, moderately well sorted; well-rounded grains, quartz, chert, mica; friable; flat bedded to very low angle crossbedded (tangential bases), some current ripple bedding (asymmetric); *Ophiomorpha* (more concentrated near top), *Thallasinoides* on upper surfaces; shell coquina *(Ostrea)* -filled scoured trough at top	50.0	15.2
Bivalvia: *Crassostrea* sp. aff. *C. subtrigonalis* (Evans and Shumard); rare boring by *Clione*; wood frags.		
Total thickness Iles Formation	±1,056.25	± 321.9
Mancos Shale:		
Buck Tongue, upper part:		
4. Mudstone, medium-dark-gray (N4)	43.3	13.1
Total tickness Buck Tongue, upper part..............	43.0	13.1
3. Loyd sandstone bed: Sandstone, grayish-yellow (5Y 8/4), very fine grained, silty ("sugary"); weathers massive; *Ophiomorpna*	25.0	7.6
Bivalvia: cf. *Veniella* sp. (poor external mold) *Clisocolus* n. sp. aff. *C. dubius* and aff. *C. transversa* (Whitfield)		
Buck Tongue, lower part:		
2. Mudstone, silty, light-olive-gray (5Y 61)	77.0	23.5
Foraminfera: *Spiroplectommanina semicomplanata* (Carsey) *Haplofragmoides excavatus* Cushman and Waters		
Total thickness Buck Tongue, lower part.............	77.0	23.5

DECEPTION CREEK SECTION-(cont.)

Mancos Shale (cont.) Buck Tongue, lower part (cont.)	Feet	Meters
Unnamed sandstone of B. *asperiformis* range age:		
1. Sandstone, pale-greenish-yellow (10Y 8/2), fine-grained, well-rounded, moderately well sorted, friable; large-scale foreset bedding, medium-scale troughs; *Chondrites?*, *Ophiomorpha* mostly concentrated near top	34.0	10.4
Total thickness Mancos Shale (part)	179.0	54.6

MORGAN GULCH SECTION, NE1/4 sec. 5, T. 5 N., R. 93 W., Horse Gulch 7.5 min. Quadrangle, Moffat County, Colorado Section measured with Jacob Staff and tape by L. W. Kiteley and N. Noreen, July 1978. Pollen and spores identified by Fred May; megafauna identified by E. G. Kauffman, U.S. National Museum.

Mesaverde Group: Iles Formation:	Feet	Meters
18. Sandstone, yellowish-gray, very fine to fine-grained; trough crossbedded; clay pebbles; sharp scour base over underlying shale	23.0	7.0
17. Shale, medium dark-gray, carbonaceous	15.0	4.6
16. Sandstone, light-gray to dark yellowish-orange, very fine grained to silt-sized, ripple-laminated; carbonaceous plant debris and carbonaceous woody fragments	5.0	1.5
15. Shale, similar to unit 17	50.0	15.2
14. I-2 sandstone, equivalent: Sandstone, lenticular, light-gray, fine- to medium-grained, moderate to well-sorted, well-rounded; trough crossbedded; clay pebbles; abundant plant debris and carbonaceous woody fragments	8.0	2.4
13. Shale, similar to unit 17	12.0	3.7
12. Siltstone, mottled light-gray to dark-gray, carbonaceous; plant rootlets; plant debris	3.0	0.9

MORGAN GULCH SECTION-(cont.)

	Feet	Meters
Mesaverde Group:		
Iles Formation:		
11. Shale, medium-gray, carbonaceous	20.0	6.1
10. Shale, light-gray, medium- to large-scale trough-crossbedded; claystone pebbles; *Toredolithus* at base; sharp scour base (includes low-angle flat bedded marine? sandstone in lower third)	100.0	30.5
9. Claystone; interbedded siltstone, thinly laminated; small-scale trough crossbedding to low-angle flat bedding	7.0	2.1
8. Coal	3.0	0.9
7. Claystone, thinly laminated	6.0	1.8
6. Coal	15.0	4.6
5. <u>I-1 sandstone</u>: Sandstone, grayish-yellow (5Y 8/4), very fine to fine-grained (silt sized near base). Dominantly low angle flat-bedded (a few small-scale trough crossbeds) in lower half with sharp basal contact; *Ophiomorpha* (large) near base and concentrated in a zone at +30 ft (9 m) above base. Upper half flat bedded to low angle crossbedded; "white" weathering in uppermost 16 ft (5 m)	56.0	17.1
Total thickness Iles Formation (part)	329.0	98.8
Mancos Shale:		
4. Claystone; interbedded thin tabular siltstones, especially at top	155.0	47.2
3. Siltstone, light-gray to grayish-orange, thinly horizontally laminated; forms concretions	1.0	0.3
2. Shale, medium-gray	81.0	24.7

MORGAN GULCH SECTION-(cont.)	Feet	Meters
Mancos Shale (cont.)		
1. First Mancos ss of Konishi (1959a): Sandstone, light-gray to grayish-orange, fine-grained, moderately well sorted, rounded to angular; ironstone concretions and rounded pebbles on bedding surfaces; *Ophiomorpha, Gyrochorte*, oysters, sharks teeth on bedding surfaces; excellent porosity	9.0	2.7
Total thickness Mancos Shale (part)	245.0	74.7

DUFFY MOUNTAIN SECTION, C sec. 25, T. 5 N., R. 93 W.; NW1/4 sec. 30, E1/2 sec. 19, SE1/4 sec. 18, SW1/4 sec. 17, T. 5 N., R. 92 W., Axial, Horse Gulch, and Round Bottom 7.5 min. Quadrangles, Moffat County, Colorado Section measured with Jacob Staff and tape by L. W. Kiteley and J. R. Peterson, July 1977.

Mesaverde Group: Iles Formation:	Feet	Meters
38. Trout Creek Sandstone Member: Sandstone, "whitish" weathering, low-angle cross-bedded to horizontally bedded; *Ophiomorpha*; weathers in rounded masses	64.5	19.7
37. Shale, light-olive-gray, and interbedded sandstone, light-yellowish gray; *Inoceramus*	116.0	35.4
36. Sandstone, lenticular, very fine to medium grained; sharp scour base; interbedded silty shale, medium-gray (N5) to medium dark-gray; carbonaceous shale; weathers pale brown (5YR 5/2) to grayish-brown (5YR 3/2); thin coal beds. Contact at top of unit is sharp between coal bed and overlying marine shale	24.0	7.3
35. Sandstone, yellowish-gray to light-gray, fine- to medium-grained, fair-sorted, cherty, slightly friable; large-scale trough crossbedded and small-scale low-angle crossbedding	19.0	5.8

DUFFY MOUNTAIN SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
34. Covered	10.0	3.0
33. Sandstone, similar to unit 35	24.5	7.5
32. Poorly exposed; mudstone; interbedded sandstone	25.0	7.6
31. Poorly exposed; sandstone	15.0	4.6
30. Poorly exposed; claystone, light-gray; interbedded sandstone. Basal 20 ft (6.0 m) consists of locally thickened sandstone interval of underlying unit	63.0	19.2
29. Sandstone, yellowish-gray (5Y 7/2) to grayish-orange (10YR 7/4), very fine to medium-grained, poorly sorted; large-scale crossbedding; sharp scour base	20.0	6.1
28. Claystone, gray; interbedded thin (up to 3 ft, 0.9 m) lenticular sandstone, massive-bedded	30.0	9.1
27. Sandstone, massive-bedded	5.0	1.5
26. Claystone, gray, carbonaceous; interbedded carbonaceous shale (1-2 ft, 0.3-0.6 m, at top of unit)	10.0	3.0
25. Sandstone, light-yellowish-gray to grayish-orange, very fine to medium-grained, poorly sorted, friable; large scale trough crossbedded, dominantly unidirectional; sharp scour base	13.5	4.1
24. Mostly covered; probably shale, gray, and interbedded thin sandstone, similar to unit 22	15.0	4.6

DUFFY MOUNTAIN SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
23. Sandstone, light-yellowish-gray, gray-orange-weathering (10YR 7/4), very fine- to medium-grained, friable; ironstone concretions at base, and thin interbedded clay "drapes"; medium-scale trough crossbeds (festoon) and rippled beds; unit thins and thickens and contains pebble lags	15.0	4.6
22. Poorly exposed; shale, medium-gray (N5), slightly carbonaceous; ironstone concretions; interbedded thin (1 ft, 0.3 m) silty sandstone, very fine to fine-grained, poorly sorted, clay pebbles; ripple laminated; root traces (basal 6 ft, 1.8 m)	21.0	6.4
21. Claystone, medium-gray (N5), slightly carbonaceous (basal 13 ft); overlain by sandstone, lenticular, light-yellowish-gray, grayish-orange-weathering (10YR 7/4, low-angle-crossbedded and current-rippled	15.0	4.6
20. Covered in upper 9 ft (2.7 m); sandstone, light-gray (N7), olive-gray (5Y 3/2) where case hardened; weathers light brown (5YR 5/6) to moderate brown (5YR 4/4); very fine to fine grained; thinly laminated to thin bedded (4 cm); medium-scale festoon crossbedded	19.0	5.8
19. Claystone, light-gray (N7) to yellowish-gray (5Y 8/1); coaly and abundant carbonaceous woody fragments; interbedded thin siltstones and very fine grained sandstones; poorly exposed; ironstone concretions weathering out	73.0	22.3

DUFFY MOUNTAIN SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
18. Sandstone, yellowish-gray (5Y 7/2) to dusky-yellow (5Y 6/4), very fine- to fine-grained, cherty, moderately well sorted, thin- to medium-bedded (up to 15 cm), low-angle-crossbedded; contains large (up to 11 cm) ironstone concretions; contorted in places; weathers in rounded masses	15.0	4.6
17. Predominantly covered. At 16.6 ft (5 m) above base, sandstone, silty, yellowish-gray (5Y 7/2) to dusky-yellow (5Y 6/4), very fine to fine-grained; poorly sorted chert; thin bedded (4 cm); trough crossbedded; weathers massive; small (2 cm) ironstone concretions weathering out. At 23 ft (7 m) siltstone and thin-bedded sandstone, very fine to fine-grained	49.6	15.1
(Cross over Milk Creek, units 17-38 measured on north side.)		
16. Sandstone, yellowish-gray (5Y 7/2) to dusky-yellow (5Y 6/4), very fine to fine-grained, moderately well sorted, very thinly laminated to laminated (0.5 cm); medium-scale foreset bedding, local climbing ripples; claystone "drapes"; contorted and brecciated in places with claystone clasts up to 30 cm long; rounded ironstone concretions (up to 10 cm) in brecciated claystones and sandstones; base scoured into underlying shale and undulatory; unit thins and thickens	29.9	9.1
15. Mudstone, silty, dark-gray (N3); contains possible charophyte vegetative parts	15.0	4.6
14. Sandstone, fine-grained, micaceous, poorly sorted; interbedded siltstone; medium-scale trough crossbedded to ripple bedded at tops of troughs; large claystone pebbles	18.9	5.8

DUFFY MOUNTAIN SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
13. Shale, carbonaceous, interbedded coal and thin sandstones (up to 2 ft, 0.6 m), and siltstones. Sandstone, light-gray, very fine to fine-grained; very thin (2 cm) flat bedded clay pebbles; contorted bedding in places	75.0	22.9
12. Claystone, gray; interbedded carbonaceous shale, coal, siltstone, and sandstone. Sandstones, lenticular (up to 4 ft, 1.2 m), light-gray, very fine grained, flat-bedded to wedge planar crossbedded, contorted. Siltstones (up to 4 ft, 1.2 m thick), very low angle crossbedded; weathers massive. Thick coal beds containing ironstone concretions at 45-50 ft (14-15 m) and 55-60 ft(17-18 m) above base	100.0	30.5
11. Sandstone, grayish-yellow (5Y 8/4) to very light gray (N8), very pale orange (10YR 8/2) to grayish-brown (5YR 3/2) weathering, very fine to medium-grained; unit thins and thickens (>100 ft, 30 m) along strike; and small- and medium-scale trough crossbedding in thin parts, medium to large-scale troughs in thickened parts; claystone "drapes" and clay pebbles; abundant woody debris (logs and stems) at base (*Toredolithus* borings numerous); carbonaceous debris throughout	91.0	27.7
10. Shale, carbonaceous, moderate-brown (5YR 4/4) to dark-yellowish-orange (10YR 6/6); interbedded sandstones, lenticular (up to 4 cm), pale-yellowish-orange (10YR 8/6) to grayish-orange (10YR 7/4), very fine to fine-grained, ripple-laminated; rounded clay clasts; woody plant impressions	120.0	36.6

DUFFY MOUNTAIN SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
9. I-2 sandstone: Sandstone, grayish-orange (10YR 7/4) in lower half to yellowish-gray (5Y 8/1) in upper half, very fine to fine-grained (coarsening upward); quartz, chert; dominantly flat bedded, some trough cross bedding; sharp basal contact; root traces at top; *Ophiomorpha* abundant in lower half, few in number in upper half; broken *Inoceramus* shells form fossil hash	33.4	10.2
8. Poorly exposed; alternating shale and thin (1-2 ft, 0.3-0.6 m), lenticular sandstones. Sandstones are rippled in basal 10 ft (3 m); compound foresets crossbedded upper 65 ft	75.0	22.9
7. Coal, black (N1), hard	2.0	0.6
6. Shale, carbonaceous, moderate-brown (5YR 4/4) to dark-yellowish-orange (10YR 6/6)	3.0	0.9
Pollen and spores: *Laevigatosporites* *Cyathidites* *Alnipollenites* *Betulaepollenites* *Proteacidites* *Ephedrapites*		
5. Sandstone I-1: sandstone; grayish orange (10YR 7/4) in lower half to yellowish-gray (5Y 8/1) in upper half, very fine to fine grained (coarsening upward); quartz, feldspar, chert; trough cross-bedded (lower half) to low-angle flat bedded (upper half); root traces at top; *Ophiomorpha* abundant in lower half, few in number in upper half; chevron burrow Bivalve: *Inoceramus* (s. l.) sp. aff. *I. Barabini* Morton (worn adult valve)	42.1	12.8
Total thickness Iles Formation	1,267.4	386.3

DUFFY MOUNTAIN SECTION (cont.)

Mancos Shale (part):	Feet	Meters
Buck Tongue of Mancos Shale, upper part:		
4. Shale, olive-gray (5Y 3/2	105.0	32.0
Total thickness Buck Tongue, upper part...........	105.0	32.0

Pollen and spores:
Deflandrea victoriensis
Trithyrodinium robustum
Aquilapollenites
Palaeohystrichophora infusorioides
Proteacidites

3. Loyd Sandstone Bed: Sandstone, clayey, grayish-orange (10YR 7/4), very fine grained; weathers massive, in rounded masses; *Ophiomorpha* (small to large), *Thalassinoides,* and small smooth-walled burrows *(Planolites?)*	25.0	7.6

Bivalvia:
Cymbophora subtilis Stephenson
Cymella n. sp. aff. *C. montanensis* Henderson
Pinna sp. (fragment indet.)
Mytilus (Mytilus) n. sp. cf. *M. quadratus* Gabb
Phelopteria linguaeformis (Evans and Shumard)
Ostrea (Ostrea) sp. indet. (fragments only)
Large disc-like bivalve, cf. *Cyprimeria* sp.
cf. *Panopea* sp. indet.
Dosiniopsis deweyi (Meek & Hayden)
Oxytoma (Hypoxytoma) n. sp. cf. O. (H.) *nebrascana* (Evans and Shumard)
Thyasira sp. aff. *T. becca* Kauffman (worn)
Small indet. bivalves, one is phosphatized, the rest not, suggesting that there may be some reworked, or remanie, specimens. Disconformity near here?

Ammonite:
Baculites sp. (small juvenile and adult segments) indet.

2. In part covered; dominantly claystone, silty, olive-gray (5Y 3/2)	190.0	57.9

DUFFY MOUNTAIN SECTION (cont.)

Mancos Shale (part)-(cont.)	Feet	Meters
1. First Mancos sandstone of Konishi (1959a): Sandstone, yellowish-gray (5Y 7/2) to grayish-orange (10YR 7/4), very fine to fine-grained (coarsening upward), poorly sorted; chert and mica; tabular planar crossbedding with rippled tops; rounded clay clasts on bedding surfaces; upward curving smooth-walled burrows *(Asterosoma?)*, bioturbation especially at tops of bed sets	20.0	6.1

Bivalvia:
Inoceramus (s.i.) (fragment) cf.
I. proximus Toumey
Ammonite:
Baculites sp. indet.

Total thickness Mancos Shale (part)	340.0	103.6

KONISHI SECTION (Type section of the LOYD SANDSTONE MEMBER), NE1/4 sec. 31, T. 5 N., R. 92 W., Monument Butte 15 min. Quadrangle, Moffat County, Colorado Section measured by D. A. Beattie, B. G. Kerr, K. Konishi, and G. Venable, July and September 1957 (Konishi 1959b), and remeasured and annotated by L. W. Kiteley, July 1978. Numbers of units are those of Konishi, (1959b). Notes, in parentheses, are by Kiteley. Megafauna identified by W. A. Cobban.

Mesaverde Group: Iles Formation (part):	Feet	Meters
113. I-2 sandstone: Sandstone, white on top, brown on bottom, very fine grained, well-sorted; subangular grains, slightly calcareous; massive except basal portion (27 ft, 8.2 m) merging into sandy shale. Basal 27 ft (8.2 m) consists of siltstone and very fine grained sandstone in beds up to 4 ft (1.2 m) and interbedded thin (up to 1 ft, 0.3 m) bioturbated and rippled silty claystone; some low-angle crossbedding and medium-scale symmetrically filled troughs in sandstone interbeds; *Ophiomorpha*; ironstone concretions and iron boxwork structure.) Upper 85 ft (25.9 m) weathers rounded and is good ledge-former ("Rim Rock" of Hancock, 1925)	112.0	34.1

KONISHI SECTION-(cont.)

		Feet	Meters
Mesaverde Group (cont.) Iles Formation (cont.)			
114.	Shale, silty, gray to light-black, calcareous, and thin tabular siltstones (up to 3 ft (0.9 m) thick; very thinly bedded (2 cm); horizontally bedded to low angle crossbedded; horizontal burrows, thin rounded sand-filled smooth tubes *(Planolites?)* (up to 4 cm length)	63.0	19.2
115.	I-1 sandstone: Sandstone, silty, pale-greenish-brown, very fine grained, medium to poorly sorted, subangular grains, very calcareous, slightly friable. Basal 17 ft (5.18 m) is thin bedded and merges into underlying claystone; large *Ophiomorpha* near top; *Inoceramus convexsus*	59.0	18.0
	Total thickness Iles Formation (part)	234.0	71.3
Mancos Shale (part): Buck Tongue, upper part:			
116.	Mostly concealed; shale	57.0	17.4
	Total thickness Buck Tongue, upper part	57.0	17.4
117.	Loyd Sandstone Bed: Sandstone, silty, green to greenish-gray (grayish-yellow-green, 5GY 7/2), fine- to medium(?)-grained, well-sorted, extremely calcareous, friable; subrounded grains (laminated, horizontally bedded to low angle crossbedded in places); concretionary at certain horizons with nuclei of fossils; weathers massive; a few burrows to none	104.0	31.7
	Bivalvia: *I. subcompressus* Ammonite: *Baculites* sp.		
	Total thickness Mancos Shale (part)	161.0	49.1

MEASURED SECTIONS (cont.)

UTE GULCH SECTION, SW NE sec. 17, T. 5 N., R. 91 W., Castor Gulch 7.5 min. Quadrangle, Moffat County, Colorado Section measured with Jacob Staff and tape by N. Noreen and L. W. Kiteley.

Mesaverde Group: Iles Formation (part):	Feet	Meters
9. Sandstone, light-gray to yellowish-gray, very fine to fine-grained, trough crossbedded; ironstone concretions; overlies coal and clinker	14.0	4.3
8. Poorly exposed; coal at top and at 40 ft (12.2 m) above base; siltstone at 55 ft (16.8 m) above base	59.0	18.0
7. I-4 sandstone: Sandstone, siltstone, and thin interbedded claystone and coal. Upper 38 ft (11.6 m) consists of sandstone, grayish-orange, very fine to fine-grained, massive-weathering; 4 ft (1.2 m) iron-stained band 15 ft (1.5 m) below top; *Toredolithus* at base. Basal 15 ft (4.6 m) consists of siltstone interbedded with claystone, dark-red-stained (burned); ironstone concretions in basal few feet; sharp scour base over coal bed and thin interbedded rippled siltsone	±75.0	±22.9
6. Shale, very carbonaceous, medium-gray to brownish, coaly (clinker near top); interbedded thin siltstone, ripple-bedded, and coal; weathers to light bluish gray and brick red (burned)	5.0	1.5
5. Shale, very carbonaceous, medium-gray to brownish, coaly; interbedded siltstone, yellowish-gray, ripple-bedded, and thin coal beds; roots(?) or smooth-walled burrows(?)	31.0	9.5
4. Sandstone, yellowish-gray, very fine to fine-grained, noncalcareous; wedge planar crossbedded (wedge sets); contorted bedding above which are climbing ripples at top of sets; woody debris, carbonaceous shale, carbonaceous debris in basal 1-2 ft (0.3-0.6 m)	12.0	3.7

UTE GULCH SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation (part)-(cont.)	Feet	Meters
3. Shale, carbonaceous; interbedded 3-ft (0.9-m) coal at top	13.0	4.0
2. I-3 sandstone: Sandstone, yellowish-gray, very fine grained; low-angle crossbedding (probable trough cross-beds?); rounded claystone and iron-stone concretions; a few *Ophiomorpha*	30.0	9.1
1. Poorly exposed; probably claystone siltstone, and coal	50.0	15.2
Total thickness Iles Formation (part)	289.0	88.1

CASTOR GULCH SECTION, NW1/4 NW1/4 sec. 21, T. 5 N., R. 91 W., Castor Gulch 7.5 min. Quadrangle, Moffat County, Colorado Section measured with Jacob Staff and tape by L. W. Kiteley and N. Noreen, June 1978.

Mesaverde Group: Iles Formation (part):	Feet	Meters
16. Sandstone, very silty, yellowish-gray, very iron stained, very fine grained; bedding indistinct; weathers rounded	20.0	6.0
15. Siltstone, light-gray; interbedded medium-dark-gray silty claystone, carbonaceous	55.0	16.7
14. Sandstone, light-gray to dark-yellowish-orange, very fine grained; root traces; thinly interbedded carbonaceous shale	2.0	0.6
13. Covered	13.0	4.0
12. I-3 sandstone: Sandstone, light-gray fine-grained, well-sorted, well-rounded, nonargillaceous; moderately good porosity. Upper 38 ft (11.6 m): Sandstone, lenticular, trough cross-bedded to rippled in uppermost 19 ft (5.8 m); low angle crossbedded in basal 19 ft (5.8 m). Lower 5 ft (1.5 m): gradational into under-lying claystones	43.0	13.1

CASTOR GULCH SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation (part)-(cont.)	Feet	Meters
11. Covered	17.0	5.2
10. Sandstone, light-gray, very fine to fine-grained, poorly sorted, subrounded, noncalcareous, dominantly horizontally bedded; erosional surface (up to 2.5 ft, 0.8 m thick) filled with shell hash at top	18.0	5.5
9. Poorly exposed; siltstone, carbonaceous shale, and coal. Siltstone (1 ft, 0.3 m) at 42 ft (12.8 m) above base; siltstone, thinly laminated; contains plant impressions; overlies coal; at 40 ft (12.1 m) above base	66.0	20.1
8. Sandstone, very fine to fine-grained, poorly sorted, argillaceous; medium scale trough crossbedded with ripples at tops of troughs; claystone pebbles; coaly, carbonaceous plant debris and iron boxwork structure at base; sharp scour base over carbonaceous shale with thin coal stringers	12.0	3.7
7. Shale, carbonaceous; interbedded siltstones, lenticular, and coal; marine bivalve shells in float	50.0	15.2
6. <u>I-2 sandstone</u>: Sandstone, siltstone, and claystone (coarsening upward). Upper 70-75 ft (21-22.9 m): Sandstone, very fine to fine-grained; low-angle crossbedded to horizontally flatbedded in upper 15 ft (4.6 m) where appears "white" in color; massive appearing in lower 55-60 ft (17-18 m); *Ophiomorpha* in zone at 15 ft (4.6 m) above base, none in upper part; minor contorted bedding near base and iron boxwork structure. Basal 10-15 ft (3.0-4.5 m): Claystone, pale-greenish (5GY 7/2); comminuted carbonaceous plant debris; interbedded siltstones and carbonaceous shale. Siltstones at top are lenticular and form medium-scale		

CASTOR GULCH SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
trough crossbeds that are wide and shallow (1-2 ft x 6-8 ft, 0.3-0.6 x 1.8-2.4 m), thinly laminated and symmetrically filled; carbonaceous shale in upper several cm; claystone pebbles in siltstone. Basal several feet consists of siltstone and sandstone in thin beds that are horizontal to low angle crossbedded and contain horizontal smooth-walled burrows *(Planolites?)*; interbedded pale-greenish (5GY 7/2) to olive-gray mudstone	85.0	25.9
5. Mudstone, olive-gray	9.0	2.7
4. Mudstone, similar to unit 5, but includes two thin (1 ft, 0.3 m) lenticular sandstones, very fine grained, horizontal flat to low-angle crossbedded; horizontal smooth-walled burrows *(Planolites?)*	15.0	4.6
3. Sandstone, very fine grained, horizontal flat to low-angle crossbedded; horizontal smooth-walled burrows *(Planolites?)*	5.0	1.5
2. Mudstone, olive-gray	50.0	15.2
1. I-1 sandstone: Sandstone, light-gray, very fine-grained, slightly argillaceous, slightly calcareous; horizontally bedded to low-angle crossbedded; *Ostrea* (disarticulated) and shell "hash" in upper one-quarter; *Ophiomorpha, Thallasinoides,* and smooth-walled horizontal burrows *(Planolites?)*	16.0	4.9
Total thickness Iles Formation (part)	386.0	117.7

HAMILTON STORE SECTION, NE1/4 sec. 21, T. 5 N., R. 91 W., Hamilton 7.5 min. Quadrangle, Moffat County, Colorado
Section measured with Jacob Staff by L. W. Kiteley and N. Noreen, June 1978.

	Feet	Meters
Mesaverde Group:		
Iles Formation (part):		
11. I-2 sandstone: Sandstone and siltstone (coarsening upward). Upper half: Sandstone, yellowish-gray, fine- to medium-grained, poorly sorted, highly quartzose; small and medium scale trough crossbedded; claystone pebbles and ironstone concretions; *Toredolithus* at sharp scour base; iron boxwork structure. Lower half: Sandstone, light-yellowish-gray, "white"-weathering near top, very fine grained; low angle crossbedded near base to horizontal flat bedded at top; *Ophiomorpha* in upper one-third	49.0	15.0
10. Claystone, silty, olive-gray (5Y 4/1)	18.0	5.5
9. Sandstone, silty, very fine grained; interbedded claystone halfway up from base. Sandstone, horizontally bedded to low-angle crossbedded; horizontal smooth-walled burrows *(Planolites?)*	7.0	2.1
8. Claystone, silty, olive-gray	54.5	16.6
7. I-1 sandstone: Sandstone, very fine to fine-grained, slightly argillaceous, slightly calcareous; interbedded claystone at 8 ft (2.4 m) above base, bioturbated to slightly rippled; horizontally bedded to low angle crossbedded near base to horizontally bedded near top; *Ophiomorpha* concentrated at top	25.0	7.6
Total thickness Iles Formation (part)	153.5	46.5
Mancos Shale:		
Buck Tongue, upper part:		
6. Claystone, silty, olive-gray	15.0	4.6

HAMILTON STORE SECTION-(cont.)

Mancos Shale: Buck Tongue, upper part:	Feet	Meters
5. Sandstone, lenticular, very fine grained; horizontally bedded	1.0	3.0
4. Claystone, silty, olive-gray	12.5	3.8
3. Sandstone, similar to Unit 5	2.5	0.8
2. Claystone, silty, olive-gray	57.2	17.4
Total thickness Buck Tongue, upper part	88.2	29.6
1. Loyd Sandstone Bed (part): Sandstone, grayish-yellow-green (5GY 7/2), very fine grained; thin-bedded, horizontally bedded and trough-crossbedded; *Ophiomorpha*	26.0	7.9
Total thickness Mancos Shale (part)	114.2	37.5

'BELLERING COW' SECTION, SE1/4 sec. 22, T. 5 N., R. 91 W., Hamilton 7.5 min. Quadrangle, Moffat County, Colorado Section measured with Jacob Staff and tape by L. W. Kiteley and N. Noreen, July 1978.

Mesaverde Group: Iles Formation (part):	Feet	Meters
19. I-4 sandstone: Sandstone, grayish-orange; "white" at top, very fine to fine grained (coarsening upward), poorly sorted, slightly calcareous, horizontally bedded; ironstone concretions and iron boxwork structure; *Ophiomorpha* especially in a zone at about 25 ft (7.6 m) above base. Thin lenticular fine-grained sandstone with small-scale trough cross-bedding and ironstone concretions in upper few feet	30.0	9.1
18. Shale, carbonaceous; interbedded coal; large oysters in float	75.0	22.9
17. I-3 sandstone: Sandstone, dark-yellowish-orange; "white" in upper half; horizontal flat bedded to low angle crossbedded; *Ophiomorpha*	32.0	9.8

'BELLERING COW' SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)		Feet	Meters
16.	Shale, carbonaceous; interbedded coal; olive-gray shale in upper part; large oysters in float	55.0	16.8
15.	Sandstone, dark-yellowish-orange, very fine grained (fining upward), medium-scale trough-crossbedded; interbedded claystone "drapes", rippled; sharp scour base over coal bed	30.0	9.1
14.	Poorly exposed; claystone; interbedded coal (some clinker)	44.0	13.4
13.	Shale, carbonaceous; interbedded thin siltstones	2.0	0.6
12.	Claystone, medium-dark-gray; interbedded carbonaceous shale and coal	5.0	1.5
11.	Sandstone, yellowish-gray, very fine grained, calcareous, trough-cross-bedded; ironstone concretions and rounded clay pebbles; carbonaceous plant debris and wood in basal part; sharp scour base	4.0	1.2
10.	Claystone, medium-dark-gray; inter-bedded carbonaceous shale, coal, and thin tabular sandstones, very fine-grained	23.0	7.0
9.	I-2 sandstone: Sandstone, siltstone, and claystone. Upper 35 ft (10.7 m): Sandstone, banded light-gray to dark-yellowish-gray; upper 10 ft (3.0 m) appears "white"; very fine grained, noncalcareous; dominantly horizontally thin bedded to massive appearing; ironstone concretions; *Ophiomorpha* to within 5 ft (1.5 m) of top; *Ostrea* (disarticulated) and shell hash at 5 ft (1.5 m) below top. Lower 30 ft (9.1 m): Siltstone; interbedded claystones, grayish-orange, small-scale trough-crossbedded; ironstone concretions and iron boxwork structure in uppermost part; a few *Ophiomorpha* increasing in number up-		

'BELLERING COW' SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation (part)-(cont.)	Feet	Meters
ward; finely ribbed bivalve on uppermost bedding surface	65.0	19.9
8. Claystone, olive-gray; thinly interbedded siltstone at 60 ft (18.2 m) above base	82.0	25.0
7. I-1 sandstone: Sandstone, silty, grayish-orange (10YR 7/4), calcareous, horizontally thick bedded (up to 3 ft, 1 m) and medium-scale trough crossbedded (1 x 9 ft, 0.3 x 3 m); ironstone concretions and claystone pebbles; iron boxwork structure	12.0	3.7
Total thickness Iles Formation (part)	459.0	139.9
Mancos shale: Buck Tongue, upper part:		
6. Claystone, olive-gray	11.0	3.4
5. Siltstone, yellowish-gray calcareous, thin-bedded; horizontally bedded to low-angle crossbedded; contorted in place	3.0	0.9
4. Claystone, olive-gray	6.0	1.8
3. Siltstone, similar to unit 5	3.0	0.9
2. Claystone, olive-gray	65.0	19.9
Total thickness Buck Tongue, uper part	98.0	26.9
1. Loyd Sandstone Bed: Sandstone, silty, grayish-green, very fine grained; horizontal bedding to low-angle crossbedded; concretionary with fossils forming nuclei of concretions; weathers rounded ("lumpy"); *Ophiomorpha*, mud-filled cylindrical horizontal burrows *(Planolites?)*	35.0	10.7
Total thickness Manco Shale (part)	123.0	37.5

MEASURED SECTIONS (cont.)

STOCK PASS GULCH, NE1/4 sec. 23, T. 5 N., R. 91 W., Hamilton and Castor Gulch 7.5 min. Quadrangles, Moffat County, Colorado. Section measured with Jacob Staff by N. Noreen, and L. W. Kiteley, July 1978.

Mesaverde Group: Iles Formation (part):		Feet	Meters
11.	Shale, carbonaceous, brownish-black; 1-ft (0.3 m) oyster bed at top; dark red stained (burned)	6.0	1.8
10.	Sandstone, very silty, yellowish-orangish-gray, very fine to fine-grained, noncalcareous, horizontally bedded; *Inoceramus* fragments and *Ostrea* (disarticulated) throughout	11.0	3.4
9.	Shale, carbonaceous, brownish-black; interbedded coal at 5 ft (1.5 m) above base; oysters in float	10.0	3.0
8.	Siltstone, lenticular; ripple-bedded; interbedded carbonaceous shale at top	7.0	2.1
7.	<u>I-4 sandstone</u>: Sandstone, yellowish-gray; uppermost 16 ft (4.9 m) appears white, fine grained; horizontally bedded to crossbedded; *Ophiomorpha,* large, and iron boxwork structure in basal 25 ft (7.6 m)	41.0	12.5
6.	Poorly exposed; claystone, brownish-gray, platy; interbedded 3-4 ft (0.9-1.2 m) coal at 20 ft (6.1 m) above base; thin-bedded siltstone at top[1]	56.0	17.0
5.	Siltstone, thin-bedded, ripple-bedded[1]	5.0	1.5
4.	Poorly exposed; probably claystone; interbedded coal at 5 ft (1.5 m) above base[1]	25.0	7.6

[1] Note: Local development of lenticular, very silty, crossbedded sandstone overlies I-3 sandstone (unit 3) in NE1/4 SW1/4 sec. 23, T. 5 N., R. 91 W. Measured thickness 43.0 13.1

STOCK PASS GULCH-(cont.)

Mesaverde Group-(cont.) Iles Formation (part)-(cont.)	Feet	Meters
3. I-3 sandstone: Sandstone, orangish-gray; "white" in upper part, very fine to fine grained, noncalcareous; tabular crossbedded to horizontally bedded near top, *Ophiomorpha* in basal 3 ft (0.9 m) and at 20 ft (6.1 m) above base; good porosity	36.0	11.0
2. Shale, carbonaceous, brownish-black; interbedded coal, olive-gray claystone, platy, at about 40 ft (12.2 m) above base	80.0	24.0
1. Sandstone, orangish-gray, very fine to fine-grained fining upward to silt-sized; sharp basal contact. Thin ripple-bedded siltstone in basal 3 ft (0.9 m)	14.0	4.3
Total thickness Iles Formation (part)	291.0	88.7

HORSE GULCH SECTION, SW1/4 NW1/4 sec. 24, and E1/2 SW1/4 sec. 13, T. 5 N., R. 91 W., Hamilton and Castor Gulch 7.5 min. Quadrangles, Moffat County, Colorado. Section measured by C. D. Masters, and R. K. Bambach, July 1963 (Masters, 1966), and by L. W. Kiteley and N. Noreen, with Jacob Staff and tape, June and July 1978. Details of coal beds from Hancock (1925). Megafauna identified by E. G. Kauffman, U.S. National Museum, and W. A. Cobban, U.S. Geological Survey.

Mesaverde Group: Iles Formation:	Feet	Meters
11. I-4 sandstone: Upper 50 ft (15.2 m): Sandstone, lenticular, yellowish-gray, very fine to fine-grained, poorly sorted, trough crossbedded; clay pebbles and ironstone concretions along bedding planes at base of troughs. Lower 20 ft (6.1 m): Sandstone, light-gray to "white" at top, very fine to fine-grained (coarsening upward); a few *Ophiomorpha* in lower half	70.0	21.3
10. Poorly exposed; probably claystone; carbonaceous plant debris; *Ostrea* shells (disarticulated) in float	35.0	10.7

HORSE GULCH SECTION-(cont.)

Mesaverde Group-(cont.)
Iles Formation (part)-(cont.)

9.	I-3 sandstone: Sandstone, siltstone and interbedded claystone, from top to base: Uppermost 45.0 ft (13.7 m): Sandstone, light-gray to orangish-gray, fine- to medium-grained; poorly sorted, noncalcareous, medium-scale wedge planar cross-bedded; claystone pebbles and ironstone concretions along bedding planes; sharp scour base; *Toredolithus* at base; excellent porosity. Middle 0.5 ft (0.15 m): Shale, carbonaceous, coaly. Lower 23.5 ft (7.1 m): Sandstone, "white" at top, very fine to fine-grained, poorly sorted; massive appearance; a few *Ophiomorpha*; moderately good porosity. Basal 6 ft (1.8 m): Siltstone and claystone. Upper 3 ft (0.9 m) consists of thinly interbedded medium-gray claystone and siltstone with horizontal smooth-walled burrows *(Planolites?)*. Lower 3 ft (0.9 m) massive-appearing siltstone with a slightly undulatory upper contact	75.0	22.9
8.	Claystone, medium-dark-gray; comminuted plant fragments; interbedded siltstone with small horizontal smooth tubes *(Planolites?)*, finely ribbed bivalves(?), and broken *Inoceramus* shells	35.0	10.7
7.	Siltstone; interbedded claystone and coal. Siltstone is ripple laminated and contains comminuted plant debris. Claystone, fissile, ripple-laminated	25.0	7.6
6.	Claystone, medium-dark-gray; interbedded carbonaceous shale and coal	65.0	19.8
5.	Sandstone, siltstone and interbedded claystone. Upper 25 ft (7.6 m): Sandstone, fine- to medium-grained (fining upward), medium-scale wedge planar crossbedded, ripple bedded at tops of sets; some contorted bedding; claystone pebbles along bedding planes;		

HORSE GULCH SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
rafted carbonaceous and coaly debris throughout; *Toredolithus* at bases of crossbedded units. Lower 40 ft (12.1 m): Siltstone and interbedded claystone; horizontally bedded to medium scale trough crossbedded in siltstone (lower three-fourths) to ripple bedded (upper one-quarter); iron boxwork structure and ironstained claystone concretions; *Ophiomorpha* in lower part, smooth-walled cylindrical burrows (U-in-U) in upper thin bedded rippled siltstones	65.0	19.8
4. Sandstone, silty, very fine grained, thin bedded (5 cm), horizontally bedded and small-scale trough cross-bedded to rippled; interbedded shale, grayish-olive (10Y 4/2) to dusky-yellow (5Y 6/4); comminuted plant fragments; horizontal small smooth tubes *(Planolites?)*	70.0	21.3
3. I-1 sandstone: upper part: Sandstone, grayish-orange (10YR 7/4), very fine grained, subrounded, slightly calcareous, horizontally bedded; current ripple bedded locally; ironstone concretions along bedding surfaces. Lower part: claystone interbedded and siltstone; bioturbated in claystone to nonbioturbated in siltstone; *Thallasinoides*	31.0	9.4
Total thickness Iles Formation (part)	471.0	143.5
Mancos Shale: Buck Tongue, upper part:		
2. Poorly exposed; probably claystone	68.0	20.7
Total thickness Buck Tongue of Mancos Shale, upper part	68.0	20.7

HORSE GULCH SECTION-(cont.)

Manco Shale (cont.)	Feet	Meters
1. Loyd Sandstone Bed: Sandstone, silty, greenish-gray (5GY 8/1), fine grained, medium-scale crossbedded; interbedded siltstone, thinly laminated; small sandstone concretions in siltstone contain fossils as nuclei; *Ophiomorpha*, clay-filled in sandstone concretions (1.2 cm diameter)	15.0	4.6
Total thickness Mancos Shale (part)	83.0	25.3

Ammonites:
Baculites perplexus Cobban

Bivalvia:
Corbula sp. juv.
"Corbula" sp.
Granocardium (Ethmocardium) white; (Dall)
G. n. sp.
Oxytuma (Hypoxytoma) nebrascana (Evans and Schumard)
Phelopteria linguaeformis (Evans and Shumard)
Thryacia? sp.
Pinna sp. (fragment)
Synclonema sp. cf. *S. dall;* (Gabb)
Dosiniopsis sp. aff. *D. dewey;* (Meek and Hayden)
Cymbophora sp. cf. *C. warrenana* (Meek and Hayden)
Thyasira? sp.
Crassostrea? frags.

POVERTY GULCH SECTION, NE1/4 sec. 19, T. 5 N., R. 90 W., Hamilton and Castor Gulch 7.5 min. Quadrangles, Moffat County, Colorado Section measured with Jacob Staff and tape by L. W. Kiteley and N. Noreen, July 1978. Megafauna identified by E. G. Kauffman, U.S. National Museum.

Mesaverde Group: Iles Formation:	Feet	Meters
27. I-7 sandstone: Sandstone, clayey. Upper part; sandstone, dark-yellowish-gray, "white" at top, very fine to fine-grained, poorly sorted, non-calcareous. Basal 2-3 feet: sandstone, light-gray, medium-grained, horizontally bedded to low-angle crossbedded; iron boxwork structure; *Ophiomorpha*	25.0	7.6

POVERTY GULCH SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)		Feet	Meters
26.	Covered	15.0	4.6
25.	I-6 sandstone: Sandstone, light-gray fine-grained, subrounded; chert, clay (possibly kaolinite), calcareous; horizontally bedded	10.0	3.0
24.	Covered	5.0	1.5
23.	Sandstone, silty; orangish-gray to dark-yellowish-orange with iron streaks, very fine to fine grained; contorted bedding; ironstone concretions; sharp scour base	15.0	4.6
22.	Poorly exposed; probably carbonaceous shale	3.0	0.9
21.	I-5 sandstone: Sandstone, very silty, orangish-gray, subrounded, slightly calcareous, high-angle crossbedded to massive appearing; large ironstone concretions; coaly fragments, *Ostrea* shells, and broken *Inoceramus* shells in a zone 4 ft (1.2 m) above base; top is marked by a distinct erosional surface containing a 1.5-ft (0.46-m) shell lag deposit	9.0	2.7
	Fish scales *Crassostrea* frags. *Inoceramus* frags. *Pseudoptera subtortuosa* (Meek and Hayden) *Granocardium* sp. cf. *Dosiniopsis* cf. *Phelopteria* sp. *Thracia* n. sp. (large form) naticid gastropod *Turritella* sp. inoceramid cf. *Endocostea typica* (Whitfield) many other indet. bivalves		
20.	Poorly exposed; shale, carbonaceous; interbedded lenticular sandstone, 4 ft (1.2 m) thick at 17 ft (5.1 m) above base	46.0	14.0

POVERTY GULCH SECTION (cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)	Feet	Meters
Bivalvia: *"Inoceramus" (Endocostea?) barabini* (Morton)		
19. <u>I-3 sandstone</u>: Sandstone and siltstone. Upper 35 ft (10.7 m): Sandstone, orangish-gray; white in upper 10 ft (3 m); massive. Basal 4 ft (1.2 m): Siltstone, thin-bedded; interbedded light-gray silty claystone	39.0	11.9
18. Claystone, gray; interbedded thin siltstone	23.0	7.0
17. Siltstone, thin-bedded, low-angle crossbedded	3.0	0.9
16. Coal, shale, carbonaceous; interbedded coal	22.0	6.7
15. Sandstone, orangish-gray, very fine grained, medium-scale trough cross bedded; contorted near base; ironstone concretions and claystone pebbles; sharp scour base; *Toredolithus* 18 ft (5.5 m) above base in 3 ft (0.9 m) claystone bed which forms break between two sandstone units	57.0	17.3
14. Shale, carbonaceous; interbedded light-gray claystone; coal at 15 ft (4.5 m) above base and at top	33.0	10.0
13. Sandstone, yellowish-gray, fine- to medium-grained, noncalcareous, trough-crossbedded; ironstone concretions and clay pebbles; sharp scour base	23.0	7.0
12. Shale, carbonaceous; transitional into 3-ft (0.9-m) coal bed at top	5.0	1.5
11. Siltstone, ripple-bedded	4.0	1.2

POVERTY GULCH SECTION-(cont.)

Mesaverde Group-(cont.) Iles Formation-(cont.)		Feet	Meters
10.	Poorly exposed; probably carbonaceous shale	8.0	2.4
9.	I-2 sandstone: Sandstone, yellowish-gray, fine- to medium-grained (coarsening upward), subangular to subrounded, poorly sorted, calcareous; claystone pebbles, ironstone concretions and iron boxwork structure in lower part; contorted bedding; broken shell fragments at 25 ft (7.6 m) above base; good porosity	55.0	16.8
8.	Siltstone, thin-bedded; interbedded gray claystone	14.0	4.3
7.	Sandstone, light-yellowish-gray, very fine grained, calcareous, trough-crossbedded; claystone pebbles, ironstone concretions; distinct flat-bedded siltstone break at base	5.0	1.5
6.	Sandstone, very fine to fine-grained; (coarsening up), grayish-orange to dark-yellowish-orange, noncalcareous; scattered *Ophiomorpha* in lower part	30.0	9.0
5.	Siltstone; interbedded claystones, medium-gray; medium scale trough crossbedded in siltstone; a few *Ophiomorpha* burrows, vertical smooth-walled tubes *(Scolithus)*, upward-curving smooth tubes *(Asterosoma)*	20.0	6.1
4.	Mudstone, silty, light-olive-gray to yellowish-gray, noncalcareous	70.0	21.3

POVERTY GULCH SECTION-(cont.)

	Feet	Meters
Mancos Shale (part):		
Buck Tongue, upper part:		
3. I-1 sandstone: Siltstone; interbedded mudstone, medium-gray, noncalcareous, thin horizontally bedded to low-angle crossbedded; nonburrowed in siltstone to bioturbated in mudstone and claystone; a few *Ophiomorpha* near top; broken *Inoceramus* in float	54.0	16.5
Total thickness Iles Formation (part)	593.0	180.7
2. Claystone, olive-gray	51.0	15.5
Total thickness Buck Tongue of Mancos Shale upper part	51.0	15.5
1. Loyd Sandstone Beds: Sandstone, grayish-green, very fine grained ("sugary") some low-angle crossbedding; weathers rounded; *Ophiomorpha*; other fossils (no collection)	52.0	15.8
Total thickness Mancos Shale (part)	103.0	31.3

Table 1.--*Diagnostic characteristics of facies of the upper Mancos Shale and Iles Formation in northwestern Colorado*

Facies	Lithology, texture[1] and thickness relations (geometry)	Sedimentary structures and contacts[2]	Trace fossils	Paleocurrent date[3]	Adjoining facies	INTERPRETATION OF DEPOSITIONAL ENVIRONMENT
A. Olive-gray mudstones and interbedded tabular to lenticular sandstones and siltstones	Mudstone, olive-gray to medium-dark-gray, silty and sandy, blocky to fissile; interbedded very thin to medium bedded (up to 0.3 m) sandstone. Includes thicker (0.3-1.5 m) elongated to lenticular sandstone bodies, genetically related to facies G sandstones and siltstones.	Parallel horizontally laminated to very thin ripple bedded (rounded, sinuous crested wave-current ripples); sharp basal and upper contacts on sandstones, finely dsseminate, carbonaceous plant debris; alternating burrowed (bioturbated) in claystones to nonburrowed in sandstones. Thickened elongate to lenticular sandstone bodies are laminated to very thin bedded; wedge planar crossbedded (10^{o} dip), or small- and medium-scale bimodal trough cross-bedding; sharp bed booundaries; nonburrowed (with the exception of a few *Planolites*).	*Gyrochorte*, *Crossopodia*, *Nereites?*, *Planolites*, starfish resting trace	May be bimodal or consistent direction onshore	Facies C, E, G laterally; overlies greenish-gray mudstone ((Mancos Shale); underlies facies C and D	OFFSHORE-SHOREFACE TRANSITIONAL (PRODELTA)
B. Thick tabular to lenticular sandstones	Sandstone, grayish-green, yellowish-gray, and pale greenish-yellow, very fine to fine grained, moderately well sorted to poorly sorted, rounded to angular quartz, chert, K-feldspar, and rock fragments (litharenite). Ranges from 2.7 to 31.7 m thick, laterally persistent to lenticular.	<u>Loyd sandstone bed</u>: Dominantly massive; local concretions range from a few cm to 6.0 m.	*Ophiomorpha* *Thallasinoides* *Chondrites* *Planolites*		Facies A laterally, basally, and overlying	SHALLOW MARINE SAND BARS
		<u>1st Mancos sandstone of Konishi (1959a)</u>: Tabular planar crossbedded or trough corssbedded, ripple bedded; rounded, iron-stained clay clasts on bedding surfaces; contains *Ostrea* fragments, shark teeth	*Ophiomorpha*, *Asterosoma*, *Gyrochorte*, *Planolites*, *Thallasinoides* bioturbation structures	Unimodal S48°W (minor 180° reversal)		
		<u>Unnamed sandstone of B. asperiformis age</u>: Very large-scale foreset bedding, tabular planar crossbedding, minor small- and medium-scale trough crossbedding.	*Ophiomorpha* *Chondrites* *Siphonites*	Unimodal S59°W (mean vector)		

Table 1.--*Diagnostic characteristics of facies of the upper Mancos Shale and Iles Formation in northwestern Colorado*--continued

Facies	Lithology, texture[1] and thickness relations (geometry)	Sedimentary structures and contacts[2]	Trace fossils	Paleocurrent date[3]	Adjoining facies	INTERPRETATION OF DEPOSITIONAL ENVIRONMENT
C. Thick lenticular sandstone with sharp bases	Sandstone, yellowish-gray to light gray at top, very fine- to fine-grained, sub-angular to well rounded, well to poorly sorted, quartz, chert, K-feldspar, micas, diverse rock fragments (litharenite). Up to 17.0 m thick.	Very large foresets; tabular and wedge planar in upper one-quarter; horizontally bedded and small- to medium-scale trough crossbedded in lower three-fourths; sharp basal contact (undulatory); fossil debris locally. *Ostrea* filled channels at top of unit at locality 2.	*Ophiomorpha Thallasinoides, Planolites;* bioturbation structures; root traces at top	Bipolar E-W at locality 4, and N10-20°W and S23°-30°E at localities 2 and 3.	Facies A laterally; overlies facies A; underlies facies F	DESTRUCTIONAL DELTA FRONT
D. Thick sheet sandstones with sharp bases and underlying thin lenticular sandstones and siltstones	Sandstone, grayish-orange to yellowish-gray, light gray at top; very fine-to fine-grained; sub-angular to subrounded; moderate to well sorted; quartz, chert, K-feldspar, plagioclase rock fragments (sublitharenite) Basal part, 3.0-4.5 m consists of interbedded carbonaceous and greenish-gray claystone and siltstone in 0.3-0.6 m thick beds. Unit up to 34 m thick.	Upper three fourths: Massive in appearance (gently seaward-dipping laminae); contorted near base (in locally thickened parts); low-angle to flat, tabular, wedge planar and trough crossbedded (in thinner parts between thickened parts). Top 4.5-6.0 m of thickened parts stand in relief above thinner parts; sharp contact at base *Inoceramus* and *Ostrea* shell fragments at various horizons. Basal one-quarter: sandstone, silty, trough crossbedded. Troughs are broad, shallow, 0.4-0.6 x 1.8-2.4 m laminated and symmetrically filled; rounded claystone pebbles along bedding surfaces; interbedded thin carbonaceous shale, and greenish-gray claystone.	*Ophiomorpha* in zone at 4.5 m above base of upper "massive" sandstone; root traces at top.	Polymodal? Unimodal	Facies G and A laterally; overlies facies A; underlies facies F; locally facies G	CONSTRUCTIONAL DELTA FRONT
E. Thick sheet sandstones with gradational bases	Sandstone, yellowish-gray to orangish-gray, light gray at top, very fine to fine grained (coarsening upward), subrounded to well rounded, poorly to well sorted, quartzose. Where unit is poorly sorted it contains marine fauna and carbonaceous debris; top may be erosional, and overlain by 4.5-6 m of shell debris. Basal 1.5-3 m consists of interbedded claystone, sandstone, and siltstone. Units range from <9 m up to 17 m; average 10.6 m.	Horizontal or flat-bedded to low-angle crossbedded; medium-scale, trough crossbedded about three-fourths distance above base; gradational lower contact	*Ophiomorpha* in basal three-fourths, rare to absent in upper one-fourth; root traces at top		Facies F and A laterally; overlies facies A; underlies F or locally, G or H. Where unit is poorly sorted, underlies facies A and overlies facies F	BEACH FORESHORE AND SHOREFACE DEPOSITS

Table 1.--*Diagnostic characteristics of facies of the upper Mancos Shale and Iles Formation in northwestern Colorado*--continued

Facies	Lithology, texture[1] and thickness relations (geometry)	Sedimentary structures and contacts[2]	Trace fossils	Paleocurrent date[3]	Adjoining facies	INTERPRETATION OF DEPOSITIONAL ENVIRONMENT
F. Carbonaceous shales, medium- and light-gray mudstones, and coal	Shale, carbonaceous (moderate brown, 5 YR 4/4, to dark yellowish orange, (10 YR 6/6 when weathered, fissile due to aligned plant detritus; interbedded light-gray (N7) and medium-gray (N5) mudstone, coal; minor sandstone and siltstone	Horizontal or flat bedded to ripple bedded, local contorted bedding; contains ironstone concretions: abundant carbonized plant debris locally in medium and light-gray mudstones	*Planolites* locally; root traces; *Charophyte?*; bioturbation structures locally (*Ostrea* in float)		Interbedded with facies G, H, and J, overlies facies C, D, and E	INTERDISTRIBUTARY MARSH AND SWAMP DEPOSITS AND FLUVIAL FLOODPLAIN
G. Lenticular silty sandstones with sharp bases, and associated overlying lithofacies	Sandstone, yellowish-gray to light gray; very fine- to medium-grained, subrounded to rounded; moderate to well sorted; quartz, chert, rock fragments, minor K-feldspar (litharenite). Units range from 5.8 m up to 30.0 m and average 18 m; lenticular	Medium-scale to large-scale trough crossbedded (festoon); rippled at tops of sets; contorted at base, carbonaceous plant material and woody debris at base of troughs; claystone pebbles and ironstone concretions along bedding planes; claystone "drapes" or interbeds locally; sharp scour base. Basal several feet consists locally of interbedded bioturbated siltstone and claystone. Associated overlying lithofacies: 0.3-4.8 m of interbedded carbonaceous shale, clayey sandstone, and coal capped by about 1.2 m of mottled gray and yellowish-gray, slightly contorted sandstone with root traces.	Plant impressions and root traces; *Toredolithus*-bored wood at base of unit	S36°E to the SE	Facies F laterally, basally, and overlying	DISTRIBUTARY CHANNELS
H. Thin tabular sandstones or siltstones with sharp bases	Sandstone, clayey, and siltstone, light-gray to dark yellowish-orange, more landward sequences consist of sandstone; more seaward, siltstone (landward coarsening). Units are tabular (uniform thickness) and lenticular; range from 0.3-1.8 m in thickness, average about 1 m.	Rippled bedded (asymmetric) and planar bedded; climbing ripples; contorted bedding; sharp scour base. Laminated to very thin bedded. Contains rounded clay clasts, carbonaceous plant debris, and woody fragments.	Root traces (some mottling), plant impressions; *Planolites*	N45°E, dip S65°E	Facies F, laterally, basally, and overlying	CREVASSE SPLAYS

Table 1.--*Diagnostic characteristics of facies of the upper Mancos Shale and Iles Formation in northwestern Colorado*--continued

Facies	Lithology, texture[1] and thickness relations (geometry)	Sedimentary structures and contacts[2]	Trace fossils	Paleocurrent date[3]	Adjoining facies	INTERPRETATION OF DEPOSITIONAL ENVIRONMENT
J. Lenticular sandstones with sharp scour bases	Sandstone, light yellowish-gray to grayish-orange, very fine to medium-grained, angular to rounded, poorly sorted, quartz, chert, K-feldspar, plagioclase, rock fragments (litharenite). Units range from about 4-6 m thick and are lenticular	Planar and medium- and large-scale trough crossbedding (festoon) ripple bedded at tops of sets; claystone pebbles and ironstone concretions at base of sets; thinly interbedded clay "drapes;" sharp scour bases; contorted bedding; carbonaceous plant debris	Plant impressions		Facies F laterally, basally, and overlying	FLUVIAL STREAMS
K. Lenticular trough crossbedded sandstones with sharp scour base	Similar to facies J except moderately well sorted (sublitharenite). Unit is 13 m thick, and lenticular	Medium scale trough crossbeds, claystone pebbles, local large ironstone concretions.	Bioturbation; *Planolites* and *Scolithus* in interbedded thin rippled silty sandstones and mudstones adjacent to facies K sandstone	Bimodal N20°-30°E and S30°-40°W.	Facies A laterally and facies F overlying; overlies facies A.	TIDALLY INFLUENCED DISTRIBUTARY CHANNEL

[1]After Folk (1974)

[2]Stratification and cross-stratification classified according to McKee and Weir (1953)

[3]Paleocurrent data collection and synthesized following methods of Reiche (1938),; Pettijohn, Potter, and Siever (1973, p. 134-140) and Pettijohn and Potter (1977). Crossbed readings corrected for tectonic tilt wherever necessary

Table 2.--*Petrography of selected sandstones, Mancos Shale and Mesaverde Group in northwest Colorado*

[Abbreviations: Qtz., quartz; chrt, chert; Ksp, potassium feldspar; rfs, rock fragments; mod., moderate; CO_3, carbonate; allog., allogenic; auth., authigenic; app., appendix, pages 71 to 110]

SAMPLE: 77-LK-1 LOCALITY: Duffy Mt. (app.) First Mancos sandstone of Konishi (1959)

sorting: mod-well
rounding: rounded-subangular-angular

Major detrital grains:

Qtz-chrt	Ksp	Rfs
62%	6%	31%

Minor: mica, chlorite heavy minerals (1%)

Other: iron minerals, chlorite, hematite, mica (8%)

Cement: CO_3 (calcite), qtz. overgrowths (16%)[1]
Matrix: "squashed" sedimentary rfs., allog. clay, iron stain[1]

SAMPLE: 77-LK-2 LOCALITY: Duffy Mt. (app.) Loyd Sandstone Member

sorting: mod-poor
rounding: subangular-angular

Major detrital grains:

Qtz-chrt	Ksp	Rfs
71%	3%	25%

Minor: muscovite, chlorite, auth. kaolin, plagioclase (1%)

Other: pyrite, muscovite, iron stain

Cement: CO_3 (dolomite), qtz. overgrowths[1] (40%)
Matrix: limonite-hematite? stained matrix[1]

SAMPLE: 77-LK-4 LOCALITY: Duffy Mt. (app.) I-1 sandstone base

sorting: mod.-poor
rounding: subangular subrounded

Major detrital grains:

Qtz-chrt	Ksp	Rfs
56%	12%	31%

Minor: muscovite, biotite, plagioclase (1%)

Other: iron stain (6%)

Cement: CO_3 (dolomite)[1] (47%)
Matrix: very little[1]

SAMPLE: 77-LK-5 LOCALITY: Duffy Mt. (app.) I-1 sandstone (top)

sorting: well
rounding: subangular-subrounded-well rounded

Major detrital grains:

Qtz-chrt	Ksp	Rfs
60%	3%	36%

Minor: biotite, heavy minerals (1%)

Other: iron stain, porous zones (12%)

Cement: Qtz.overgrowths, solutions welds, kaolin[1] (0%)
Matrix: kaolin, micaceous rfs.[1]

Table 2.--*Petrography of selected sandstones, Mancos Shale and Mesaverde Group in northwest Colorado*--continued

SAMPLE: 77-LK-7 LOCALITY: Duffy Mt. (app.) I-2 sandstone

sorting: mod-well
rounding: subangular-sub rounded

Major detrital grains:

Qtz-chrt	Ksp	Rfs
83%	0%	16%

Minor: plagioclase, biotite, muscovite, heavy minerals (1%)

Other: iron stain, pores (6%)

Cement: Qtz overgrowths[1] (3%)
Matrix: minor allog. clay, "squashed" rfs[1]

SAMPLE: 77-LK-9 LOCALITY: Duffy Mt. (app.) Unit 11

sorting: mod-well
rounding: subrounded-rounded

Major detrital grains:

Qtz-chrt	Rfs
73%	26%

Minor: Ksp (1%)

Other: auth. clay, heavy minerals, mica (12%)

Cement: Qtz as overgrowths, auth. clay[1] (0%)
Matrix: auth. clay (in pores), "squashed" rfs[1]

SAMPLE: 77-LK-43 LOCALITY: Deception Creek (app.) I-1 sandstone

sorting: mod (poor in places due to burrowing
rounding: mod-well rounded

Major detrital grains:

Qtz-chrt	Ksp	Rfs
74%	6%	19%

Minor: muscovite? (1%)

Other: iron stain (7%)

Cement: CO_3 (dolomite); some replacement of grains by CO_3[1]
Matrix: allong. frags. due to burrowing, "squashed" rfs[1]

SAMPLE: 77-LK-45 LOCALITY: Deception Creek (app.) I-2 sandstone

sorting: mod.
rounding: subangular -rounded

Major detrital grains:

Qtz-chrt	Ksp	Rfs
81%	3%	15%

Minor: plagioclase, muscovite, tourmaline, other heavy minerals (1%)

Other: iron stain, pores (10%)

Cement: solution welds, tightly packed qtz grains with rims of micaceous fragments, rfs?[1] (0%)
Matrix: very little, minor "squashed rfs and limonite?

Table 2.—*Petrography of selected sandstones, Mancos Shale and Mesaverde Group in northwest Colorado*—continued

SAMPLE: 77-LK-17	LOCALITY: Duffy Mt.	Unit 25
		sorting: poor rounding: angular-rounded
Major detrital grains:		Minor: mica, heavy minerals (1%)
Qtz-chrt 50%; Ksp 5%; Rfs 44%		
		Other: CO_3 detrital grains, i.e., ankerite and dolomite (12%)
Cement: kaolin and micaceous cement[1] (0%) Matrix: not much, "squashed" rfs, solution welds[1]		

[1]John Webb, written commun., 1978